An Interactive Multisensory Virtual Environment for Developmentally Disabled

Alexandru Diaconu, Flaviu Vreme, Henrik Sæderup,
Hans Pauli Arnoldson, Patrick Stolc, Anthony L. Brooks(✉),
and Michael Boelstoft Holte

Department of Architecture, Design and Media Technology,
Aalborg University Esbjerg, Niels Bohrs Vej 8, 6700 Esbjerg, Denmark
{adiaco14, fvreme14, hsader14, holsen11}@student.aau.dk,
{psto, tb, mbh}@create.aau.dk

Abstract. This paper investigates the interaction of developmentally disabled adults with a mediated multisensory virtual reality experience within a familiar social context. This was done as part of an exploratory case study. To this end, a media technological artefact was derived from the Snoezelen concept, a multi-sensory environment for stimulation and relaxation. This system is comprised of an HTC Vive based virtual reality environment tailored to the specific requirements of the case and its stakeholders. Play sessions were conducted at Udviklingscenter Ribe, a residence and development centre for the disabled. After compiling passive and participant observations from the sessions, and interviews with key staff, a series of guidelines were proposed. These guidelines encapsulate the project's concerns and overarching trends and provide a future basis of study when designing and developing an interactive multisensory virtual environment.

Keywords: Virtual Reality · Snoezelen · Multisensory environment
Interaction · Recreation · Developmental disability

1 Introduction

With consumer Virtual Reality (VR) devices becoming more and more affordable every year, it is becoming increasingly possible for them to be used as alternatives for traditional, more expensive setups and experiences. One such example is the Snoezelen, used for sensory stimulation [1]. In place of the multi-room setup requiring a prohibitively expensive set of equipment, VR could provide a low-cost, low-maintenance alternative while offering a similar Multi-Sensory Environment (MSE) experience [2]. Institutions such as Udviklingscenter Ribe, a residence and development centre for the disabled, are looking towards VR-based MSE, as a way to supplement the daily activities of their developmentally disabled citizens. The centre offers its facilities to people from the Ribe area through its social club, Club Pil. The club caters to the social difficulties of its members, as every individual has their own goals and aspirations within the club. Exhibiting a mental age of roughly 5 years, often with severe reading and writing impairments, as well as battling psychological issues,

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the citizens at Udviklingscenter Ribe require a custom-built VR experience to fulfil their requirements. With all this in mind, this project's research team designed and developed a Multi-Sensory Virtual Environment (MSVE) starting from a Snoezelen concept and building it up with the help of an exploratory case study.

The unit of analysis for this case study is to investigate how developmentally disabled adults interact with a mediated multisensory VR experience within a familiar social context, for recreational purposes. To support the study of this case, the following research questions were established:

1. What impact does the mediation have on the experience?
2. How does the MSVE compare to other activities within the social context of Club Pil?
3. What is the biggest obstacle in experiencing the MSVE?

This paper is organised as follows. Section 2 presents the theoretical background and related work of Snoezelen, MSE, VR and interaction. In Sect. 3, the adopted methods are detailed, and Sect. 4 describes the design and implementation of the MSVE. Section 5 presents the obtaining results, which are discussed in Sect. 6. Finally, in Sect. 7, concluding remarks are given.

2 Theoretical Background and Related Work

Multisensory environments are spaces tailored to match the sensory needs of a user and designed to enable them to utilise their existing, remaining or preferred senses in a more purposeful way [1]. Snoezelen was created in the 1970s in The Netherlands as a form of multisensory environment combining play equipment with an audio-visual ambience [1]. In this paper, Snoezelen and MSE may be used interchangeably. However, the predominant use will be MSE, as Snoezelen is a registered trademark [1]. There are several traits that define MSE, including sensory stimulation; choice of opportunities; possibility of exploration; offering a sense of refreshment or invigoration; allowing for both active and passive interaction; and being a controlled environment [1–3]. However, one notable aspect connecting these attributes is that an MSE is not specifically designed for teaching skills or simply being a 'quiet' room; although therapeutic results may occur [2, 3]. Overall, MSEs are seen as a pleasant activity, and they can be purposefully used to aid in therapy with mixed therapeutic results [3]. MSEs are nonetheless a popular approach for staff and therapists that usually work with people with developmental disabilities and dementia [1, 3, 4]. This may be due to the very tailored nature of MSE, allowing and requiring preference screening by a facilitator that has a close relationship with the user, which is being guided throughout the experience [1, 3].

