Design of a Virtual Reality Tour System for People With Intellectual and Developmental Disabilities: A Case Study

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***Abstract*—This study focuses on VR as a form of therapy for individuals with intellectual and developmental disabilities (IDDs). The research aim is to develop an immersive and interactive VR system that is tailored for IDD individuals, for which most currently available VR experience systems are not optimized. Being intimately familiar with a place through an interactive VR tour will help alleviate social anxiety—very provident to IDD individuals. Accordingly, we create a hotspot-based VR tour system, which can provide an almost lifelike experience of visiting and learning about the location. We have conducted experiments with nondisabled individuals, acting as the control group, and IDD individuals, acting as the experimental group, to evaluate the tour system and compare the results between two groups. Our experiments show that the VR tour has a positive impact on the IDD individuals. In this article, we present the design of our VR tour system and its evaluation results.**

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INTELLECTUALLY AND DEVELOPMENTALLY DISABLED INDIVIDUALS

This study focuses on individuals with intellectual and developmental disabilities (IDDs)—a category of conditions that stem from an impairment in physical, language, learning, or behavioral areas. These start to manifest at the developmental level of a person's life, and will more than likely affect them for their entire lives. Most actually begin before the child is born, whereas in some cases due to factors, such as injury, infection, etc., it can happen after birth.[1]

IDD affects individuals of all races, ethnicities, and socioeconomic groups. In the United States, estimates have recently shown that 1 out of 6 children from the ages 3 to 17 have at least one developmental disability (DD). Among the most frequent were attention deficit hyperactivity disorder (ADHD), autism spectrum disorder, cerebral palsy, hearing loss, intellectual disability, and vision impairment.[1] However, these disabilities do not prevent individuals from leading fulfilling and active lives. They can partake in various activities and have the ability to comprehend, enjoy, or criticize these activities. No participant in this study had any DD that presented a limitation to fully engage in this study and the virtual experience.

Virtual Reality

VR-based applications have been proposed in gaming, education, tourism, therapy, and in other industries.[2–4] One topic that VR researchers have been exploring is therapy and treatments for individuals with IDD. The key to these studies involves immersive and interactive virtual environments in rich and realistic contexts that have user-friendly and intuitive interfaces. To achieve this, our VR system needs to take full advantage of the features and intractability of the platform.

We explored studies by da Cunha *et al.*[5–8] and built upon their work to develop a system that can benefit IDD individuals in their day-to-day lives. The immediate effects of the interactive experience were studied during trials. The study included a control group of able-bodied test subjects, and the experimental group of IDD individuals .

Our study shows that VR experiences can have a positive effect on IDD individuals. The subjects reported that they would feel more comfortable visiting a place after doing a VR tour of this nature—our statistical analysis in the "Evaluation of Data and Discussion" section expands on this. We have also found that the design of the VR environments needs to be adjusted in a way that best suits the general needs of each IDD individual while also having universal graphical elements that provide a positive experience for a wider audience. Some of the traditional control interfaces need to change, as it was sometimes an inconvenience for the IDD individual. Our current work add features, such as interactive objectives and custom points of interest (POI), to make the experience more immersive and personalized based on feedback that we got from the IDD individuals.

Our contributions in this article are as follows.

- The development of a VR tour system that is designed to explore methods of therapy for IDD individuals and helping them deal with everyday social situations.
- A set of controlled experiments with IDD individuals where they use our VR tour application and give us feedback on the system in the form of pre- and postsurvey and some questions after the fact.
- Using the data we have collected and the feedback from the IDD individuals, we have deduced ways we can innovate on the VR tour model, such as simplifying the control interface and adding interactive objectives, tour guides, and other features, that will be discussed in "Conclusion and Future Work" section in which we are working on implementing for future experiments.

