Understanding the Accessibility of Single-User Virtual Reality Environments for Adults with Intellectual and Developmental Disabilities

Piriyankan Kirupaharan
University of Rhode Island
Computer Science
Kingston, Rhode Island, USA
pkirupaharan@uri.edu

Tina-Marie Ranalli
University of Rhode Island
Department of Modern and Classical Languages and Literatures
Kingston, Rhode Island, USA
tinamarie.ranalli@uri.edu

Krishna Venkatasubramanian
University of Rhode Island
Computer Science and Statistics
Kingston, Rhode Island, USA
krish@uri.edu

Abstract

In this paper, we aim to understand accessibility issues for people with intellectual and developmental disabilities (I/DD) with single-user VR applications. To this end, we recruited eight participants with I/DD for this study. We asked each participant to use a single-user VR application (on Meta Quest 2) and then conducted semi-structured interviews about their experiences. A subsequent thematic analysis of our interviews resulted in identifying several accessibility problems in using VR for people with I/DD. Overall, we found that participants had difficulty: perceiving (including comprehending) the various elements of the virtual environment and using physical controllers to engage with (i.e., act within) the virtual environment. The participants then suggested potential improvements to make the virtual environments more accessible. Based on these findings, we call for further research in four broad areas to foster an accessible VR experience for people with I/DD.

CCS Concepts

• **Human-centered computing → Accessibility technologies**.

Keywords

Single-user VR, virtual environments, accessibility, intellectual and developmental disability, VR user experience model

ACM Reference Format:
Piriyankan Kirupaharan, Tina-Marie Ranalli, and Krishna Venkatasubramanian. 2025. Understanding the Accessibility of Single-User Virtual Reality Environments for Adults with Intellectual and Developmental Disabilities. In *Designing Interactive Systems Conference (DIS '25), July 05–09, 2025, Funchal, Portugal.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3715336.3735782

1 Introduction

Virtual reality (VR) refers to immersive technologies that engage a person's senses and create a perception of the person being in a three-dimensional (3D) synthetic, virtual environment [31]. Recent years have seen an increased interest in making virtual reality accessible to people with disabilities. To this end, much of the work in making VR accessible has focused on helping blind and low vision users [22, 93], deaf and hard-of-hearing users [44, 81], users with upper body motor impairments [36, 62], and users with speech impairments [30]. However, a community that so far has not been considered in when making virtual reality accessible is people with *intellectual and developmental disabilities (I/DD)*[1]. People with I/DD often lead a highly controlled life and have fewer possibilities than many others to engage in activities, mundane or otherwise [86]. VR as a technology not only allows people with I/DD to explore many activities but it also enables them to do so in a *sustainable* way (e.g., with a reduced carbon footprint).

Therefore, *as a first step*, we focus on understanding accessibility issues in single-user VR applications for people (*specifically adults*) with I/DD. Single-user virtual applications are VR applications that *do not share* the virtual environment with other users[2]. We view **VR-accessibility for people with I/DD** as the functional problem of *designing virtual environments* where users (in our case, people with I/DD) are able perceive – become aware of the presence of something (e.g., a virtual object) and understand its purpose – and engage – take action, influence, or control something (e.g., a virtual object) – within the virtual environment.

Given our larger aim, we intend to answer the following three research questions: (RQ1) What, if anything, do people with I/DD find challenging when perceiving the virtual environment? (RQ2) What, if anything, do people with I/DD find challenging when engaging within the virtual environment? (RQ3) What improvements (if any) would people with I/DD want to see in the design of virtual environments? In this work our aim was to center the voices of people with I/DD by grounding our analysis in their direct input and opinions. Hence, to answer these questions, we conducted a study with eight participants with I/DD after one participant was excluded. We asked each participant to use a VR application (on a Meta Quest 2 device) that introduces the various elements of VR. We then asked them questions, in a semi-structured interview, about their experience using the app. We found that participants had difficulty comprehending the various elements of the virtual environment, such as the instructions, virtual objects, and avatars. Further, we observed that participants found it challenging to use

DIS '25, Funchal, Portugal

ACM ISBN 979-8-4007-1485-6/25/07
https://doi.org/10.1145/3715336.3735782

[1] I/DD are a set of disabilities that affect a person's ability to learn, reason, problem-solve, and engage in everyday social and life skills [65]. In the US, there are over 7 million people with I/DD [64].
[2] Social VR applications, which incorporate several users in the same virtual environment, are outside the scope of the present work.

the physical controller(s) to perform actions within the virtual environment. We also asked the participants about any improvements they would like to see, which we then leveraged to suggest how to improve the accessibility of the virtual environment for people with I/DD. We then analyze the significance of these findings and call for further research in four broad areas, as a way to design accessible single-user VR applications for people with I/DD. *In the rest of the paper we use the phrases: 'people with I/DD' or 'individuals with I/DD' to mean 'adults with I/DD.'*

2 Related work

Our work falls at the intersection of VR and individuals with disabilities. Consequently, we divide the related work section into two broad categories.

2.1 Understanding VR use by individuals with disabilities

Much work has been done in developing accessible VR applications for a wide range of people with different disabilities. We categorize these broadly, based on the type of disability that it targets. For people who are blind or have low vision (BLV), work has focused on making virtual environments accessible by providing: audio guidance [10, 22, 57, 69, 84, 88, 93]; providing spatial information through haptic feedback [66, 92]; and enabling adaptive zooming or inverted colors[81, 84]. Additionally, in the context of BLV users, work has also focused on training for pedestrian safety [12, 21]; therapy for Amblyopia (also called lazy eye) [43]; and rehabilitation [34, 37]. For deaf and hard-of-hearing (DHH) individuals, work has focused on improving accessibility in virtual environments by: enabling captions [44, 81, 82]; providing vibration, pressure, and tactile sensations to convey spatial information [10, 44, 44, 81]; and using sign language [8]. VR has also been used in rehabilitation applications for DHH individuals [54]. In the context of people with motor impairments, work has focused on exploring seated locomotion techniques [36, 62]; gaze-based interactions [71, 83]; using wheelchair embodiment [40, 68, 91]; and providing rhythmic visual feedback [55]. Further, for people with motor disabilities, VR has also been utilized in the rehabilitation of hemiplegia (muscle weakness or paralysis on one side of the body) [32] and for physical therapy, [49, 61, 78, 89]. Finally, some work has also targeted people with speech impairments with applications focused on using VR for speech therapy [30, 54]. Each of these studies provides insightful guidelines. However, none of them focuses on individuals with I/DD, the focus of the present paper.

2.2 Understanding VR use by people with I/DD

Not much work has looked at VR in the context of use by people with I/DD. Most of the work in this regard for people with I/DD has focused on two broad areas: real-world skill development and rehabilitation/education. Skill development work has focused on teaching life skills [4, 14, 20, 46, 59, 60, 87]; vocational training [5, 27, 74]; leisure activities[72, 90]; shopping [26, 79], and improving social and communication skills (for children) [50]. Rehabilitation using VR has focused on areas, such as music therapy [48, 85], aggression prevention [39], managing education with cognitive impairments [25, 76, 77], and improving physical fitness [51, 52]. Although some of these papers do sometimes mention one-off accessibility issues, it was in the context of using VR as a tool rather than developing a better understanding of VR accessibility (see Table 1). These papers never delve into understanding the cause or nature of the accessibility challenges they identify, nor do they attempt to examine accessibility comprehensively. By systematically looking at accessibility, as we do in the present paper, we: (1) provide a detailed analysis of accessibility in VR for people with I/DD; and (2) contribute recommendations related to designing accessible virtual environments for people with I/DD.

3 Methodology

In this paper, we would like to understand accessibility issues for people with I/DD within the virtual environment in single-user VR applications. To this end, we asked eight participants with I/DD to use a VR app that introduces the various elements of VR and then asked them questions in a semi-structured interview about their experience using the app. We then performed a thematic analysis of the interviews with the goal of answering three research questions: (RQ1) What, if anything, do people with I/DD find challenging when perceiving the virtual environment? (RQ2) What, if anything, do people with I/DD find challenging when engaging within the virtual environment? (RQ3) What improvements (if any) would people with I/DD want to see in the design of virtual environments?

3.1 Study participants

After removing P4, there were eight (8) participants in this study. The participants had mild to severe I/DD. Some of the participants (N=3) had used a VR system at least once, while most had not (N=5). The demographics of our participants are shown in Table 2. P8, who had obtained prior permission from their physician in order to participate in the study, given their known seizure disorder, had a mild seizure in middle of one of the activities in the app and we immediately stopped the session. We had informed P8 about the VR app (Oculus First Steps [35]) we were planning to use for the study beforehand so that they could discuss it with their physician. They also had a caregiver present at the study session at all times. The caregiver helped P8 recover from the seizure. At that point P8 was feeling well enough that she chose to answer the questions that were pertinent to her experience with VR[3]. Four participants (P1, P3, P6, and P7) used both their hands to hold the controllers. P2's condition prevented them from being able to hold either controller. Similarly, P5 and P9 had a limitation with their right hand; hence they only used the left-hand controller. In all such cases, the first author used either both physical controllers (for P2) or the right-hand controller (for P5 and P9) and the participants verbally told the first author what to do in the app and when. In these cases, all engagement within the virtual environment was completely controlled by the participants; the first author solely executed what these participants said and did not decide any course of action. All participants were compensated for participating in the study. The study protocol was approved by the institutional review board (IRB), the ethics board, of our institution.

[3]There is no correlation between I/DD and seizures *per se*. On a side note, recent work has suggested that carefully designing VR displays and virtual environments can enable individuals with seizure disorders to use a wider variety of VR applications [41, 75].