MSEs are relatively accessible across Europe and North America. However, they are prohibitively expensive in terms of arrangement and furnishing, as they require not only a dedicated space, but also various technical resources to offer stimulation across all the sensory channels. This can approach several thousands of dollars in cost even for a minimal setup [3]. The cost can increase exponentially when setting up multiple rooms, each with their own experiences provided by a wide range of technological artefacts. Possibilities of lower scale, lower cost solutions have been explored [3], including the use of virtual reality systems [2]. Virtual reality has been shown to be able to artificially induce immersion through embodiment [5–8], opening up the area of possibility for MSE inspired experiences. A VR solution seems even more attractive with the consumer availability of VR systems on the market [5, 6], especially in contrast with the high cost of traditional MSE.

Virtual Reality is defined by [5] as "a computer-generated digital environment that can be experienced and interacted with as if that environment were real" (p. 9). With technological advancements, computers step out of their secondary position as tools, to being windows to different worlds, to stepping into the real world, bringing the site of the interaction from the abstract cyberspace to the world of the user [9]. Originally reserved to governments and scientists in research laboratories, VR arrived at first in the public view, and within less than two decades into consumer homes [5, 6, 10]. VR is now used not only for leisure and entertainment, but also in education, communication, simulation, scientific visualization, as well as in therapy [5], such as in helping patients suffering from phobias, anxiety [11, 12] and autism spectrum disorder [2].

Murphy [8] investigates which virtual avatar body parts are present in the top 200 consumer VR applications for the HTC Vive VR headset, as well as the impact that avatar bodily coherence has on the senses of body ownership, agency and perceived embodiment. Their results indicate that users may experience these illusions of embodiment even when virtual avatar body parts are not visible. Hence, such representations may not be essential, and instead users are affected more by sensorial immersion and interaction with smooth real time feedback [8]. Full body ownership illusions through technological immersion is also indicated to be possible through the guidelines of [6].

Gerling et al. [13] present a set of guidelines for full-body motion control with accessibility concerns for age-related impairments. Notably among these principles lies the notion of exertion management, as well as that of adaptability for different ranges of motion. Exertion management is the principle of offering plenty of relaxing tasks in-between more challenging ones, whereas individual range of motion adaptability reminds the designer to calibrate full-body interfaces to individual user abilities [13]. Additionally, a study conducted by [14] investigated how the discrepancy between virtual objects and their physical counterparts affects interaction and suspension of disbelief in substitutional virtual environments. The resulting guidelines include indications of materials and proprioceptive feedback do matter, but that users are capable of engaging with substitutes as much as with high-fidelity replicas.

3 Methods

This research work uses the case study approach for investigation, due to the benefits offered, which will be explained in detail in this section. A case study is a type of qualitative research commonly defined as an in-depth analysis of a complex phenomenon, an event, or a group of people, within its environmental context [15–17]. By investigating from multiple angles, and collecting data through varied methods [16], case studies allow researchers to make sense of a topic that would otherwise be too complex for a different qualitative research approach [17]. Unlike in controlled experiments, in case studies, the context in which an event or phenomenon occurs is part of the research because the line between the two cannot be clearly drawn [15, 16].

The following recount and detail the methods used in this research case study. The first stage is preliminary research and documentation. The research team conducted several meetings with the staff at Udviklingscenter Ribe, in which data was gathered about the way the centre operates, the nature of disabilities affecting residents, as well as the general level of activities they participate in. This continued at later stages through written communication, and regular visits to Udviklingscenter Ribe. As a result, a list of requirements for the virtual reality experience was established.