BACKGROUND

da Cunha *et al.*[5] created a systematic literature review system where they follow a set of guidelines to gather and analyze all available evidence about a specific question or research topic in a manner that is unbiased and repeatable. Using this system, they collected and studied scientific research where VR was being studied as a way to treat IDD individuals. Their analysis showed that most studies use VR merely as a medium and do not fully use its features, using standard head mounted displays (HMDs) rather than fully featured and interactive

VR systems that could provide a much richer experience. A more fully featured system would not only use HMDs as a medium to display media, but as an interactive medium, taking input from the user and reacting accordingly, making the user feel more immersed and invested in the experience. A majority of the studies that they analyzed also did not add on to the existing features of the VR software or hardware to quantify the benefits of the VR environment for the test subjects. The use of VR, in this context, spans multiple fields of study beyond computer science, including but not limited to, psychology, and interaction design. The systems also need to work well enough so that the subjects do not have technical difficulties, ruining their testing experience. VR has great potential for the treatment of IDD individuals, and better research needs to continue to be done in this area to fully utilize that potential. Their data analysis shows that one of the most important being the point of making sure that the subjects have a pleasant and immersive experience, where they can interact with objects in the world to help get the best out of the experience.

Another study was conducted by da Cunha and de Souza da,[6] which involved designing a VR experience to support the cognitive development of IDD individuals. This study had the subjects take part in a five-week experiment, which had them shopping and performing various tasks in a virtual super market. The subjects demonstrated significant cognitive improvement in terms of their abilities to perform certain tasks and also based on observations by physiotherapists. This shows that VR-based experiments can be used in treating IDD individuals. However, this study was done using a computer-generated virtual environment based on an ideal super market, and not a real-world location or setting. Therefore, while they are showing improvements in their cognitive abilities, and it is possible that they might be more comfortable shopping in real-life because of this, it would not have the same impact as having the virtual environment based on a real-world place that they would then become intimately familiar with.

The third study we are looking at was conducted by Standen and Brown[9] and it involved creating virtual environments to help IDD individuals get more comfortable with skills for independent living, enhance cognitive performance, and finally improve social skills. Virtual reality provides a safe environment for IDD individuals to perform tasks without having to worry about any real consequences to failure. Unlike real-world situations, virtual experiences allow subjects to have multiple practice attempts without fear of failure or mistakes having consequences. VR environments are also not restricted by the real world, and anything can be created to help accommodate the IDD individuals to have a better experience. The experiments involved five tasks to achieve the previously stated goals, which included grocery shopping, preparing food, orientation, road safety, and manufacturing skills. The authors claim that there is not enough evidence to prove that skills learned in a virtual world not translate to the real world, aside for in the case of people autism spectrum disorders. While their studies did show that the subjects demonstrated improvements in cognitive performances, their use of VR was limited and used computer-generated world instead of real-world settings.

The final study that we are examining in this section was conducted by Gavhane *et al.*,[10] which tackled the treatment of people with physical and mental illnesses, specifically paraplegia, posttraumatic stress disorder,[11] and phobias. They used virtual reality to recreate scenarios for the patients according to their description of the events of their fears and they can experience them in controlled and safe environments. Their studies showed that there are improvements in the welfare of the patients that finished the VR treatments by integrating custom virtual experiences to represent the relevant context for their treatment, without the risk of exposing them to real-life scenarios. This study further provides us with insight on how important and effective VR treatments are in regards to mental disorders and disabilities. A prevalent theme in this study, however, was that patients did not finish the treatments. For the phobia treatments, the patients also expressed that they would rather do the VR treatments than go into the real-world and face their fears there. From that, we can deduce that the VR experiences need to be as realistic as possible so as to give people the confidence to face the real world and be more suited for the needs of individual subjects.