General theme	Goal of the paper	Accessibility challenges mentioned in the paper	Corresponding solutions mentioned in the paper	Citation
Skill development	Training around arranging meal table	Difficulty in understanding what the virtual assistant says or does	-	[4]
		Difficulty in performing hand gestures to engage within the virtual environment	* Use physical controllers to engage within the virtual environment	
	Training around meal preparation	Difficulty in understanding multi-step instructions	* Provide breaks to allow participants to process and understand the instructions and actions	[46]
	Training around arranging meal table	Difficulty in following the instructions from a verbose virtual guide	-	[87]
		Difficulty in remembering how to perform hand gestures to engage with virtual objects	** Provide visual cues around virtual objects	
	Training around grocery shopping, cleaning, and cooking	-	-	[19]
	Training around grocery shopping	Difficulty in understanding instruction due to lack of reading skills	** Read the instructions aloud to help them understand	[26]
	Train for job-related skills	Difficulty in understanding the multi-step instructions	* Modularize the content to help the users better understand the instructions	[5]
		Difficulty in understanding the virtual environment due to insufficient feedback from the virtual environment	* Provide short modules with feedback to help the users better understand the instructions	
	Training around office skills	-	-	[74]
	Training around social skills	-	-	[60]
	Training around waste management skills	Difficulty understanding the instructions.	** Provide feedback to the users with progress sheets and stickers to help them better understand the virtual environment	[59]
	Training around taking a train	Difficulty in perceiving virtual objects within the virtual environment	* Begin with 2D training and gradually transition to VR to better perceive the virtual objects	[14]
	Improve physical fitness	Difficulty understanding the instructions due to use of complex words	-	[51]
Therapy	Drumming along to music in a virtual beach environment for therapy	-	-	[85]
	Exploring a virtual wellness center as a therapeutic activity	Difficulty using controllers to engage with virtual objects due to difficulty remembering what each button does	* Streamline controller design to make it easier for users to remember the function of each button and better engage within the virtual environment	[72]
		Difficulty in understanding the instructions	* Introduce a virtual guide to assist the users in understanding the instructions	
	Personalizing and interacting with avatars in VR for therapy	Difficulty in engaging with virtual objects on the ground	** Provide a grabbing action within the virtual environment that allows the users to easily engage with the virtual objects	[47]
	Preventing aggression by practicing coping mechanisms in VR	-	-	[39]
Other	Evaluating the use of hand gestures in VR for individuals with Down syndrome	Difficulty performing hand gestures to engage with virtual objects	* Avoid gestures requiring two fingers or high precision to engage within the virtual environment	[28]
	Identify accessibility barriers in AR/VR for people with disabilities	Difficulty using controllers to engage with virtual objects	-	[24]

Table 1: A summary the accessibility challenges and the corresponding solutions mentioned in work involving people with I/DD while using VR applications. Here, * indicates solutions proposed by authors where as ** indicates solutions that were actually implemented.

3.2 Study design

During this study, each participant used the VR system for one session. All sessions were conducted in person with each session lasting around 1-1.5 hours. Participants were informed that they could take breaks at any time and we also offered pauses between tasks to ensure participants' comfort. No participant reported experiencing any fatigue or discomfort during the study. We primarily conducted these sessions at the participants' preferred locations in order to make it easy for them to participate. At the beginning of each session, we showed the participants a PowerPoint presentation that provided a basic introduction to VR. It covered topics such as: the definition of VR, the hardware used in VR systems, the operation of the physical controllers, and information about potential cybersickness. Using our team's extensive experience working with people with I/DD, the presentation slides were made accessible for people with I/DD and utilized simple language and lots of images and videos, for ease of understanding.

We used Meta Quest 2 as the VR system for this study [70]. We chose Quest 2, as it is a relatively cheap, untethered VR platform

ID	Disabilities	Has used VR before	Physical controller operation	Completed the study
P1	Autism	Yes	The participant used both controllers	Yes
P2	I/DD, Aperts syndrome	No	The first author used both controllers	Yes
P3	I/DD, Spina bifida	Yes	The participant used both controllers	Yes
P5	I/DD, cerebral palsy	Yes	The first author only used the right-hand controller	Yes
P6	Down syndrome	No	The participant used both controllers	Yes
P7	I/DD	Yes	The participant used both controllers	Yes
P8	I/DD, seizure disorder	No	The participant used both controllers	No
P9	I/DD, cerebral palsy	No	The first author only used the right-hand controller	Yes

Table 2: Demographics of the participants in the user study, all of whom have some form of I/DD, per AAIDD's definition [65]. Several participants did not wish to elaborate on their specific condition. For such participants, we listed their disability as I/DD. P4 was not included in this paper because they decided not to continue with the study, due to the extreme difficulty they had in engaging with the VR system and its application. The participants were equally split between males and females (4 each) with an age range of 21 to 56 years.

that is easy to set up and use. Since we met our participants at a location of their choice, we needed a VR system that could be set up and used under most conditions. There are no VR apps designed specifically for people with I/DD that we could use for this study. Consequently, we selected the Oculus First Steps [35] app to use for this study. There are four main reasons for choosing this app:

- This app allows its users to experience all the salient features of the VR platform. This allowed us to see the various ways in which the virtual environment presents accessibility problems (or not) for people with I/DD.
- This app utilizes all the common actions typically performed within a virtual environment (e.g., reaching, grabbing, releasing, etc.) [38].
- This app comes with Quest 2 and is therefore reliable and optimized for use with the platform. This property is essential, as it allowed us to focus on the participants' experience within the virtual environment rather than deal with reliability issues.
- This app is designed so that the user does not have to stand and does not include locomotion within the virtual environment. These characteristics met our requirements of: having users perform our study while seated and minimizing cybersickness. It is understood that one of the main reasons for cybersickness in VR is the relative motion of the user's avatar within the virtual environment [9, 18].

The version of the First Steps app we used for our study included 10 activities. Each activity in the app required the use of physical controllers, where the participant had to press specific combinations of buttons on the controllers and, if need be, move their arms to engage with virtual objects (e.g., to throw or grab virtual objects). The app had a first-person perspective. The controllers initially appeared as controllers, then morphed into a pair of disembodied hands (with or without virtual controllers, depending on the activity) as the user's *avatar*. We list the expected engagement for each activity here, as it provides context to the findings in the next section. These were: (1) *Buttons tutorial:* Press the important buttons (e.g., trigger button, grip button, etc.) on the physical controllers to learn about them and then reach to depress a virtual button at arm's length; (2) *Blocks:* Pick up blocks and release or throw them; (3) *Ping pong:* Pick up a ping pong paddle with one (virtual) hand and a ball with the other (virtual) hand and hit the ball with the paddle; (4) *Paper airplane:* Pick up a paper airplane and throw it; (5) *Model rockets:* Pick up a model rocket with one hand, pull its string with the other hand to launch the rocket; (6) *Tethered ball:* Make a fist and punch the tethered ball hanging from the ceiling of the virtual environment. (7) *Blimp:* Pick up a virtual remote control and use it to fly a blimp; (8) *Video game console:* Pick up a shooting game cartridge or dancing game cartridge, insert it into the console, and press a virtual button on the console to activate the game; (9) *Shooting game:* Pick up one of two virtual guns (one-handed versus two-handed) and shoot targets; (10) *Dancing game:* Grab each cable at either side of the screen and insert them into the virtual outlets, then shake hands with the virtual *non-playing avatar* (in the form of a robot), and move your hands and spin the robot to dance; (11) *Exit:* Pick up an exit cartridge, insert it into the console, and press a virtual button on the console to exit the app.

The activities were not necessarily sequential in nature. After activity 1, activities 2-4 were available to the participant at the same time, then 5-6. While a particular virtual object was present, the user could engage with the object as many times as they wanted, as the objects would regenerate. For example, if a user throws a paper airplane, a new one would appear instantaneously in its place. Since there were so many virtual objects with which to engage, they were sometimes placed outside the participant's field of view, requiring them to turn their head to perceive and engage with the objects. Activities 9 and 10 could be done in any order, depending on which cartridge was inserted first. Both games had to be played at least a little bit before the exit cartridge became available for the participant to exit the app. After each participant used the app, we asked them questions about their experience with each activity in the app, in the order in which they completed the activities (in order to help them remember), as well as their overall experience with the app. The entire process was video-recorded, audio-recorded, and screencast-recorded for analysis, with the participants' consent.

3.3 Study analysis

After the user study, the audio recordings of the interviews were transcribed. The video and screencast recordings were then analyzed to gain further insights into what participants said in the audio recordings. All three authors then performed a reflective thematic analysis of the study transcripts. We used Braun and Clark's six-step recursive approach to thematic analysis of our work, as described in [16]. The authors collaboratively performed the coding and analysis in order to achieve a richer interpretation of meaning than attempting to achieve consensus would generate. The coding and theme development were conducted inductively and evolved throughout the analytic process. The results of our analysis are described findings in the next few sections and summarized in Table 3.

4 A simplified VR user experience model

Before we delve into the details of the accessibility issues for people with I/DD in our findings, we believe it would be useful to have a suitable *model* that can help us understand a user's experience of the virtual environment in VR. To this end, we first identified three existing models in the literature that describe the user's experience of VR [11, 15, 73]. However, none of these models was particularly useful, as none of them captures the user experience in sufficient detail.

As a result, we propose a **simplified VR user experience model** that delves into the essential components of a user's experience within the virtual environment in the context of a single-user VR application. This model views the VR system as consisting of two elements: the VR headset worn by the user on their head and the physical controllers held in each of the user's hands (if gestures are supported, the hands themselves acts as controllers). The VR headset renders the 3D immersive virtual environment, based on the VR application being executed within the system. In this paper, we focus on standalone VR applications that have only a single user interacting within the virtual environment at a time. Figure 1 shows an overview of our simplified VR user experience model and its main elements.

Our model consists of two states: the perception state and the engagement state[4] In the **perception state**, the user processes the sensory inputs (visual, auditory, and haptic information) emanating from the *virtual environment* and projected by the *VR headset*, as a way to comprehend the virtual environment. Perceiving these sensory inputs fosters a sense of immersion for the user.

After the VR user has perceived the virtual environment, once they *decide* to engage within the environment - based on a sense of having agency within the virtual environment - they enter into the engagement state. In the **engagement state**, the user uses a set of *physical VR controllers* (or gestures, if that is possible) in the *physical environment* to *engage* within the virtual environment in some way. Each attempt at engagement within the virtual environment triggers a corresponding change within the virtual environment, or lack thereof, which acts as *feedback* from the virtual environment to the user. The feedback is usually in the form of visual, audio, and haptic information, which is, once again, received by the user, thus transitioning them back to the perception state. The whole process then repeats.

In the perception state, virtual environments typically convey to the user: (1) what is expected of user in the environment and (2) how the user can go about doing what is expected. Typically, these goals and rules are conveyed through a variety of means within the virtual environment, for instance: (1) by providing explicit *instructions* to the user within the virtual environment; (2) by designing *virtual objects* – artifacts that the user sees, hears, or feels within the virtual environment – to have specific forms, affordances, and constraints; and (3) through the design of the *avatar* that represents the user (and other "non-playing" entities) within the virtual environment. A common choice in single-user VR applications is the use of partial-body avatars, often represented as disembodied hands that may or may not hold virtual controllers [13, 33, 53, 67, 80].

In the engagement state, the user uses one or two physical controller(s) containing several buttons (or hand gestures, if supported). The inset image in Figure 1 shows the buttons that are relevant to this paper. We define *engagement* within the virtual environment to mean when the user manipulates virtual objects (usually via one or both virtual hands), based on input from the physical controller(s). Engagement typically involves the user's executing one or more of the following *actions* with the physical controllers: (1) moving one or both hands while holding the physical controller(s); (2) pressing one or more buttons on the physical controller(s); or (3) moving one or both hands while pressing button(s) on the physical controller(s). Each of these actions performed in the physical world results in a corresponding action within the virtual environment: virtual hands move to the proximity of a virtual object, the virtual hands act upon the virtual object (e.g., grabbing it or pressing it), and the virtual hands move the virtual object to a different location within the virtual environment.