Next, several interviews were conducted both with key staff at Udviklingscenter Ribe, and a therapist at a local kindergarten, which has its own Snoezelen (MSE). A visit to the local kindergarten occurred early in the study with the explicit goal of witnessing an MSE first-hand. During this visit, a guided tour took place, led by the resident therapist who had been working with children there in the MSE for over 20 years. For ethical reasons the research team could not observe the Snoezelen in active use.

After multiple sessions in which residents experienced the MSVE, approx. 20-minute-long interviews with staff at Udviklingscenter Ribe were conducted, collecting opinions and impressions of the facilitators (pedagogues). Due to their often severe disabilities, interviewing the residents directly was not feasible. The interviews were semi-structured and conducted based on guidelines and frameworks laid out by [15, pp. 89–92] [16, pp. 39–44]. The focus on the interviews were on the enjoyment experienced by the residents, as well as how the MSVE compared to their regular activities. Specifically, the interviews aimed to obtain information in three issues of interest: Background information on the facilitator, information on how the MSVE experience compares to the regular leisure activities the citizens perform, and the facilitators' own opinions and observations on the experience. The exact nature and number of follow-up questions asked differed for each interviewee, as is often the case in open-ended semi-structured interviews [15, 16].

Observations, both from passive observers and participant observers were taken. Over the course of multiple sessions, the researchers observed residents at Ribe Udviklingscenter, as they experienced the MSVE (see Fig. 1). During these sessions, one member of the research team acted as facilitator for the residents, guiding them through the experience, while the others observed and took notes, photos and video recordings. The observers were also able to observe what the participants were seeing in VR, due to a digital mirror set up on a nearby monitor. This means that the observers were able to correlate the real-world and VR actions of the participants.

Separately from the play sessions, observations were gathered as participant observers [18] by visiting Udviklingscenter Ribe during regular club opening hours and spending time with the residents there, while they were going about their usual activities. This provided valuable insight into the interactions between residents and pedagogues, as well as how they approached various activities.

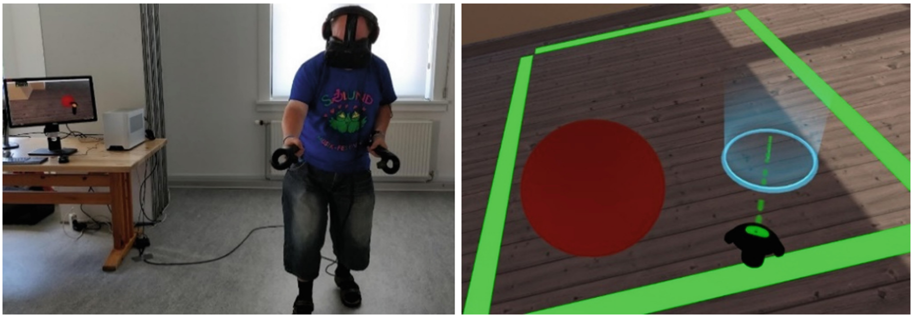

Fig. 1. Resident at Udviklingscenter Ribe trying out the MSVE during the second play session. (Color figure online)

4 Design and Implementation

A virtual reality environment has been developed for the purpose of this study. The equipment used was an HTC Vive head-mounted display with HTC Vive controllers (See Fig. 1). The implementation was done in Unity Engine, using the SteamVR software development kit (SDK) and was facilitated by employing the Virtual Reality Toolkit (VRTK), which is a free collection of software solutions to aid in VR development. These plugins contain a series of premade scripts and prefabs specifically for Unity 3D development. The direct input method, aside from head-tracked vision, is found within the HTC Vive controllers. Most notably, the SteamVR SDK allows the controllers to have identical counterparts in the virtual world. The controllers support 6 degrees of freedom (three axes for position and three axes for orientation). This helps with the suspension of disbelief in the virtual environment by providing accurate visual and proprioceptive feedback [14].