Based on our literature review, the VR experience systems need to provide a comfortable testing environment for the subjects so that they are in a good state of mind when taking part in these experiments. This will ensure that the subjects will return for subsequent tests and also go through with the whole experiment. Another very critical thing for the virtual environments is that it needs to be intuitive enough for the subjects to have an easy time interacting with their surroundings and get the most out of the experience. Finally their results show that VR therapy is effective in treating IDD individuals and multiple disabilities in many different ways. With these things in mind, we created the VR tour application based on real-world settings that would allow IDD individuals to explore places comfortably at their own pace and let them interact with the world and learn more about it. We use real-world settings to have the most impact on the subjects as they would then be able to more easily translate the skills and confidence to the real world as the places would already be familiar to them. In the "VR Tour System Overview" section, we cover the overview of our system, followed by the experiments.

VR TOUR SYSTEM OVERVIEW

Virtual Environment

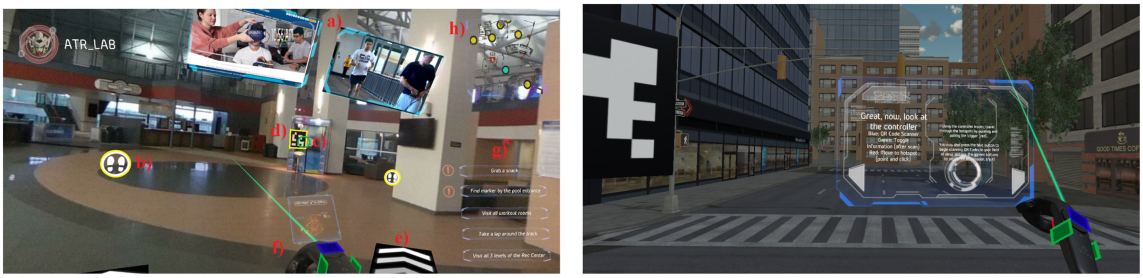
A prerendered city scene places the user in a way that they would be greeted with useful contextual information when they start. This would give them a short introduction as well as familiarize them with the most important part of the virtual environment, the hotspots [see b) of Figure 1 (a)], which are used for traversal. They sit in every scene in the direction of the next scene, and interacting with them allows the user to traverse to the location associated with it. We also showed them what a QR code [see d) of Figure 1(a)] and how to interact with it to show information [see a) of Figure 1(a)] about key locations in the scene. We want users to be able to understand the mechanics of how the tour traversal and interaction worked before going into the tour area.

Figure 1 shows an example scene, which is the entrance to our institute Recreation and Wellness Center described with a red circled hotspot in b) of Figure 1(a). The touring virtual environment is created using different scenes that each contain a 360° picture set as the skybox, with each picture being taken by the researchers at the site of the tour using a high quality 360° camera. Each scene also contains hotspots and in some cases, QR codes. In some locations in the Recreation and Wellness Center, there were already existing physical QR codes, which are detected and scanned by the VR tour system when the appropriate buttons are pressed, and in other interesting locations, we added them in the virtual world to simulate having more POI that the user can interact with. As seen in Figure 1, the 360° picture represents a portion of the tour area from the point of view of someone walking through the place in a natural and lifelike manner. We arrange the scenes so that any path the user chooses to take mimics a path they can traverse in real life. We guide users to follow these branching paths by placing virtual arrows [see e) of Figure 1(a)] pointing toward the hotspots in the scene. Each scene also has a set of hotspots unique to the location of the scene that ties to other locations and scenes. To make the tour more informative and interactive, we also have various QR codes on POI in the scene that help the user learn more about the place they are touring.

Control Interface

There are two ways to interact with the hotspots for traveling within the VR tour space. The first is the gaze-based approach. The user will have a green reticle at the center of their screen that they can use as a focal point and focus it on the hotspots, as depicted in c) of Figure 1(a). This is currently based on where the user is pointing their head rather than based on eye-tracking technology. Hotspots that are objects, indicated by an icon with shoe prints to indicate walking there, are placed in the scene in a way that each hotspot corresponds with the location where it is placed in the scene. This way, for example, if a hotspot is placed in the current scene at the location of the staircase, focusing on that hotspot for 2 s with your reticle will move you to the scene where you are now at the staircase. This duration for teleporting can be adjustable and customizable for individual preferences.