Now that we have described our model, we will use it to frame the issues in accessibility for people with I/DD when using single-user VR application.

5 Findings 1: People with I/DD experience issues in perceiving the instructions, virtual objects, and avatars within the virtual environment

In order to be able to interact within the virtual environment, it is essential for users to perceive (including comprehension) the

[4] In this first effort at understanding accessibility for people with I/DD, we deliberately avoid explicitly addressing the notion of locomotion within the virtual environment, in order to keep our model tractable.

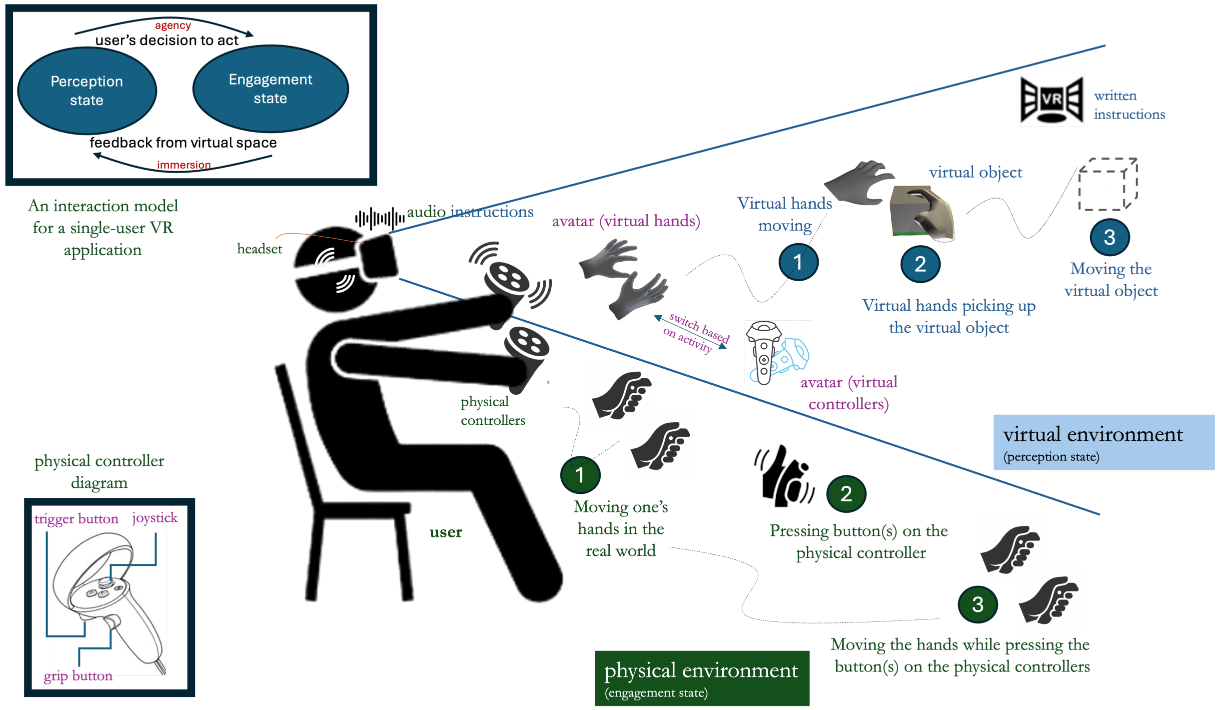


Figure 1: An illustration of our simplified VR user experience model (for a single-user VR application)

various elements of the environment itself. The participants experienced several issues in this regard (i.e., while they were in the *perception state* of our VR user experience model). These issues can be grouped into three categories, which we describe below.

5.1 Issues in perceiving instructions within the virtual environment

The virtual environments in VR are often designed with written and audio instructions for its users, to guide them through the activities they can perform within the space. Perceiving the instructions was often necessary in order to successfully engage within the virtual environment: *"I did hit [the tethered ball] with the hand without [making] a fist at first but as soon as I saw it make a fist [in the instructions], that's when I realized that I had to make a fist." (P3)*. However, we found that the participants often had difficulty with respect to the instructions. These difficulties can be divided into three categories, which we now describe.

5.1.1 Participants often did not perceive the instructions within the virtual environment. One of the most common ways for the participants to know what to do within the virtual environment was via explicit written instructions that were provided within the virtual environment. However, even when written instructions were placed directly within the user's field of view, as is common in many VR applications, most participants (P1, P2, P3, P5, P6, P9) reported not noticing or reading them: *"I didn't see [the text instructions above the ping pong paddle]." (P6)*. When we probed for the reason for not reading the written instructions, we found that one participant does not read: *"The only thing I would change to help a person like me because I can't read.... So looking at a screen where we have something like that first screen there, you should have at least that first sentence read to people. They can do that and that would make it better because then I could go in there and I can play it and not sit there and say, like, 'well, what do I do?' So if the screen can read a little bit and tell me, like, 'this is coming up' or 'this is happening,' you know, so just give me a heads up a little bit..." (P7)*. Some participants just scanned the text: *"It was like a scan. So you'd like scan over it." (P8)*. That being said, in response to a question about why they did not notice the written instructions when engaging with the blimp, one participant stated that they were too excited: *"I really need to slow down when trying new things - don't want to jump the gun or any[thing]. Always look before you leap. I was so excited." (P1)*.

Oftentimes, though not always, the app also provided audio instructions within the virtual environment to describe to the user how to interact with a virtual object. However, yet again participants found it hard to pay attention to them, as they were focused on other things: *"it took me a little while [to notice the audio instructions] because I was really looking... at my [virtual] hands too much" (P7)*. Further, as audio instructions were never repeated (and could not be replayed), most participants tried to memorize them but failed: *"So basically, so when she first told me the instructions, I just tried to remember. I couldn't memorize them completely at first." (P3)*. This led to frustration and eventually to not completing tasks with specific virtual objects: *"The rocket is not even moving." (P5)*.

5.1.2 Participants found the instructions they did notice to be complex, imprecise, incomplete, or lacking. Even when the instructions were perceivable, they were often not described well enough to

	Specific issues	Participants involved
Issues in *perceiving* the virtual environment	Participants often did not perceive the instructions within the virtual environment	P1, P2, P3, P5, P6, P9
	Participants found the instructions they did notice to be too complex, imprecise, incomplete, or lacking	P3, P5, P6, P7
	Participants often made mistakes in executing the tasks, despite the instructions	P3, P5, P6
	Participants found it challenging to understand the virtual objects' characteristics	P3, P5, P7, P8
	Participants found it challenging to understand the avatars' behavior	P5, P6, P7
Issues *engaging* within the virtual environment	Participants had difficulty remembering that they had to use the physical controller(s) to engage within the virtual environment	P6, P9
	Participants had difficulty remembering how to operate the physical controller(s)	P1, P3, P5, P6, P7, P8, P9
	Participants had difficulties when they had move their arms while operating the physical controller(s)	P3, P5, P6, P7, P8, P9
	Participants had difficulty using both physical controllers simultaneously	P3, P5, P6, P9
	Participants found it difficult to engage with the virtual objects, due to their placement	P1, P3, P5, P7, P9

Table 3: A summary of the accessibility issues for people with I/DD in using a single-user VR application

be usable for the participants. The problems with the instructions were five-fold:

- **Complexity:** Some participants (P5, P6) found it difficult to understand the instructions: *"I tried to read it many times. I tried but it was too hard." (P5).* The use of technical jargon further confused participants. For instance, when the audio instructions mentioned moving what is often called a joystick, one participant was confused and asked for clarification: *"[what do they mean by] 'thumbstick ?' " (P5).*
- **Imprecision:** Furthermore, for a few participants (P5, P9), the provided instructions were not precise. For instance, participants had difficulty understanding the audio instructions that asked them to "press the thumbstick." Instead these participants were moving the joystick around and became frustrated when nothing happened. We also observed multiple times that it was not clear which virtual object the instructions referenced, which caused the participants to be confused about what they were expected to do. For instance, P9 read the written instructions above the remote control for the blimp and thought they were about the blimp instead, so they grabbed the blimp (which was next to the remote control in the environment) instead of picking up the remote control.
- **Incompleteness:** The instructions were often incomplete, which added to the participants' confusion, making it difficult for some (P3, P9) to complete the activity. For instance, the tutorial assumed the participants would know what the video game cartridges were for and how to use them and did not give detailed instructions on their use: *"It was not hard to pick up the cart[ridge] but... at first the only thing that was difficult to figure out was what to use the cart[ridge] for. I don't know, at first I thought it was like just regular pictures they put on the table." (P3).*
- **Lack:** Another issue for some participants (P5, P6, P7) was that instructions were not always present when the participant needed them: *"You don't know what all the buttons [on the physical controllers] are for because there's no really directions on what the buttons are for. So you just sit there and you say, 'Well, I'm going to play with this part and see what these buttons are then I'm going to play with these buttons and see with these buttons.' That basically was what I did.... I mean, maybe if it gave a little bit of a hint or something saying, 'hey, when you grab the paper airplane, you've got to release it this way' or something like that." (P7).* In some instances, a lack of audio instructions was a problem for the participants, for the same reason: *"And I didn't look up because there was no voice that says, 'Hey, look up to your left, look up to your right.'" (P7).*
- **Rapidity:** Further, the pace of the instructions (especially the audio instructions) was sometimes too fast for the participants (P5, P9). For instance, we observed that one participant, who was initially instructed to use the joystick, was then prompted by the audio instructions to move to the next step and use their index finger to squeeze the trigger on the physical controller. The participant, however, could not keep up with the pace of the instructions and was frustrated as a result, exclaiming: *"I'M PRESSING [IT]!" (P5).*

5.1.3 Participants often made mistakes in executing the tasks, despite perceiving the instructions. As a result of the aforementioned issues in perceiving the written and audio instructions, participants (P3, P5, P6) did not engage within the virtual environment as expected. For instance, one participant thought he was supposed to pick up the virtual video-game console instead of inserting the cartridge into it: *"I don't need to grab the console, right?" (P3).* Further, we observed that the participants sometimes generalized previous behaviors across different virtual objects. For instance, despite instructions specifying different actions for the paper airplane and the model rocket, participants threw the model rocket as they did with the paper airplane instead of pulling the string on the model rocket.