Each of these controllers have several analogue and digital buttons. Following the stakeholder meetings and observations outlined in the methods section, the main control scheme was implemented. The control scheme distinguishes between the two virtual controllers by painting them in distinct colours: green and orange. The use of colours was motivated by the target user group's inability to either read or distinguish left from right. Thus, any instructions would have to reference a familiar concept, such as colours. A different behaviour is then tied to the main analogue trigger of each controller. The green controller became responsible for navigation, while the orange controller was responsible for interaction. This distinction avoids problems caused by duplicate inputs on both controllers. The decision was made because in early test sessions the target users often pressed multiple buttons at the same time, with both hands.

The setup of the VR system includes a play area of up to 5 meters in diagonal (approx. 3.5 m by 3.5 m), which allows for natural locomotion to a certain degree. However, the virtual environments quickly become much larger, and an artificial means of locomotion is necessary. This means of locomotion is most commonly a form of teleportation, which bypasses the issue of motion sickness [5, pp. 303–304]. In this way, the user can cast a trajectory to a target destination by holding the trigger and teleporting there upon release. The player remains in the same position relative to the play area, which is in turn moved to a different location in the digital world. Players alternate between natural and artificial locomotion as they navigate the digital space, walking to cover short distances and teleporting over long ones.

The interaction control, utilised on the orange controller, is similarly performed solely with the analogue trigger on the controller. When the virtual controller enters the proximity of an interactable object, the object is highlighted with an orange aura, indicating that it can be picked up. If the trigger on the controller is held down, the object will replace the controller in the "hand" of the user and can be move around. As soon as the trigger is released, the object is dropped or thrown (depending on the velocity of the controller at the moment of release) and the controller reappears.

The environment consists of a main scene and three secondary scenes. The main scene is the most complex one, as it contains multiple type of interaction that are introduced gradually. Although the first element that is encountered is non-interactable (passive), most of the elements are predominantly aimed at active interaction. The non-interactable element is a dynamic column of coloured floating bubbles that is intended to be aesthetically pleasing. The three types of active interaction present in the main scene are manipulation of cubes, a bouncy ball and spheres that orbit in the air. Baskettargets are placed at specific points to encourage throwing interactions. Figure 2 shows a map and images of the main scene.

After going through the entirety of the main environment, users can remain there and interact with all the elements, but there is also the possibility of visiting the secondary environments. Each of these environments can be accessed by pressing one of three large buttons, each corresponding to a different destination. The destinations are indicated by large framed pictures above the buttons (to accommodate the users' illiteracy). All destinations contain buttons of their own for returning (see Fig. 2). Each of the secondary environments is themed according to a single type of interaction encountered in the main environment. As such, the secondary environments are: the cubes room, the balls room and the orbiter room.

The cubes room focuses on interaction with throwable and stackable cubes of various colours and sizes. The appearance of the room is rather bright and emphasises right angles. The interactable cubes are generally littered across the floor. A small stack of them can be seen in one side of the room, encouraging its destruction or further construction. The cubes can be manipulated in the same way as the ones in the main room: picked up, examined, thrown and stacked. These cubes are set apart by a particularly bouncy behaviour, which enables this environment's special feature. The special feature is an additional input method on the Vive controller (the grip button) that can be held to deactivate gravity. In the absence of a gravitational force, the bouncy cubes can create a spectacle of moving colour within the room if engaged correctly (see Fig. 3).