The second form of traversal uses a HTC-Vive controller, which can be augmented on our VR tour scene, as depicted in f) of Figure 1(a). The controller has a thin laser coming out of



(a) (b)

Figure 1. Virtual reality tour system, based on our institute Recreation and Wellness Center, user interface and tutorial scene. (a) VR tour user interface head-up display. (b) VR Tour Tutorial Scene.

the front of it, and pointing that at the hotspot and pulling the trigger button, identified by a red marker, will immediately teleport a user to the hotspot location, just like with the gaze-based system. Both of these methods can be used simultaneously, and the controller can be made to disappear and stay hidden if the user chooses to stick with gaze-based without having extra clutter in the scene.

In terms of scanning QR codes, there is only one way to do it in the current iteration of the project, and that is by using the controller. As seen in d) of Figure 1(a), QR codes are interactable objects placed at POI in the scene so that scanning them gives you valuable information about landmarks and key objects in the scene. The trackpad button, identified by a blue marker as depicted in f) of Figure 1(a), is pressed and a box will appear at the center of the user's view, and placing that box on top of a QR code by turning your gaze to it will scan the code and display information [see a) of Figure 1(a)] above where the object of interest is, and the scan box will go away. Pressing the gripper buttons, identified by a green marker, on the controller will dismiss the information display.

EXPERIMENTAL ENVIRONMENT

Participants

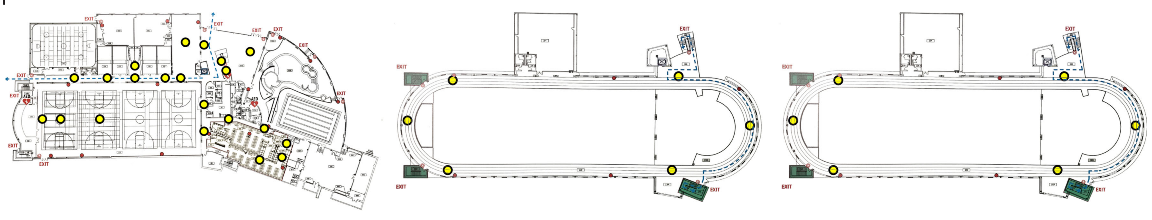
Ten nondisabled participants (eight males and two females, 23.50 ± 4.79 years) were recruited in this research. None of them had any history of developmental disabilities that would affect the study results. Five (50.0%) of the nondisabled participants were the first time users of VR headset. All ten nondisabled participants were the control group in this experiment.

Four participants (two males and two females, 23.25 ± 2.06 years) with IDD were recruited by our institute under following criteria: diagnosed with intellectual disabilities and no limitations that prevented from being able to participate in this research. None of them had experience of wearing a VR headset. The four participants with IDD are the experimental group, which the experiment uses to find the answers needed. They agreed to precede the experiment by signing written informed consent. This study was approved by our university Institutional Review Board.

Experimental Setup

For our experiments, we had developed a VR tour application of the Recreation and Wellness Center located in our institute. In order to create a virtual environment of the entire building, we visited there, in person, and took pictures of the different hotspot locations in a way that these locations formed a natural walking path across the entire facility. Figure 2 shows the hotspot locations (yellow circle) in our institute recreation center, and the first scene is indicated with the blue circle in Figure 1(a), which was discussed earlier. We created the application using the 2018 version of the Unity3d game engine (Unity Technologies, San Francisco, CA, USA). We have a system in place where each picture corresponds to a scene, and each scene has its own group of hotspots and interactive QR codes. The user can interact with these QR codes and learn more information about what they are looking at in the scene. The VR headset being used for our development and experiments is the HTC Vive Pro.