5.2 Issues in understanding the characteristics of the virtual objects

In general, the various physical characteristics of the virtual objects dictated the way a participant perceived and engaged with the object. This included the form of the virtual object: *"I just grabbed the paddle because the handle was round. So it makes it easier to grab, compared to something that's like rectangle or square. When* *you have a round object, a round sphere, it's a little easier to pick up." (P7)* and the size of the virtual object: *"Because I figured the ball was too small. I mean, if it's like a like a tennis ball or a baseball or softball, you're going to pick that up and throw it. You're not going to throw a table tennis, a little round plastic ball, because it isn't going to do nothing." (P7).*

Several participants (P3, P5, P8) found it difficult to determine what to do with some of the virtual objects, as they could not understand their purpose. For instance, one participant wanted to grab the blocks instead of shooting the blocks with the gun: *"What [are] these, blocks?... grab them." (P5).* Not knowing what to do with the virtual objects caused several participants to skip activities and not explore the virtual environment: *"There [were] rockets and other [things] but I couldn't figure out what the object was, so I couldn't play with it... but I wanted to." (P8).*

Since activities 2-6 were available at the same time, there was a paradox of choice within the virtual environment for many participants (P2, P5, P6, P7), which led them to feel overwhelmed: *"So there could be something in front of me, I'm not going to miss it... and then next I had, like, ten different items in front of me... I'm looking at everything. I go, like... 'what do I do... what do I do...' you know." (P7).*

Another issue with understanding the virtual objects was when there was no feedback in response to a participant's action. For instance, after inserting the cartridge into the console, the participant expected the console to move to the next task automatically. However, the environment expected them to press a button on the virtual console to move to the next task but this was never clearly explained: *"I think it stayed there... I think it stayed there, that's it, yeah."(P5).* Another participant expected feedback from the environment when they were not doing the activity as expected by the app but did not receive this feedback: *"Well at first, I thought I was [throwing the paper airplane] good. Like I said, I was able to do it one time perfectly well but the rest of the time I tried, I knew that I was probably doing something wrong. I just didn't know what exactly. Was it something with the plane or my throwing? " (P3).*

5.3 Issues in understanding the behavior of the avatars within the virtual environment

The single-user VR application often has only a partial-body avatar for the user. The form in which this avatar was displayed was a cause for confusion. For instance, the app initially shows the avatar as virtual hands holding virtual controllers. At some point this switches to empty virtual hands. The controllers simply disappear without any warning. Participants (P5, P6) were confused by this switch in the visual representation of their avatar: *"Wait, now I don't have the [virtual] controller anymore. What happened to it? Where is the [virtual] controller? It's gone." (P5).*

The virtual environment also contained a "non-playing avatar" that participated in dancing with the participant. One Participant found it uncomfortable if these non-playing avatars behaved in ways that were socially awkward to them within the virtual environment. For instance, one participant expressed discomfort when a non-playing avatar entered into their personal space within the virtual environment: *"I just know, the way [the robot] was moving towards me, It just felt like I was being a little... like he was coming into my space. When you have somebody coming into a little bubble that you are not used to, I wasn't really expecting them to come up that close and I was like... whoa." (P7).* The participant also mentioned that they gave a cue to the virtual character by looking into its eyes as way to let the virtual character know to give them more space but to no avail: *"It was a little uneasy when he got close to me. I felt a little like quite a bit invading my privacy. It was, like, 'getting a little bit close, buddy,' I mean like, I looked him in the eye and I'm like, 'yeah, that's a little too close for me....' Oh yeah, it would be a lot weirder if it was like [a real person]." (P7).*

6 Findings 2: People with I/DD experience issues with using the physical controllers and engaging with the 3D nature of the virtual environment

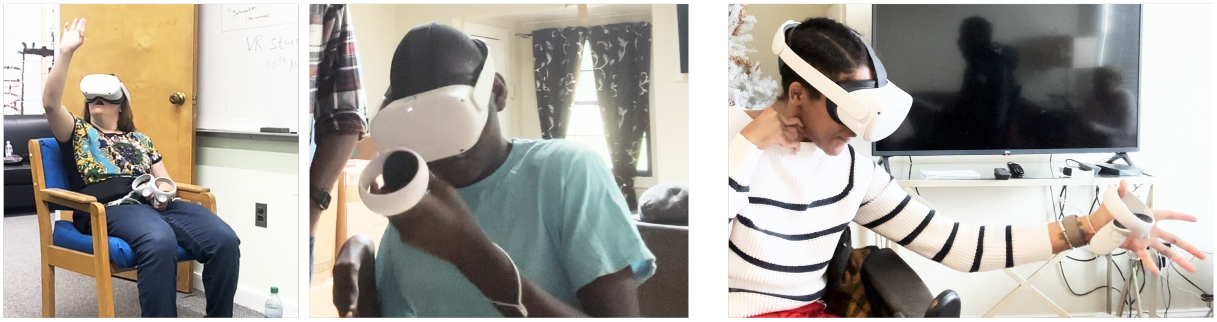
The other state in our VR user experience model is where users engage with (i.e., act within) the virtual environment, based on what they perceive through their headset (and controllers). We found there were two main classes of issues in this regard (i.e., while they were in the *engagement state* of our VR user experience model), which we describe next.

6.1 Issues in knowing how to use the physical controllers to engage within the virtual environment

Participants needed to use the physical controllers to engage with the virtual objects within the virtual environment. We found that the participants experienced several issues in using the physical controllers effectively to engage within the virtual environment. These issues were of four types, as described below.

6.1.1 Participants had difficulty remembering that they had to use the physical controllers to engage within the virtual environment. Participants (P6, P9) found it difficult to understand that they had to use the physical controller(s) to engage with virtual objects. For instance, one of the activities was to make a fist with the virtual hand and hit a tethered ball with the fist. Making a fist with the virtual hand required pressing both the trigger and grip buttons simultaneously on one of the physical controllers. However, instead of doing so, we observed that one participant put down the physical controllers and made a fist with their hands. When we asked why they did so, they replied: *"[I cannot make a fist.] Not with [the physical controllers] in my hand." (P6)* (see Figure 2 (a)). Similarly, another participant (P9) made a grabbing gesture with their fingers while holding the physical controller when attempting to pick up a virtual object instead of pressing the grip button on the physical controller.

6.1.2 Participants had difficulty remembering how to operate the physical controllers. One of the issues for the majority of the participants (P1, P3, P5, P6, P7, P8, P9) was figuring out which button to press on the physical controllers to engage with the virtual objects: *"I just think I couldn't grab [the cubes]. Maybe I didn't know how to grab it at first." (P7).* When asked why, participants stated that they found using the physical controllers to engage with virtual objects not to be intuitive: *"I'm going like, well, how do I grab the gun and how do I shoot [the blocks]. And it took me a few minutes*



(a) (b) (c)

Figure 2: Examples of participants having difficulty using the physical controllers: (a) a participant tries to grab a virtual object with their hand, after having set down the controller; (b) a participant holds the controller backwards; (c) a participant tries to grab a virtual object with their hand instead of using the controller they are holding.

to do that. Once I grabbed the gun, I had to learn which button to press to shoot, which was the top." (P7). Others did not know which buttons to press on the physical controllers, especially when this information was not displayed within the virtual environment: *"I can't see.... I didn't see anything glowing [on the virtual controllers]" (P6).*

The activities often required participants to press multiple buttons simultaneously, which was difficult for some participants. A case in point was one of the tasks that required the user to use a virtual remote control device to fly a virtual blimp. Operating the virtual remote control required pressing the trigger button on the physical controller to drive the blimp and using the joystick to change its direction. To change direction and drive the blimp, both the joystick and trigger button had to be used simultaneously, which participants found to be frustrating: *"The little dirigible thing [the blimp] was a little bit hard... uh... boy do I need to concentrate on... [how to] use the [joy]stick button to turn directions." (P1).* Even when participants managed to perform an action once, they often had difficulty in successfully performing it again: *"I tried to pick up another [block] but I couldn't - but then I picked up the paper airplane and [it also] fell out of my hand." (P7).*

Despite our having included these topics in the introduction to VR we gave participants at the beginning of each session, some participants had difficulty remembering how to hold the physical controllers. We observed that a few participants (P5, P6) held the physical controllers backwards, with the trigger button facing them (see Figure 2 (b)). This positioning made it virtually impossible for them to press the buttons on the physical controllers.

6.1.3 Participants had difficulties when they had to position their arms while operating the physical controllers. Engaging became much more challenging when the paradigm of engagement within the virtual environment changed from requiring just pressing buttons on the physical controllers to a combination of repositioning one's arms while pressing button(s) on the controller(s). A case in point was a task that required pressing a virtual button. In order to press the virtual button, the participant had to: (1) extend their arm (while holding the physical controller) to simulate getting close to the virtual button within the virtual environment; (2) press the grip button to point the virtual index finger; and (3) while holding that position, move the hand in a downward direction (as if lowering the virtual index finger to press the virtual button). A majority of the participants (P3, P5, P6, P7, P8, P9) were confused with this complex multistep approach that was necessary to press a virtual button in virtual environment and thus progress in the app: *"At first I thought I was supposed to press a [button on the physical controller]. So I knew I had to put my hand over the [virtual] button but I didn't know if I had to press one of the [physical] control[ler] buttons in order to press *that* particular [virtual button] but I figured I'd just try putting [my] hand down and see if *that* would work. So I figured *that* would work, instead of just trying to click the buttons on the [physical] controller." (P3).* Another common issue for many participants was throwing a virtual object, which required moving one's arm in a throwing motion while releasing the previously depressed buttons on the physical controller at the right time: *"So basically the airplanes, it was not so much picking it up [where] I had trouble but the throwing part... I had trouble.... So basically, I was able to grab it perfectly fine and I just thought, like I did with the ping pong things but throwing it, on the other hand, *that* was a little challenging " (P3).*

6.1.4 Participants had difficulty when they had to use both physical controllers simultaneously. Participants (P3, P5, P6, P9) found it difficult to engage with virtual objects that required using both physical controllers (and thus both hands). For instance, it was often difficult for participants to throw the virtual ping pong ball in the air with one hand and hit it with the virtual ping pong paddle, using the other hand: *"I don't know how to do that for that quick, throw the ball in the air and hit it right straight." (P3).* Additionally, one participant had trouble engaging with a virtual gun that required using two hands: *"Not [challenging] at the beginning [when using a single virtual gun with one hand]. I think it was towards when I had to use two hands to hold the guns. *That* tends to be a little difficult for me to like maneuver it because... it's one thing to hold a gun with one hand but if you have to hold it with two hands and maneuver, now *that* might be tough." (P3).*

6.2 Issues in engaging with virtual objects not located directly in front of the user

In addition to the issues from the physical controllers, the placement of virtual objects within the virtual environment made it difficult for several participants (P1, P3, P5, P7, P9) to engage with them. The virtual objects were rendered at different locations within the virtual environment and not always in front of the user: *"[Virtual objects placed] in the left corner and in the right corners were very very high, where you got to try to get very, very, very high up in the corner." (P8).* Participants found it hard to engage with virtual objects not directly in front of them: *"I just think how to make sure I'm in the right spot... but it was hard, like picking up [virtual objects]. I have to place myself in the right areas in order for me to, like, pick it up." (P9).* In such cases, participants often needed multiple attempts to position their hands in order to reach a virtual object to pick it up: *"It took me a couple of tries to [shake hands with the virtual robot]. When you're shaking somebody's hand, you got to make sure you have that right [height]. If I came and shook your hand, it's going to be like this [participant demonstrates shaking hands at the usual height]." (P7).* Similarly, participants also found it difficult to engage with virtual objects that were placed on their non-dominant side. For instance, we observed that one participant (P6) attempted to grab a virtual cable on their left side by moving their left (non-dominant) hand but eventually had to use their right hand to successfully reach and grab it (by simultaneously pressing the appropriate buttons on the physical controller). This problem of the virtual objects' positioning relative to the participant was much worse for the participants using wheelchairs. These participants (P2, P3, P9) often tried to move their wheelchairs to position themselves in front of the virtual objects to engage with them (rather than reaching their hand toward the virtual object): *"I think I'm on top of this table. I think I'm not in middle of the table, I'm more on the side." (P3).*

7 Findings 3: People with I/DD wanted several accessibility improvements to the design of virtual environments

Finally, we asked the participants their thoughts on what they would like to see improved with respect to the virtual environment. Their responses fell into three broad themes, which we describe below.