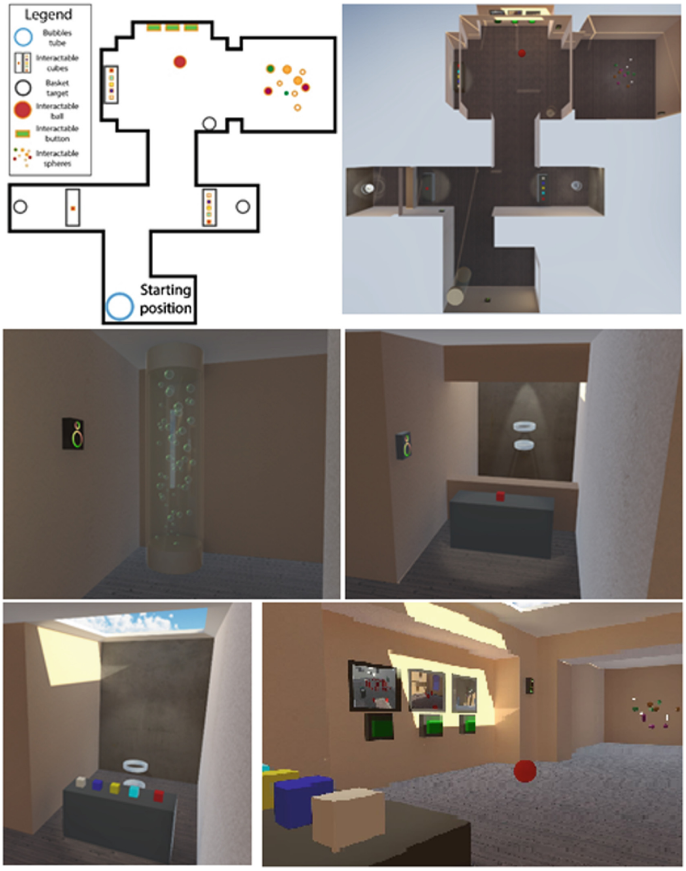

Fig. 2. Main scene map and images showing the non-interactable dynamic column of coloured floating bubbles; three types of interactables: cubes, bouncy balls, and orbiting spheres; and navigation buttons on wall to enter the secondary scenes. (Color figure online)

The balls room is a relatively small, well-lit environment. The salient element is a collection of several red bouncy balls of different sizes. Target baskets are mounted on the walls, reminding the user of the interactions in the main room. Two of the walls contain angled recessions that add variety to the rebound behaviour (see Fig. 3).

The orbiter room is named after the behaviour of the central interactable component, a collection of spheres hovering in mid-air. Once disturbed form their original positions by a user interaction, the spheres will attempt to return. However, due to their antigravitational properties and bouncy surface, they will instead travel around the large environment at the speed at which they were displaced. The user can pick these coloured spheres up, some of them luminescent, and explore the side-corridors or add to the dynamic spectacle (see Fig. 3).