The experiments were conducted in our laboratory as the test areas. Our VR tour system was



(a) (b) (c)

Figure 2. VR hotspot distribution map (yellow represents the point where picture is taken). (a) The base floor blueprint. (b) The first floor blueprint. (c) The second floor blueprint.

tested on a desktop (Intel i7-7700k, GTX 1080Ti), and the HMD used was the HTC Vive Pro. We put two Vive sensors on each side of the test areas to make sure that every movement of user are fully tracked, and we display what user were seen during the test on an 32-in monitor to help us understand and analyze participant's behavior, as shown in Figure 3.

Paradigm

In order to help IDD individuals gain daily life experiences with assisting technology, a case study has been defined. The case study consisted of a tour of our institute's student Recreation and Wellness Center, as shown with three blueprints Figure 2. The experiment is composed of three sessions: presurvey, VR tour, and postsurvey. Each participant fills out the presurvey, which asks about the participant's background with VR and preliminary questions about their mental state. During VR tour, participants are required to wear a VR headset. The tour started with a short tutorial (110.28 ± 27.76 s for nondisabled and 371.22 ± 163.44 s for disabled participants) to guide them through how to use the different control mechanisms. Then, participants are allowed to travel inside the virtual recreation center while our system automatically records the amount of time the participants spend in each scene for further data analysis. All IDD individuals except one, who felt fervescence and decided to finish the tour earlier, successfully completed the tour. All, including the one IDD individual who finished the tour early, completed the postsurvey, which reflects the presurvey in some aspects and was designed to with the idea of evaluating the system and collecting feedback to improve the VR experience for all our users.

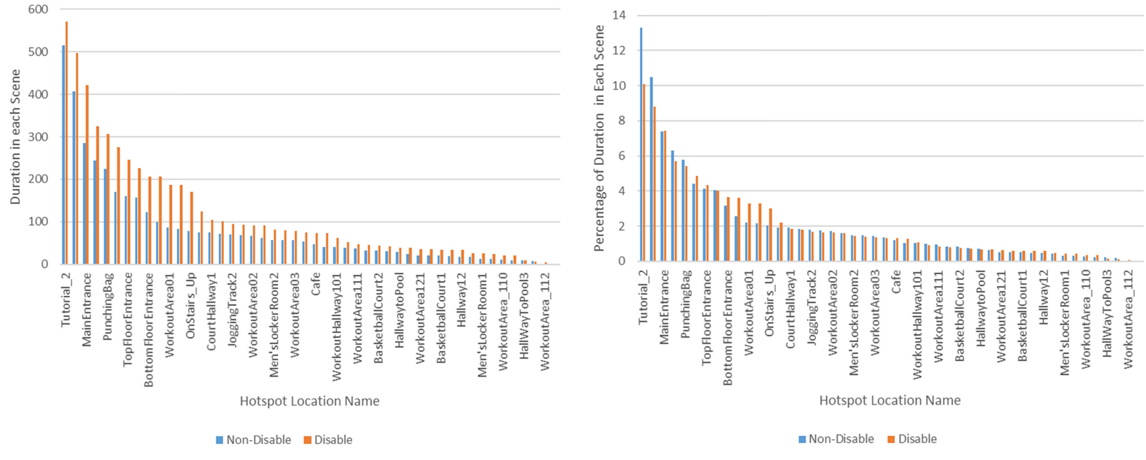
Figure 3. VR tour experience testing with an IDD individual.

Data Analysis

The results of three experimental sessions were statistically analyzed for quantitative (via in-system data collection) and qualitative (via pre- and postsurvey) evaluation of the proposed system. For the qualitative analysis, we calculated number of scene changes (equivalent to number of hotspot clicked) [see Figure 5 (a)], how long each participant stayed on each scene [see Figure 5(b)], and total duration stayed at each location [see Figure 5(c)], which combine duration of scenes of the same location. Pre- and postsurvey results were analyzed for qualitative tests including familiarity for the subjects with the settings of the tour [see Figure 6 (a)], how they feel about the user interface and also their overall comfort and immersion [see Figure 6(b)]. Both quantitative and qualitative factors were statistically compared between participant groups and survey types, respectively, using one-way analysis of variance (ANOVA) test,[12] and paired *t*-test.[13]