7.1 Participants suggested improvements to the way the instructions are presented within the virtual environment

A few participants (P5, P7, P9) suggested improvements to both the written and audio instructions. One participant mentioned that having audio instructions throughout the entire VR app, not just in some places, would help those with limited literacy: *"I would change it to help a person like me because I can't read. So looking at a screen where we have something like that first screen there, you should have at least that first sentence read to people." (P7).* Another participant mentioned that she wanted the audio instructions to repeat: *"I wish [the audio instructions] would repeat." (P9).* When it came to the scope of the instructions, the participants wanted them to provide hints on how to engage with the virtual objects: *"I mean, maybe if it gave a little bit of a hint or something saying, 'hey, when you grab the paper airplane, you got to release it this way' or something like that" (P7).* Another participant wanted improvements to the written instructions, in terms of their display size: *"[If the written instructions are] closer, I can see them... yeah, [make the written text] bigger, bigger." (P5).*

7.2 Participants wanted notifications about changes to the virtual environments in order to have more control

All but one of the participants who completed the app's activities (P2, P3, P4, P6, P7, P9) had difficulty in situations where they had the option of engaging with multiple virtual objects at the same time. Consequently, participants wanted notifications about changes to the virtual environment and control over how long they engage with the activities:

> *It was just, there was too many things that just popped up at once.... Maybe if they could work on, like, if you want the game to last more longer, be more interesting, you might have like two minutes in-between something so they can sit there for two minutes and play with the blocks and then the computer or the virtual thing can say, 'okay, something's coming up,' then you can go and do that. If it's the paper airplane, then the virtual thing will say, 'okay, this is coming up next.' So it kind of, like, prepares you because I was looking at the blocks and I was playing with the blocks and then all of a sudden I had all this other stuff and I'm looking at them all like, 'this is too much, there's too much stuff here' because it's just overwhelming. (P7)*

7.3 Participants wanted the avatars and virtual objects to appear more realistic

Another suggestion from several participants (P1, P3, P7, P9) was to make avatars and objects more akin to their real world counterparts. In this regard, they suggested the introduction of the following properties to the virtual environment:

- **Display more features in one's avatar:** Participants suggested they want to be able to see more than the virtual hands and the virtual controllers inside the virtual environment: *"Too bad I can't see my feet in here " (P1).*
- **Make activities more realistic:** Participants mentioned that they would like specific activities within the virtual environment (e.g., ping pong) to more closely simulate their real-world counterparts. In response to a question about with whom they would like to play, one participant stated: *"With [my brother]" (P5).*
- **Make virtual objects more realistic:** Participants also mentioned having difficulty with understanding what certain virtual objects were supposed to be. They wanted the virtual objects to be rendered more realistically: *"... all the things, you might want to make a bit more accurate, though, with the graphics and all of that." (P1).*

8 Designing single-user VR applications to address the needs of people with I/DD is an emerging research area that needs further exploration

Based on our interview study, we argue that single-user VR applications intended for use by people with I/DD must be designed with their specific needs in mind and adopt a user-centered approach to ensure accessibility and usability. In this section, we describe the implications of our findings by discussing four areas for opportunity in accessibility research in the context of designing single-user virtual environments for people with I/DD.

8.1 Opportunity 1: Explore ways to provide appropriate information to people with I/DD to help them effectively perceive the virtual environment

One can think of VR environments as broadly existing in a continuum, ranging from the *realistic* (i.e., like the real world) to the *weird* (i.e., creative, based on the VR application creator's imagination) [58]. Therefore, the more realistic a virtual environment, the less information the user needs and conversely the weirder the virtual environment, the more information needs to be provided. The other dimension to consider depends on the goals imagined by the virtual environment's creator. The more specific the goals to be achieved within the environment, the more guidance is needed. Further, the abilities of individuals with I/DD is another critical factor in how much information to provide. Individuals who have more severe I/DD may require clear, easy to understand, step-by-step instructions. Understanding the interplay of these factors allows designers to customize the amount and type of instruction provided, ensuring that all users with I/DD can have a meaningful and accessible VR. However, how to effectively balance and tailor these factors to create virtual experiences that are accessible to people with I/DD remains an open question that needs to be explored, often in an app-specific manner.

8.2 Opportunity 2: Explore novel modes of engagement that are suitable for people with I/DD

In our findings we found that participants often had difficulties using the physical controllers. The participants often did not know which buttons to press, sometimes forgot the button combinations, or had trouble pressing the required button combinations on the controller(s). They sometimes also forgot to use the controller(s) altogether and gravitated toward the unprompted use of gestures. Consequently, we approach the problem in engagement for people with I/DD in two ways: first, by addressing the issue of using the physical controllers and second, by exploring alternative modes of engagement that do not require the use of physical controllers. One possible strategy to address the issue of using the physical controllers would be to use of some form of just-in-time guidance. For instance, one can imagine a situation where VR-based eye-gaze tracking is used [1, 63] to determine the virtual object with which the user wants to interact and then perhaps overlay an animation of the controller above it to show the various ways in which one could manipulate it. Another possibility would be to use hand gestures, which several of our participants naturally gravitated toward. Several studies have explored hand gestures for people with I/DD in a 2D space [2, 17, 56]. Prior work has investigated the use of hand gestures in VR applications for individuals with Down Syndrome [29]. Further studies are needed in order to understand: (1) users' different levels of comfort when performing hand gestures, especially over the long term, and (2) the cognitive load associated with learning the hand gestures. Another approach to avoid using physical controllers would be to utilize voice commands. Existing studies in the 2D space show that people with I/DD like a voice input mode [7]. However, how to design voice commands for VR environments needs further exploration.

8.3 Opportunity 3: Explore screencast-based real-time annotations as a way to assist people with I/DD in the single-user VR context

From our findings, we know that people with I/DD may have difficulties perceiving or engaging within the virtual environment, depending on its design. In such cases, there is no good way for an *assistant* to help the user. Most single-user VR applications currently provide screencasting, which allows others to view what the person using the headset is seeing. One possible way to help users with I/DD is via real-time annotations where the assistant can see the virtual environment from the screencast device and use this device to annotate into the 3D space of the virtual environment for users with I/DD to view through their headset. This can be thought of as being analogous to the annotation capabilities in video conferencing tools like Zoom, except in the single-user VR space. Having said that, there needs to be a way to control the amount of assistance that can be provided with such a system (e.g., from making simple annotations to introducing virtual objects into the space from outside). This control should be augmented with guidelines on the level of assistance that should be given to the VR user via screencasting, especially when it comes to people with I/DD (since they are often infantilized by others [6]). These questions should be tackled in order for assistants to help people with I/DD to engage within the virtual environment via the screencast feature.

8.4 Opportunity 4: Explore strategies to increase immersion and agency within the virtual environment for people with I/DD

A particular issue we observed in this study was that participants often only interacted with objects within their field of view (FoV). The human binocular FoV can reach up to 190°, while most popular consumer VR headsets currently offer around half of that [45]. Since the VR environment provides a 360° view, what participants were viewing was a very small sliver of the world in which they were immersed. In our study, we found that participants often did not fully understand this immersive nature of the virtual environment. As a result, their perceived agency within the environment [3] (i.e., their understanding of their ability to influence and control the world around them) was also severely limited. Therefore, one of the design issues that we believe needs to be addressed is to make individuals with I/DD aware of the 360° environment around them. This awareness would also help users orient themselves relative to other objects within the virtual space. How to effectively convey the immersive nature of the virtual environment and as a result promote the level of perceived agency for the user is an open question. One could imagine the use of visual signifiers as an obvious step in this regard. Other approaches that could be used include spatial audio-based signifiers [23, 42], which provide directional cues or sounds to make the individual with I/DD turn and see things to their side and behind them within the virtual space. However, spatial audio has to be designed such that people with I/DD pay attention to it, unlike the audio instructions, as mentioned in our findings. Another method would be to use haptic signatures, especially if controllers are being used, [10, 44, 44, 81]. However, how to design a haptic signature that would give directional and exploratory cues to individuals with I/DD in a virtual environment is an open question.

9 Study limitations

The methodology of our study has few limitations that we briefly discuss. First, the responses sought from the participants were instantaneous reactions after their use of a specific VR app. We believe this evaluation has value and provides useful information regarding VR accessibility issues. That being said, it is possible that their responses to certain questions may have been more nuanced if they had used a different app or used this app for a longer period of time. Second, for a few participants, the first author had to use at least one of the controllers because of their upper extremity impairment. As VR accessibility is not just about engaging with the virtual environment but also on the perception of the virtual environment, we believe that this accommodation provided by the first author did not affect our findings. Third, we deliberately selected an app that does not require locomotion, teleportation, or movement of the avatar through the virtual environment. The reason for this choice was to minimize any presence of cybersickness coloring their opinion about the rest of their VR experience. Finally, all of our participants live in the United States; therefore their perspectives and experiences may differ from those of people with I/DD from other cultures and regions.

10 Conclusion

In this paper, we sought to understand the accessibility issues for people with I/DD in using single-user VR applications. To this end, we asked eight participants with I/DD to use a VR app (on a Meta Quest 2 device) that introduces the various elements of VR and then asked them questions in a semi-structured interview about their experience using the app. We found that participants had difficulty perceiving the various elements of the virtual environment and engaging within the virtual environment using the physical controller(s). Based on these findings, we present four major research opportunities that can help improve the VR accessibility for people with I/DD in single-user VR applications.

Acknowledgments

We would like to thank all of our reviewers and participants for their invaluable help with this paper. This work is supported in part by the National Science Foundation grant IIS-2408481.

References

[1] Isayas Berhe Adhanom, Paul MacNeilage, and Eelke Folmer. 2023. Eye tracking in virtual reality: a broad review of applications and challenges. *Virtual Reality* 27, 2 (2023), 1481–1505.