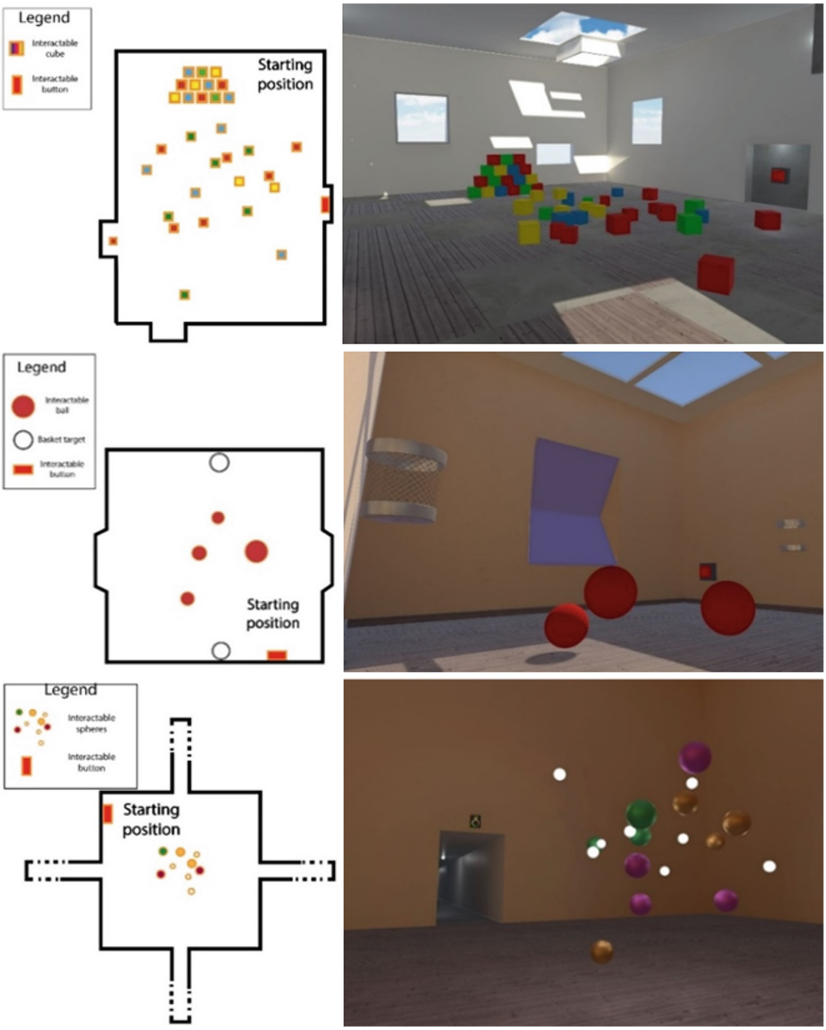

Fig. 3. Maps and images of the three secondary scenes: the cubes room, the balls room and the orbiter room. (Color figure online)

5 Results

The results section presents the trends and themes extracted from two different play sessions at Udviklingscenter Ribe, where residents tried out the MSVE. A total of ten residents (three female) participated in the sessions: five in the first and six in the second, with one individual taking part in both sessions. For privacy and ethical reasons, the research team was not given detailed information about each specific resident that took part in the two sessions, but instead presented with an overview of the group as a whole. Their ages range between 18 and 75. They exhibit various stages of developmental disabilities, with most of the citizens having a mental age between 5 and 6 years. Most have reading and/or writing impairments, cannot distinguish left from right, and some have psychological issues. They all live on their own with occasional help from qualified support staff. They visit Club Pil regularly to socialize, take part in activities and to eat dinner together. Themes extracted from the observations during these two sessions are:

- Users expect to be able to use both hands when picking up/interacting with objects in the virtual world. This inability to do so leads to confusion.
- Users grasp at objects that are out of reach. This could be due to lack of depth perception within the virtual reality experience, likely due to inadequacy in the technological implementation.
- Control scheme is too difficult to understand and/or remember, requiring constant guidance.
- All participants were observed expressing at least some visible enjoyment during the sessions, and vocalized enthusiasm after they finished. They were generally in a better mood after the play session than before.
- Teleportation may not be the optimal choice for locomotion in this context and for this specific user group.

In addition to the above observations, themes were also extracted from the interviews conducted with pedagogues at Udviklingscenter Ribe. The pedagogues have vast experience in helping people with these disabilities and are considered experts in the field. The interviews provide insight which could otherwise not be gained from observations by outside persons. The themes gathered from the interviews are as follows:

- The closest experiences to this MSVE are video games, which residents play regularly at Club Pil (named devices include PlayStation, PC, mobile). Other activities include board games, card games, cooking and eating together, painting.
- Facilitators shared their insights into the residents' underlying motivations: the desire to improve social skills and overcome low self-esteem, the desire to belong, striving to be like their respective role models.
- The staff anticipates difficulties in learning to operate the system as efficient facilitators. They would require training with VR equipment in general and this MSVE in particular before feeling confident enough to use it with the residents.
- Symbolism and colours are recommended in terms of visual cues, due to general illiteracy and the nature of developmental disabilities among residents.
- Overall, the experience was fun and engaging for the residents. Consensus among the pedagogues interviewed was that it left a lasting positive impression on those who participated.

6 Discussion

The data collected as part of this case study revealed several overarching trends regarding the usage of the MSVE in the social activities context of Udviklingscenter Ribe, specifically during Club Pil hours. This section will elaborate on these matters from the theoretical perspective, and ultimately propose a set of considerations addressing the framing of the case.

The first question that was investigated in this case regards the impact of mediation on the MSVE. The user interaction with the system was mediated; however, the mediation was heavily focused on getting the users accustomed to the system. In contrast, a typical MSE mediated session focuses on the individual's sensory sensibilities, under guidance from a facilitator that has a close relationship with the user [1, 3]. As such, a definitive answer implies a facilitator that is both familiar with the individual user, as well as well-versed in the full extent of the possibilities the system offers.