EVALUATION OF DATA AND DISCUSSION

Figures 4–6 illustrate the analysis of the data collected by our background timer script for the

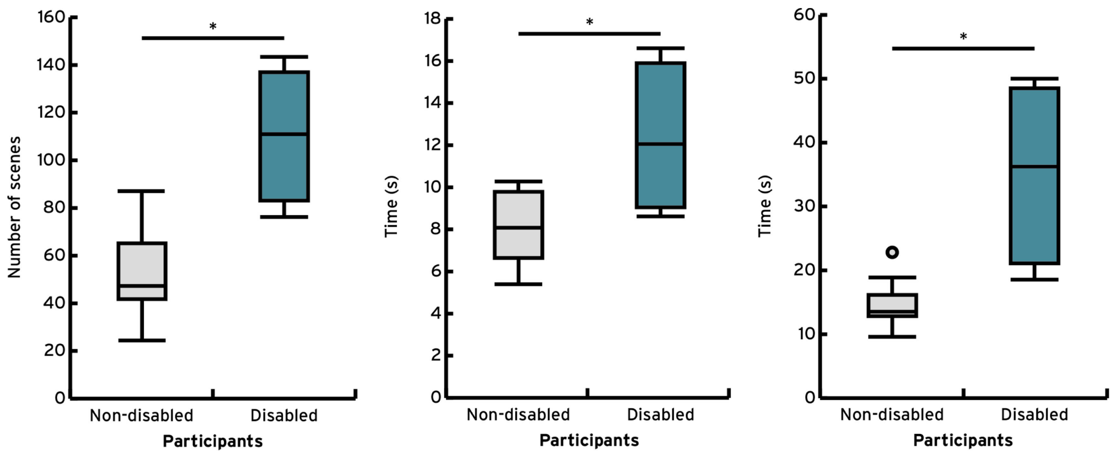


(a) (b)

Figure 4. Test results based on each location associated with their time duration during VR touring. (a) Total duration stayed at each location. (b) Percentage of duration stayed at each location.

nondisabled subjects and the IDD individuals. Figure 5 shows that the IDD individuals (in gray; box plot) moved around between scenes more [see Figure 5(a)], exploring more [see Figure 5 (b)], and staying longer [see Figure 5(c)] at both each scene and location than the nondisabled participants (in pine; box plot) did. The differences of these three quantitative factors were significantly different ($p < 0.05$) between the disabled and the nondisabled participants using one-way ANOVA test. We also can see that, across the whole tour, the IDD individuals spent more total time at each location than the nondisabled participants. They also moved around and changed scenes a lot. This was due to many factors, including the fact that a lot of the nondisabled subjects were already familiar with the setting of the tour, and were speeding around in the tour using the controller. On the other hand, while most of the subjects with developmental disabilities were familiar with the setting of the tour, they were more impressed by the technology and wanted to explore the Rec Center more. At times, they would get turned around and stuck in what they would think is a loop, but they would quickly recover and continue on the tour. They made sure to explore all of the Rec Center and check out the intractable objects to learn more about the scenes.

Through presurveys and postsurveys, we evaluated qualitative features of our system using paired *t*-test to see what effect the experiment had on the subjects based on multiple



(a) (b) (c)

Figure 5. Test results based on each location associated with their time duration during VR touring. (a) Number of scene changes. (b) Total duration between scenes. (c) Total duration stayed at each location.