[2] Mendoza G. Alfredo, J. Alvarez R. Francisco, Mendoza G. Ricardo, Acosta E. Francisco, and Muñoz A. Jaime. 2015. Analyzing Learnability of Common Mobile Gestures used by Down Syndrome Users. In *Proceedings of the XVI International Conference on Human Computer Interaction* (Vilanova i la Geltru, Spain) *(Interacción '15)*. Association for Computing Machinery, New York, NY, USA, Article 1, 8 pages. doi:10.1145/2829875.2829876

[3] Ala Alsaleh, Moritz Schubert, and Dominik Endres. 2023. The Effect of Sense of Agency on Self-Efficacy Beliefs: A Virtual Reality Paradigm. In *ACM Symposium on Applied Perception 2023* (Los Angeles, CA, USA) *(SAP '23)*. Association for Computing Machinery, New York, NY, USA, Article 10, 11 pages. doi:10.1145/3605495.3605795

[4] Beatrice Aruanno, Franca Garzotto, Emanuele Torelli, and Francesco Vona. 2018. HoloLearn: Wearable Mixed Reality for People with Neurodevelopmental Disorders (NDD). In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility* (Galway, Ireland) *(ASSETS '18)*. Association for Computing Machinery, New York, NY, USA, 40–51. doi:10.1145/3234695.3236351

[5] Pinaki Prasanna Babar, Mike Barry, and Roshan L Peiris. 2023. Understanding Job Coaches' Perspectives on Using Virtual Reality as a Job Training Tool for Training People with Intellectual Disabilities. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (<conf-loc>, <city>Hamburg</city>, <country>Germany</country>, </conf-loc>) *(CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 300, 7 pages. doi:10.1145/3544549.3585915

[6] N. J. Baladerian, T. F. Coleman, and J. Stream. 2014. Abuse of People with Disabilities; Victims and Their Families Speak Out. Retrieved Feb 27, 2020 from http://disability-abuse.com/survey/survey-report.pdf

[7] Saminda Sundeepa Balasuriya, Laurianne Sitbon, Andrew A. Bayor, Maria Hoogstrate, and Margot Brereton. 2018. Use of Voice Activated Interfaces by People with Intellectual Disability. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction* (Melbourne, Australia) *(OzCHI '18)*. Association for Computing Machinery, New York, NY, USA, 102–112. doi:10.1145/3292147.3292161

[8] Dimitrios Batras, Jean-François Jégo, and Chu-Yin Chen. 2016. Deaf Poetry: saying everything without speaking. In *Proceedings of the 3rd International Symposium on Movement and Computing* (Thessaloniki, GA, Greece) *(MOCO '16)*. Association for Computing Machinery, New York, NY, USA, Article 51, 2 pages. doi:10.1145/2948910.2955108

[9] Nilotpal Biswas, Anamitra Mukherjee, and Samit Bhattacharya. 2024. "Are you feeling sick?" – A systematic literature review of cybersickness in virtual reality. *ACM Comput. Surv.* 56, 11, Article 284 (jun 2024), 38 pages. doi:10.1145/3670008

[10] Pradipta Biswas, Pilar Orero, Manohar Swaminathan, Kavita Krishnaswamy, and Peter Robinson. 2021. Adaptive Accessible AR/VR Systems. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 92, 7 pages. doi:10.1145/3411763.3441324

[11] Douglas A Bowman. 1999. Interaction techniques for common tasks in immersive virtual environments. *Georgia Institute of Technology* (1999).

[12] Ellen Lambert Bowman and Lei Liu. 2017. Individuals with severely impaired vision can learn useful orientation and mobility skills in virtual streets and can use them to improve real street safety. *PLoS One* 12, 4 (April 2017), e0176534.

[13] Jennifer Brade., Alexander Kögel., Christian Fuchs., and Philipp Klimant. 2020. Impact of First Person Avatar Representation in Assembly Simulations on Perceived Presence and Acceptance. In *Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020) - GRAPP*. INSTICC, SciTePress, Virtual Conference, 17–24. doi:10.5220/0008878700170024

[14] Ross Brown, Laurianne Sitbon, Lauren Fell, Stewart Koplick, Chris Beaumont, and Margot Brereton. 2016. Design Insights into Embedding Virtual Reality Content into Life Skills Training for People with Intellectual Disability. In *Proceedings of the 28th Australian Conference on Computer-Human Interaction* (Launceston, Tasmania, Australia) *(OzCHI '16)*. Association for Computing Machinery, New York, NY, USA, 581–585. doi:10.1145/3010915.3010956

[15] Grigore C. Burdea and Philippe Coiffet. 2003. Virtual Reality Technology. *Presence: Teleoperators & Virtual Environments* 12 (2003), 663–664. https://api.semanticscholar.org/CorpusID:60307652

[16] David Byrne. 2022. A worked example of Braun and Clarke's approach to reflexive thematic analysis. *Quality & quantity* 56, 3 (2022), 1391–1412.

[17] Doris Cáliz, Ployplearn Ravivanpong, Andrea Schankin, Janio Jadán-Guerrero, Washington Caraguay, and Leonardo Arellano. 2021. Examining the usability of touchscreen gestures for adults with DS. *Journal of Reliable Intelligent Environments* 7, 4 (Dec. 2021), 355–380.

[18] Jean-Rémy Chardonnet, Mohammad Ali Mirzaei, and Frédéric Merienne. 2021. Influence of navigation parameters on cybersickness in virtual reality. *Virtual Real.* 25, 3 (sep 2021), 565–574. doi:10.1007/s10055-020-00474-2

[19] James Chung-Wai Cheung, Ming Ni, Andy Yiu-Chau Tam, Tim Tin-Chun Chan, Alyssa Ka-Yan Cheung, Ocean Yu-Hong Tsang, Chi-Bun Yip, Wing-Kai Lam, and Duo Wai-Chi Wong. 2022. Virtual reality based multiple life skill training for intellectual disability: A multicenter randomized controlled trial. *Engineered Regeneration* 3, 2 (2022), 121–130. doi:10.1016/j.engreg.2022.03.003

[20] James Chung-Wai Cheung, Ming Ni, Andy Yiu-Chau Tam, Tim Tin-Chun Chan, Alyssa Ka-Yan Cheung, Ocean Yu-Hong Tsang, Chi-Bun Yip, Wing-Kai Lam, and Duo Wai-Chi Wong. 2022. Virtual reality based multiple life skill training for intellectual disability: A multicenter randomized controlled trial. *Engineered Regeneration* 3, 2 (2022), 121–130.

[21] Mark Colley, Marcel Walch, Jan Gugenheimer, Ali Askari, and Enrico Rukzio. 2020. Towards Inclusive External Communication of Autonomous Vehicles for Pedestrians with Vision Impairments. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3313831.3376472

[22] Jazmin Collins, Crescentia Jung, Yeonju Jang, Danielle Montour, Andrea Stevenson Won, and Shiri Azenkot. 2023. “The Guide Has Your Back”: Exploring How Sighted Guides Can Enhance Accessibility in Social Virtual Reality for Blind and Low Vision People. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (<conf-loc>, <city>New York</city>, <state>NY</state>, <country>USA</country>, </conf-loc>) *(ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 38, 14 pages. doi:10.1145/3597638.3608386

[23] Gustavo Corrêa De Almeida, Vinicius Costa de Souza, Luiz Gonzaga Da Silveira Júnior, and Maurício Roberto Veronez. 2024. Spatial Audio in Virtual Reality: A systematic review. In *Proceedings of the 25th Symposium on Virtual and Augmented Reality* (Rio Grande, Brazil) *(SVR '23)*. Association for Computing Machinery, New York, NY, USA, 264–268. doi:10.1145/3625008.3625042

[24] Chris Creed, Maadh Al-Kalbani, Arthur Theil, Sayan Sarcar, and Ian Williams. 2024. Inclusive AR/VR: accessibility barriers for immersive technologies. *Universal Access in the Information Society* 23, 1 (01 Mar 2024), 59–73. doi:10.1007/s10209-023-00969-0

[25] Rian Dutra da Cunha, Frâncila Weidt Neiva, and Rodrigo Luis de Souza da Silva. 2018. Virtual Reality as a Support Tool for the Treatment of People with Intellectual and Multiple Disabilities: A Systematic Literature Review. *Revista de Informática Teórica e Aplicada* 25, 1 (Feb. 2018), 67–81. doi:10.22456/2175-2745.77994

[26] Rian Dutra da Cunha and Rodrigo L. S. Silva. 2017. Virtual reality as an assistive technology to support the cognitive development of people with Intellectual and multiple disabilities. https://api.semanticscholar.org/CorpusID:2820529

[27] Vagner Figueredo de Santana, Rodrigo Laiola Guimarães, and Andrea Britto Mattos. 2016. Identifying Challenges and Opportunities in Computer-Based Vocational Training for Low-Income Communities of People with Intellectual Disabilities. In *Proceedings of the 13th Web for All Conference* (Montreal, Canada) *(W4A '16)*. Association for Computing Machinery, New York, NY, USA, Article 2, 8 pages. doi:10.1145/2899475.2899480

[28] Marta Sylvia Del Rio Guerra, Jorge Martin-Gutierrez, Renata Acevedo, and Sofía Salinas. 2019. Hand Gestures in Virtual and Augmented 3D Environments for Down Syndrome Users. *Applied Sciences* 9, 13 (2019). doi:10.3390/app9132641

[29] Marta Sylvia Del Rio Guerra, Jorge Martin-Gutierrez, Renata Acevedo, and Sofía Salinas. 2019. Hand gestures in virtual and augmented 3D environments for Down syndrome users. *Appl. Sci. (Basel)* 9, 13 (June 2019), 2641.

[30] Oche A. Egaji, Ikram Asghar, Mark Griffiths, and William Warren. 2019. Digital Speech Therapy for the Aphasia Patients: Challenges, Opportunities and Solutions. In *Proceedings of the 9th International Conference on Information Communication and Management* (Prague, Czech Republic) *(ICICM '19)*. Association for Computing Machinery, New York, NY, USA, 85–88. doi:10.1145/3357419.3357449

[31] Stephen R Ellis. 1994. What are virtual environments? *IEEE Computer Graphics and Applications* 14, 1 (1994), 17–22.