The second question that was investigated in this case refers to a comparison between the MSVE and other activities that are being run in the same social context at the location (Club Pil). The collected data revealed that a VR system is not completely foreign to the users and facilitators, as it is thematically related to video games. As indicated previously, the participants are familiar with using personal computers, video game consoles and mobile devices for leisure activities. Nevertheless, they have not experienced a VR environment before, which led to a high novelty factor experience. Consequently, another prevalent theme was that the participation was fun, exciting and enjoyable. Participants had positive comments and reactions both during interaction and afterwards.

As per the staff interviews (detailed above, in Sect. 5. Results), the experience is comparable to the other leisure activities at Club Pil. Specifically, they are similar with regards to providing the escapism that many residents seek due to their low self-esteem and feeling of being different. Games of all kinds allow residents to practice their social skills in a safe environment together. At the same time, games also enable them to step in the shoes of their respective role models (such as superheroes). However, the proposed MSVE experience differs from the usual Club Pil activities as follows: It is a much more personal experience, as they step alone into the virtual world; It is a physically intensive activity; They interact one-on-one with a facilitator for extended periods of time, allowing for a better mutual understanding.

The last and maybe most fruitful inquiry pertains to the biggest obstacle in the engagement with the MSVE. This has been identified as being the control scheme. There are several facets to this consideration. To begin with, it was noted that controls were simply not intuitive enough for most of the users. This is reflected most notably in their attempts at grabbing objects with both of their hands, which the implementation did not fulfil. Furthermore, several shortcomings were observed as participants grasped at objects beyond their reach, indicating issues with spatial and depth cues [5, 6]. Conversely, the visual cues provided semantic separations that were received positively, at least according to the experts interviewed. Given that users can experience illusions of embodiment even when virtual body parts are not present [8], it seems that the sense of agency and/or bodily coherence overtook the functional capacity of the control scheme. In other words, the existing sense of embodiment characteristic of the human nature [7, 9] inhabits the virtual experience in the lack of any other element to simulate it. As presented by [5] and [6], properly implementing an embodied VR experience is a challenging and sophisticated task. When such fundamental problems arise for the users, the technical design side is the primary suspect. Moreover, as seen in the data, all participants had the ability to achieve some of the interactions in the MSVE, despite their varying degrees of physical impairments. It is concluded that the main issue resides not necessarily in the physical accessibility of the interaction scheme, as much as in the application of an embodied interaction perspective in the design procedure.

The shortcomings in the control scheme also influence the mediation aspect. As a facilitator is a principal requirement for the MSVE, difficulties on their side affect the experience for the user. During the stakeholder interviews, their concern towards a potentially steep learning curve regarding VR for themselves as facilitators was noted. Even though the stakeholders agree that the MSVE experience was pleasant for the users and expressed their clear interest in it, a training period with the system will be helpful when working with their residents. This raises questions, which can be addressed through a usability-oriented design process.

Having reviewed the results from this case study, we propose the following guidelines for researchers and facilitators:

- The facilitator should be both familiar with the individual user, and well-versed in the full extent of the possibilities the system offers. This would ensure the best mediated experience.
- Extra attention is necessary in making the controls as simple and intuitive as possible, to ensure that the controls are understandable, usable, and memorable for the user regardless of their developmental level.
- The system must be reliable and flexible, in order to adapt to the wide range of needs of this target group. Disruptions should not require a session to stop or restart.

7 Conclusion

This study set out to explore how developmentally disabled adults interact with a mediated multisensory VR experience within a familiar social context, for recreational purposes. It did so by designing and implementing an interactive MSVE, which was evaluated through observations of play sessions and interviews with pedagogues at Udviklingscenter Ribe. The compiled data was used to extract themes, from which design guidelines were derived. In summary, the most important findings, which should be taking into account when designing and implementing an interactive MSVE: the facilitator should be familiar with the individual user, the MSVE and associated VR technology; the controls should be simple and intuitive; and the system should be reliable and flexible.

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