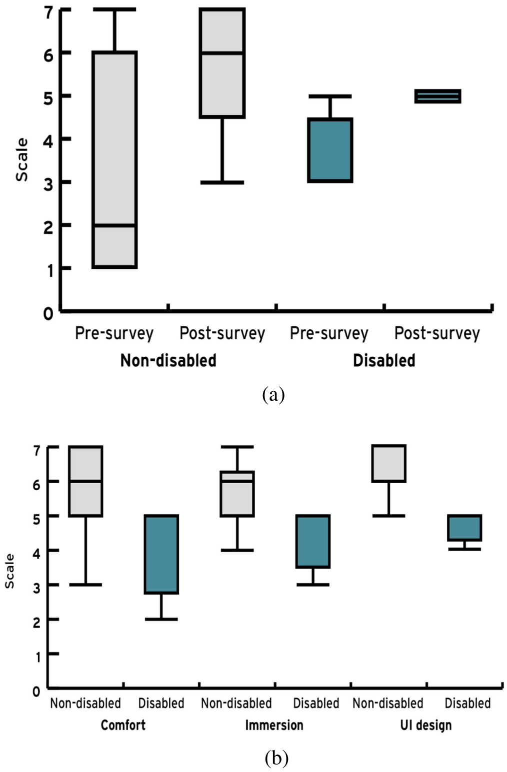


Figure 6. Results from pre- and postsurveys. (a) Level of familiarity with the recreation center. (b) Evaluation after the VR tour from post-survey.

Table 1. Level of familiarity.

Category: Level of familiarity				
Participants	Healthy	Healthy	Disabled	Disabled
	Pre	Post	Pre	Post
1	1	3	3	5
2	1	3	3	5
3	1	5	5	5
4	1	6	3	5
5	1	6		
6	3	6		
7	5	6		
8	6	7		
9	7	7		
10	7	7		
AVG	3.2	4.25	3.5	5
STD	2.52	1.5	1	0
VAR	411.78	791.58	791.58	791.58

factors (see Figure 6). In Figure 6(a) and Table 1, we observe the level of familiarity (scale from 1–7; 7 being the most familiar) that the subjects have with the Recreational Center. While most of them were at least a little familiar already due to them being students at their university, not all of them went there regularly. The paired *t*-test results were not statistically significant ($p > 0.05$), but we can see that the experiment increased the level familiarity all subjects have with the Recreational Center. The nondisabled participants started off and ended up being more familiar overall, but there is still some crossover with the levels of familiarity for them. While on the other hand, all the IDD individuals were more familiar than they were before the experiment, but it was still lower than the highest value for the nondisabled subjects.

Although the comparison between nondisabled and disabled individuals was not statistically significant ($p > 0.05$) using one-way ANOVA test, the nondisabled subjects scored higher than the IDD individuals in these three categories: comfort (scale from 1–7; 7 being the most comfortable), immersion (scale from 1–7; 7 being the most immersive), and user interface (UI) design (scale from 1–7; 7 being the most intuitive) [see Figure 6(b)]. Out of these results, the *p*-value scores for comfort and immersion were not significant ($p > 0.05$) but the *p*-value for UI design was statistically significant ($p < 0.05$). These quantitative results can be further elaborated on through their responses to follow-up questions after the tour was concluded, which showed that while they did enjoy the tour, they found the control interface to be a little difficult to get used to, specifically in regards to the controller. For instance, one of the IDD individuals expressed that they enjoyed that the pictures were taken when there were no people, making them more comfortable while exploring the tour. Most of them also showed interest in this experiment being applied to other places, such as museums, concerts, and malls, where there are usually a lot of people. Being able to explore at their own pace allowed them to really take their time and more easily and carefully see the places that are usually populated with a lot of people, but in this case, stress of a social setting does not exist. During the tests, the subjects with developmental disabilities mostly preferred traversing the tour using the gaze-based traversal rather than the controller, which made them take longer time but also kept them immersed in the scene. They let us know that this was due to the fact that the controllers were too confusing and cumbersome at times and exploring using gaze-based traversal was easier and more enjoyable. This gave us the insight that we need to make sure the control interface is simpler and more intuitive, as a lot of the subjects with developmental disabilities not only had trouble traversing with the controller, but especially had trouble with scanning QR codes and toggling data. While they did enjoy exploring the setting on their own, the IDD individuals expressed interest in having some kind of guide with them that would help them get through the tour and explain things better to them.