[32] Aviv Elor, Mircea Teodorescu, and Sri Kurniawan. 2018. Project Star Catcher: A Novel Immersive Virtual Reality Experience for Upper Limb Rehabilitation. *ACM Trans. Access. Comput.* 11, 4, Article 20 (nov 2018), 25 pages. doi:10.1145/3265755

[33] James Coleman Eubanks, Alec G. Moore, Paul A. Fishwick, and Ryan P. McMahan. 2020. The Effects of Body Tracking Fidelity on Embodiment of an Inverse-Kinematic Avatar for Male Participants. In *2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, Virtual Conference, 54–63. doi:10.1109/ISMAR50242.2020.00025

[34] Habib M. Fardoun, Lorenzo C. González, and Abdulfattah S. Mashat. 2013. Rehabilitation low vision algorithm: for people with central or multiple losses of vision. In *Proceedings of the 7th International Conference on Pervasive Computing Technologies for Healthcare* (Venice, Italy) *(PervasiveHealth '13)*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), Brussels, BEL, 339–343. doi:10.4108/icst.pervasivehealth.2013.252363

[35] Meta 2023. *First Steps*. Meta. https://www.meta.com/experiences/1863547050392688/

[36] Rachel L. Franz, Jinghan Yu, and Jacob O. Wobbrock. 2023. Comparing Locomotion Techniques in Virtual Reality for People with Upper-Body Motor Impairments. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (<conf-loc>, <city>New York</city>, <state>NY</state>, <country>USA</country>, </conf-loc>) *(ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 39, 15 pages. doi:10.1145/3597638.3608394

[37] Bhanuka Gamage, Leona Holloway, Nicola McDowell, Thanh-Toan Do, Nicholas Seow Chiang Price, Arthur James Lowery, and Kim Marriott. 2024. Broadening Our View: Assistive Technology for Cerebral Visual Impairment. In *Extended Abstracts of the 2024 CHI Conference on Human Factors in Computing Systems (CHI EA '24)*. Association for Computing Machinery, New York, NY, USA, Article 64, 9 pages. doi:10.1145/3613905.3650740

[38] Giorgos Ganias, Christos Lougiakis, Akrivi Katifori, Maria Roussou, Yannis Ioannidis, and Ioannis Panagiotis Ioannidis. 2023. Comparing Different Grasping Visualizations for Object Manipulation in VR using Controllers. *IEEE Transactions on Visualization and Computer Graphics* 29, 5 (2023), 2369–2378. doi:10.1109/TVCG.2023.3247039

[39] Chris N W Geraets, Roelof Dolfijn, Lisanne M Robbemond, Albert Scholte, Stéphanie Klein Tuente, and Wim Veling. 2023. Virtual reality aggression prevention training for people with mild intellectual disabilities: A feasibility study. *J. Ment. Health Res. Intellect. Disabil.* (Nov. 2023), 1–22.

[40] Kathrin Gerling, Patrick Dickinson, Kieran Hicks, Liam Mason, Adalberto L. Simeone, and Katta Spiel. 2020. Virtual Reality Games for People Using Wheelchairs. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (<conf-loc>, <city>Honolulu</city>, <state>HI</state>, <country>USA</country>, </conf-loc>) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–11. doi:10.1145/3313831.3376265

[41] Adrian Goldsworthy, Mohd Fairuz Shiratuddin, Oystein Tronstad, John F. Fraser, Matthew Olsen, Lotti Tajouri, and Kok Wai Wong. 2025. Do virtual reality interventions cause seizures in the critically ill? A rapid review. *Australian Critical Care* 38, 4 (2025), 101231. doi:10.1016/j.aucc.2025.101231

[42] Amit Hirway, Yuansong Qiao, and Niall Murray. 2022. Spatial audio in 360° videos: does it influence visual attention?. In *Proceedings of the 13th ACM Multimedia Systems Conference* (Athlone, Ireland) *(MMSys '22)*. Association for Computing Machinery, New York, NY, USA, 39–51. doi:10.1145/3524273.3528179

[43] Ocean Hurd and Sri Kurniawan. 2019. Insights for More Usable VR for People with Amblyopia. In *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility* (Pittsburgh, PA, USA) *(ASSETS '19)*. Association for Computing Machinery, New York, NY, USA, 706–708. doi:10.1145/3308561.3356110

[44] Dhruv Jain, Sasa Junuzovic, Eyal Ofek, Mike Sinclair, John R. Porter, Chris Yoon, Swetha Machanavajhala, and Meredith Ringel Morris. 2021. Towards Sound Accessibility in Virtual Reality. In *Proceedings of the 2021 International Conference on Multimodal Interaction* (Montréal, QC, Canada) *(ICMI '21)*. Association for Computing Machinery, New York, NY, USA, 80–91. doi:10.1145/3462244.3479946

[45] Crescent Jicol, Christopher Clarke, Emilia Tor, Rebecca M Dakin, Tom Charlie Lancaster, Sze Tung Chang, Karin Petrini, Eamonn O'Neill, Michael J Proulx, and Christof Lutteroth. 2023. Realism and Field of View Affect Presence in VR but Not the Way You Think. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 399, 17 pages. doi:10.1145/3544548.3581448

[46] Cécile Lacôte-Coquereau, Toinon Vigier, and Matthieu Perreira Da Silva. 2023. Experimenting in virtual reality with an autistic public having language and intellectual development disorders: lessons learned and recommendations. In *Proceedings of the 2023 ACM International Conference on Interactive Media Experiences Workshops* (<conf-loc>, <city>Nantes</city>, <country>France</country>, </conf-loc>) *(IMXw '23)*. Association for Computing Machinery, New York, NY, USA, 8–11. doi:10.1145/3604321.3604380

[47] Simon Langener, Randy Klaassen, Joanne VanDerNagel, and Dirk Heylen. 2022. Immersive virtual reality avatars for embodiment illusions in people with mild to borderline intellectual disability: User-centered development and feasibility study. *JMIR Serious Games* 10, 4 (Dec. 2022), e39966.

[48] Liza Lee and Tz Yuan Li. 2016. The impact of music activities in a multi-sensory room for children with multiple disabilities on developing positive emotions: A case study. *Journal of the European Teacher Education Network* 11 (2016), 1–12.

[49] Rastislav Lipovský and Hugo Alexandre Ferreira. 2015. Self hand-rehabilitation system based on wearable technology. In *Proceedings of the 3rd 2015 Workshop on ICTs for Improving Patients Rehabilitation Research Techniques* (Lisbon, Portugal) *(REHAB '15)*. Association for Computing Machinery, New York, NY, USA, 93–95. doi:10.1145/2838944.2838967

[50] Tommaso Loiacono, Marco Trabucchi, Nicolò Messina, Vito Matarazzo, Franca Garzotto, and Eleonora Aida Beccaluva. 2018. Social MatchUP -: A Memory-like Virtual Reality Game for the Enhancement of Social Skills in Children with Neurodevelopmental Disorders. https://doi.org/10.1145/3170427.3188525. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New

York, NY, USA, 1–6. doi:10.1145/3170427.3188525

[51] Meir Lotan, Shira Yalon-Chamovitz, and Patrice L Tamar Weiss. 2009. Improving physical fitness of individuals with intellectual and developmental disability through a Virtual Reality Intervention Program. *Research in developmental disabilities* 30, 2 (2009), 229–239.

[52] Meir Lotan, Shira Yalon-Chamovitz, and Patrice L Tamar Weiss. 2010. Virtual reality as means to improve physical fitness of individuals at a severe level of intellectual and developmental disability. *Research in developmental disabilities* 31, 4 (2010), 869–874.

[53] Jean-Luc Lugrin, Maximilian Ertl, Philipp Krop, Richard Klüpfel, Sebastian Stierstorfer, Bianka Weisz, Maximilian Rück, Johann Schmitt, Nina Schmidt, and Marc Erich Latoschik. 2018. Any "Body" There? Avatar Visibility Effects in a Virtual Reality Game. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Reutlingen, Germany, 17–24. doi:10.1109/VR.2018.8446229

[54] Lin Ma, Qian Yu, Jingbin Huang, and Yuzhong Sun. 2022. Based on the Exploration of VR in the Teaching and Training of Special Children. In *Proceedings of the 2022 3rd International Conference on Education Development and Studies* (Hilo, HI, USA) *(ICEDS '22)*. Association for Computing Machinery, New York, NY, USA, 37–41. doi:10.1145/3528137.3528155

[55] M. Rasel Mahmud, Alberto Cordova, and John Quarles. 2023. The Eyes Have It: Visual Feedback Methods to Make Walking in Immersive Virtual Reality More Accessible for People With Mobility Impairments While Utilizing Head-Mounted Displays. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (<conf-loc>, <city>New York</city>, <state>NY</state>, <country>USA</country>, </conf-loc>) *(ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 36, 10 pages. doi:10.1145/3597638.3608406

[56] Jorge Martin-Gutierrez and Marta Sylvia Del Rio Guerra. 2021. Analysing touch-screen gestures: A study based on individuals with Down syndrome centred on Design for all. *Sensors (Basel)* 21, 4 (Feb. 2021), 1328.

[57] Chris McCarthy, Tuan Dung Lai, Stuart Favilla, and David Sly. 2020. Towards an Immersive Auditory-based Journey Planner for the Visually Impaired. In *Proceedings of the 31st Australian Conference on Human-Computer-Interaction* (Fremantle, WA, Australia) *(OzCHI '19)*. Association for Computing Machinery, New York, NY, USA, 387–391. doi:10.1145/3369457.3369499

[58] Joshua McVeigh-Schultz and Katherine Isbister. 2021. The Case for "Weird Social" in VR/XR: A Vision of Social Superpowers Beyond Meatspace. https://doi.org/10.1145/3411763.3450377. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 17, 10 pages. doi:10.1145/3411763.3450377

[59] Stefan Carlo Michalski, Nicholas Charles Gallomarino, Ancret Szpak, Kieran William May, Gun Lee, Caroline Ellison, and Tobias Loetscher. 2023. Improving real-world skills in people with intellectual disabilities: an immersive virtual reality intervention. *Virtual Real.* (April 2023), 1–12.

[60] María M. Montoya-Rodríguez, Vanessa de Souza Franco, Clementina Tomás Llerena, Francisco J. Molina Cobos, Sofía Pizzarossa, Ana C. García, and Vanesa Martínez-Valderrey. 2023. Virtual reality and augmented reality as strategies for teaching social skills to individuals with intellectual disability: A systematic review. *Journal of Intellectual Disabilities* 27, 4 (2023), 1062–1084. doi:10.1177/17446295221089147 arXiv:https://doi.org/10.1177/17446295221089147 PMID: 35420906.