CONCLUSION AND FUTURE WORK

As we have seen in this case study, our novel approach of the VR tour system has potential in helping IDD individuals. All of our test subjects, the individuals without disabilities and those with IDD, really enjoyed the VR tour and the experience of being able to easily and freely navigate a location at their own pace and learn what they can about it. Having a tutorial stage at the beginning of the application also gave them the confidence to start the VR tour with all the knowledge they would need in order to have a fulfilling experience. The lack of on-screen clutter let them enjoy the visuals of the tour, which they exclaimed were very crisp and clear, and even lifelike. After examining the feedback acquired during the postsurvey from the IDD participants, they testified the VR tour immersive and enjoyable, and even suggested that this kind of technology could be applied to other scenarios, such as concerts and museums. Our experiments concluded that while the IDD individuals did enjoy the tour application and found it to be very informative and comfortable to explore a place in that manner, the control interface needs some improvement, specifically with interacting with the informative QR codes. We can also deduce that this would have a positive impact on their lives overall as it would help alleviate social pressure in many of situations and help make them feel more prepared to take on the world. We found that they enjoyed using the gaze-based control interface and in general had no problems with using the controller for traversal. However, once they had to use the controller to interacting with the QR codes, they started having some difficulties. Overall, they were comfortable, immersed, and engaged in the experience enough, and all expressed interest in returning for subsequent experiments to see what other experiences we can give them the ability to have.

Using this feedback, we want to streamline the experience more and tailor it around their needs and their suggestions and try to avoid putting them in situations where they are annoyed or overwhelmed by the control interface. We need to improve how the controller is used for traversal, but more importantly we need to improve how the QR interaction works. We want to streamline the controls in a way that has only the trigger be used for both traversal and interaction with QR codes. Another thing is the actual QR code. We are looking at using a different marker that is more intuitive and stands out in the scene so that they know that something interesting awaits them when they interact with it. Since they also expressed interest in a guide, we are aiming to add a virtual tour guide in the application that will give them contextual information about the various locations they visit and even point them toward the location of interactable objects they can get information from.

Data[14] show that IDD individuals often come from low-income areas. Due to the fact that current VR technology is expensive and requires high-end computers, whereas sometimes being cumbersome and complicated, we developed a mobile version of the VR tour that provides the exact same features with simple gaze-based controls for navigation and interaction. This would provide an easily accessible version of the application with simpler controls, which we believe would be beneficial for IDD individuals. We have yet to conduct experiments with this application, but we are confident this will please a lot of the previous subjects as well as future ones, and make them feel more comfortable and immersed, therefore getting more out of the experience.

Another approach we have considered is to add objectives that the users can go after that helps them learn more about the location they are touring [see g) of Figure 1(a)]. An example of what a map would look like is shown in h) of Figure 1(a), it would show an overview of where the user is and the locations of other hotspots.

In addition to having QR codes placed around the scenes in the VR tour, we want the users to also have the ability to add their own custom POI to the scenes. The UI for that on top of the controller and how it would appear when implemented are shown in f) of Figure 1(a). The users will be able to choose where to place these contextual POI and leave a voice note on the location to describe it. Other users can see POIs left by previous users and vote thumbs up or down in regard to how they felt about the POI's accuracy and helpfulness. Biometric data would also be collected while the user is going through the tour so that we can have more data from which to draw conclusions and use to give us an idea of how the users felt during the tour. This would include, but not be limited to, heart rate and other such biometrics. We also plan on getting more IDD individuals who are willing to help us test out the new features and improvements we currently are working on adding. Due to the low population of IDD individuals (around 1% of the population[14]), and the difficulty of finding subjects, our sample size is not as large as we hoped, but the data can still be used to improve the system for future tests and our findings are still valuable for our research.

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