[61] Francesca Morganti, Paola Sabattini, and Roberto Casale. 2016. Embodied rehabilitation: when lokomat supported walking treatment and virtual reality spatial cognition meet. In *Proceedings of the 4th Workshop on ICTs for Improving Patients Rehabilitation Research Techniques* (Lisbon, Portugal) *(REHAB '16)*. Association for Computing Machinery, New York, NY, USA, 74–77. doi:10.1145/3051488.3051503

[62] Martez Mott, John Tang, Shaun Kane, Edward Cutrell, and Meredith Ringel Morris. 2020. "I just went into it assuming that I wouldn't be able to have the full experience": Understanding the Accessibility of Virtual Reality for People with Limited Mobility. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (<conf-loc>, <city>Virtual Event</city>, <country>Greece</country>, </conf-loc>) *(ASSETS '20)*. Association for Computing Machinery, New York, NY, USA, Article 43, 13 pages. doi:10.1145/3373625.3416998

[63] Aunnoy K. Mutasim, Wolfgang Stuerzlinger, and Anil Ufuk Batmaz. 2020. Gaze Tracking for Eye-Hand Coordination Training Systems in Virtual Reality. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–9. doi:10.1145/3334480.3382924

[64] National Disability Navigator. 2022. Population Specific Fact Sheet – Intellectual Disability. https://nationaldisabilitynavigator.org/ndnrc-materials/fact-sheets/population-specific-fact-sheet-intellectual-disability/. Accessed 2022.

[65] American Association of Intellectual and Developmental Disabilities. 2020. American Association of Intellectual and Developmental Disabilities. Retrieved Feb 27, 2020 from https://www.aaidd.org/intellectual-disability/definition

[66] Hrishi Olickel, Parag Bhatnagar, Aaron CS Ong, and Simon T. Perrault. 2017. GooseBumps: Towards Sensory Substitution Using Servo Motors. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces* (Brighton, United Kingdom) *(ISS '17)*. Association for Computing Machinery, New York, NY, USA, 425–428. doi:10.1145/3132272.3132293

[67] Ye Pan and Anthony Steed. 2019. Avatar Type Affects Performance of Cognitive Tasks in Virtual Reality. In *Proceedings of the 25th ACM Symposium on Virtual Reality Software and Technology* (Parramatta, NSW, Australia) *(VRST '19)*. Association for Computing Machinery, New York, NY, USA, Article 6, 4 pages. doi:10.1145/3359996.3364270

[68] Siyou Pei, Alexander Chen, Chen Chen, Franklin Mingzhe Li, Megan Fozzard, Hao-Yun Chi, Nadir Weibel, Patrick Carrington, and Yang Zhang. 2023. Embodied Exploration: Facilitating Remote Accessibility Assessment for Wheelchair Users with Virtual Reality. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (<conf-loc>, <city>New York</city>, <state>NY</state>, <country>USA</country>, </conf-loc>) *(ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 37, 17 pages. doi:10.1145/3597638.3608410

[69] Nicholas Polys and Sheeban Mohd Wasi. 2023. Increasing Web3D Accessibility with Audio Captioning. In *Proceedings of the 28th International ACM Conference on 3D Web Technology* (San Sebastian, Spain) *(Web3D '23)*. Association for Computing Machinery, New York, NY, USA, Article 6, 10 pages. doi:10.1145/3611314.3615902

[70] Meta 2024. *Quest 2*. Meta. https://www.meta.com/quest/products/quest-2/tech-specs/#tech-specs

[71] Björn Severitt, Nora Jane Castner, Olga Lukashova-Sanz, and Siegfried Wahl. 2023. Leveraging gaze for potential error prediction in AI-support systems: An exploratory analysis of interaction with a simulated robot. In *Companion Publication of the 25th International Conference on Multimodal Interaction* (Paris, France) *(ICMI '23 Companion)*. Association for Computing Machinery, New York, NY, USA, 56–60. doi:10.1145/3610661.3617163

[72] Alfred Shaker, Xiangxu Lin, Do Yeon Kim, Jong-Hoon Kim, Gokarna Sharma, and Mary Ann Devine. 2020. Design of a Virtual Reality Tour System for People With Intellectual and Developmental Disabilities: A Case Study. *Computing in Science & Engineering* 22, 3 (2020), 7–17. doi:10.1109/MCSE.2019.2961352

[73] W.R. Sherman and A.B. Craig. 2018. *Understanding Virtual Reality: Interface, Application, and Design*. Morgan Kaufmann. https://books.google.com/books?id=D-OcBAAAQBAJ

[74] James Hugo Smith-Spark, Rebecca Gordon, and Ashok S. Jansari. 2022. The impact of developmental dyslexia on workplace cognition: Evidence from a virtual reality environment. In *Proceedings of the 33rd European Conference on Cognitive Ergonomics* (Kaiserslautern, Germany) *(ECCE '22)*. Association for Computing Machinery, New York, NY, USA, Article 1, 4 pages. doi:10.1145/3552327.3552340

[75] Laura South, Caglar Yildirim, Amy Pavel, and Michelle A. Borkin. 2024. Barriers to Photosensitive Accessibility in Virtual Reality. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 58, 13 pages. doi:10.1145/3613904.3642635

[76] P. J. Standen and D. J. Brown. 2006. Virtual reality and its role in removing the barriers that turn cognitive impairments into intellectual disability. *Virtual Reality* 10, 3 (01 Dec 2006), 241–252. doi:10.1007/s10055-006-0042-6

[77] Penny J Standen, David J Brown, and JJ Cromby. 2001. The effective use of virtual environments in the education and rehabilitation of students with intellectual disabilities. *British journal of educational technology* 32, 3 (2001), 289–299.

[78] Muxiao Sun, Qinglei Bu, Ying Hou, Xiaowen Ju, Limin Yu, Eng Gee Lim, and Jie Sun. 2023. Virtual Reality Music Instrument Playing Game for Upper Limb Rehabilitation Training. In *Companion Publication of the 25th International Conference on Multimodal Interaction* (Paris, France) *(ICMI '23 Companion)*. Association for Computing Machinery, New York, NY, USA, 96–100. doi:10.1145/3610661.3617159

[79] Sing-Fai Tam, David Wai-Kwong Man, Yuk-Piu Chan, Pan-Ching Sze, and Chi-Ming Wong. 2005. Evaluation of a Computer-Assisted, 2-D Virtual Reality System for Training People With Intellectual Disabilities on How to Shop. *Rehabilitation Psychology* 50, 3 (2005), 285.

[80] Yujie Tao, Cheng Yao Wang, Andrew D Wilson, Eyal Ofek, and Mar Gonzalez-Franco. 2023. Embodying Physics-Aware Avatars in Virtual Reality. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 254, 15 pages. doi:10.1145/3544548.3580979

[81] Mauro Teófilo, Vicente F. Lucena, Josiane Nascimento, Taynah Miyagawa, and Francimar Maciel. 2018. Evaluating accessibility features designed for virtual reality context. In *2018 IEEE International Conference on Consumer Electronics (ICCE)*. IEEE, Las Vegas, USA, 1–6. doi:10.1109/ICCE.2018.8326167

[82] Mauro R.S. Teófilo, Alvaro A.B. Lourenço, Juliana Postal, Yuri M.L.R. Silva, and Vicente F. Lucena. 2019. The Raising Role of Virtual Reality in Accessibility Systems. *Procedia Computer Science* 160 (2019), 671–677. doi:10.1016/j.procs.2019.11.029 The 10th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN-2019) / The 9th International Conference on Current and Future Trends of Information and Communication Technologies in Healthcare (ICTH-2019) / Affiliated Workshops.

[83] Jingze Tian, Yingna Wang, Keye Yu, Liyi Xu, Junan Xie, Franklin Mingzhe Li, Yafeng Niu, and Mingming Fan. 2024. Designing Upper-Body Gesture Interaction with and for People with Spinal Muscular Atrophy in VR. In *Proceedings of the*

CHI Conference on Human Factors in Computing Systems (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 60, 19 pages. doi:10.1145/3613904.3642884

[84] Shari Trewin, Vicki L. Hanson, Mark R. Laff, and Anna Cavender. 2008. PowerUp: an accessible virtual world. In *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility* (Halifax, Nova Scotia, Canada) *(Assets '08)*. Association for Computing Machinery, New York, NY, USA, 177–184. doi:10.1145/1414471.1414504

[85] Abel Vargas, Paloma Díaz, and Telmo Zarraonandia. 2020. Using Virtual Reality and Music in Cognitive Disability Therapy. In *Proceedings of the International Conference on Advanced Visual Interfaces* (Salerno, Italy) *(AVI '20)*. Association for Computing Machinery, New York, NY, USA, Article 35, 9 pages. doi:10.1145/3399715.3399916

[86] Krishna Venkatasubramanian, Tina-Marie Ranalli, Priyankan Kirupaharan, and Liam Cannon. 2024. Considering Trauma in Accessible Design for Adults with Intellectual and Developmental Disabilities. *Commun. ACM* 68, 1 (Dec. 2024), 60–67. doi:10.1145/3676310

[87] Francesco Vona, Emanuele Torelli, Eleonora Beccaluva, and Franca Garzotto. 2020. Exploring the Potential of Speech-based Virtual Assistants in Mixed Reality Applications for People with Cognitive Disabilities. In *Proceedings of the International Conference on Advanced Visual Interfaces* (Salerno, Italy) *(AVI '20)*. Association for Computing Machinery, New York, NY, USA, Article 21, 9 pages. doi:10.1145/3399715.3399845

[88] Ryan Wedoff, Lindsay Ball, Amelia Wang, Yi Xuan Khoo, Lauren Lieberman, and Kyle Rector. 2019. Virtual Showdown: An Accessible Virtual Reality Game with Scaffolds for Youth with Visual Impairments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3290605.3300371

[89] Peixuan Xiong, Yukai Zhang, Nandi Zhang, Shihan Fu, Xin Li, Yadan Zheng, Jinni Zhou, Xiquan Hu, and Mingming Fan. 2024. To Reach the Unreachable: Exploring the Potential of VR Hand Redirection for Upper Limb Rehabilitation. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 242, 11 pages. doi:10.1145/3613904.3642912

[90] Shira Yalon-Chamovitz and Patrice L Tamar Weiss. 2008. Virtual reality as a leisure activity for young adults with physical and intellectual disabilities. *Research in Developmental Disabilities* 29, 3 (2008), 273–287.

[91] Kexin Zhang, Elmira Deldari, Yaxing Yao, and Yuhang Zhao. 2023. A Diary Study in Social Virtual Reality: Impact of Avatars with Disability Signifiers on the Social Experiences of People with Disabilities. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (<conf-loc>, <city>New York</city>, <state>NY</state>, <country>USA</country>, </conf-loc>) *(ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 40, 17 pages. doi:10.1145/3597638.3608388

[92] Yuhang Zhao, Cynthia L. Bennett, Hrvoje Benko, Edward Cutrell, Christian Holz, Meredith Ringel Morris, and Mike Sinclair. 2018. Enabling People with Visual Impairments to Navigate Virtual Reality with a Haptic and Auditory Cane Simulation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (<conf-loc>, <city>Montreal QC</city>, <country>Canada</country>, </conf-loc>) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3173574.3173690

[93] Yuhang Zhao, Edward Cutrell, Christian Holz, Meredith Ringel Morris, Eyal Ofek, and Andrew D. Wilson. 2019. SeeingVR: A Set of Tools to Make Virtual Reality More Accessible to People with Low Vision. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3290605.3300341