Enabling Patients with Neurological Diseases to perform Motor-Cognitive Exergames under Clinical Supervision for Everyday Usage

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Abstract

Immersive group-based virtual reality (VR-) based Exergames have enormous potential to provide a safe and personal everyday interaction space for older adults with neurological diseases supervised by clinical therapist. However, therapists are often tightly scheduled and their work is very demanding, thus new therapeutic systems should reduce their workload and improve life of patients at the same time. While patients with dementia or Alzheimer's disease should not use VR Exergames on their own, therapist need to be in control of the games flow and be able to react to mood shifts and current capabilities of the patient.

In this paper, we present our co-developed VR exergame for older adults with dementia and their therapist to improve cognition through everyday exercise and complement continual biography work by cooperative experience. The older adults visit their community room and solve motor-cognitive tasks in stereoscopic 360° videos, while experience and difficulty can be dynamically controlled by the therapists.

Index Terms: Human-centered computing—Human computer interaction (HCI)—HCI design and evaluation methods—User studies; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Collaborative interaction

1 Background

Older adults with neurological diseases often live a more isolated life at retirement homes due to a limited movement range and interpersonal interactions. Community rooms though can always be accessed to participate in different regular joined group activities led by therapist. Immersive group-based virtual reality (VR-) based Exergames have enormous potential to provide a safe, personal space. On the other hand, therapists are often tightly scheduled and their work is very demanding, thus new therapeutic systems should reduce their workload and improve life of patients at the same time. While patients with dementia or Alzheimer's disease should not use VR Exergames on their own, therapist need to be in control of the games flow and be able to react to mood shifts and current capabilities of the patient.

To address this challenge we present an exergame, which has been developed as part of a larger collaborative research and development project funded by the German Federal Ministry of Education and Research [11]. The project aims to bring innovative therapies and new technologies closer to relevant users by using living labs and closely coupled development processes. The main focus of our project is to develop exergames for older adults with neurological disorders, in particular dementia and Alzheimer's disease. By closely cooperating with a living lab project [5], we have direct access to patients and clinical experts at a hospital for seniors close to our university.

This hospital is an ideal partner as well, since patients have been regularly playing exergames using the Microsoft Kinect[1] device in all of their community rooms for the past two years. These games created by the start-up Retrobrain[2] are for individual or group use and can be accessed without a supervising clinician. Thus, patients are not only participating in regular scheduled sessions, but also play the exergames on their own or with friends and family members. The Kinect gaming console itself was optimized for clinical usage. For instance, a single button turns on the entire experience, which significantly eases handling and reduces errors. Due to the good experiences with this technology, the clinic and the therapists eagerly accepted our VR approach and assisted us by making appointments with patients for the last year.

Creating exergames for older adults with dementia is a challenging and difficult task. Especially older adults with neurological diseases require more cognitive resources to accomplish movement tasks such as walking, reaching or simply standing. [1] Performance of this group can be improved by adjusting visual stimuli to augment perception [6]. As demonstrated by Olzaran et al., therapy without medication is superior when focus is on quality of life. At the same time, cognition and everyday basic skills are affected with an approaching intensity [9]. In addition, Multi-domain training (cognitive, motor, social) is especially potent when improving mood and cognitive performance capabilities [9]. Computerized training can also be used to improve cognitive abilities as shown by Schmiedek et al. [12] Another study shows that participants with light cognitive impairments showed improvements in visual attentiveness after cognitive training [4]. Physical activity also improves spatial memory by increasing hippocampus volume as seen on MRT [3].

Controlling schemes and game mechanics need to be straightforward, whereas novel game mechanics cannot be learned anymore. We gained an in-depth understanding about these challenges during the development process, in which we conducted an intensive requirement analysis (including several interviews, focus groups, personas and usability studies) following a human-centered design process. In such a process, it is important to consider ethical, legal, and social implications (ELSI) continuously throughout the project. Especially when working on research with patients, it is important to ask the right ethical questions e.g. regarding informed consent and (if at all) who should be able to decide if a new therapy should be tested or administered. We required consent forms signed by legal representatives at all times. Important decisions always should be supported through an independent ethics-committee and every party involved in such research should work with full disclosure of any conflicts of interest that might arise while studying a disease. [13] In Germany there is the "General Data Protection Regulation" (GDPR) in effect, which considers all data which can be connected to a specific person in any way. Health related data is defined separately and needs to be given specifically so that it may be recorded and studied. In addition, violations of data security are punished harshly, and appropriate security measures for access and storage are necessary.

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[1] https://developer.microsoft.com/de-de/windows/kinect
[2] https://www.retrobrain.de/memore/

Our advisors on data safety and security advised us to encrypted data transmission and written acknowledgement of anyone who handles sensitive data during our research. We are storing our data on a separate virtual machine that runs a daily backup and is only accessible via a VPN for administration and TLS / HTTPS for data transmission. Examples of more specific ELSI considerations in our project are:

- **Ethical:** Is it questionable to immerse patients with neurological diseases in a realistic representation of the world?
- **Legal:** What precautionary measures need to be taken before having a patient participate in our study?
- **Social:** How do we reduce or prevent physical and mental overload during and after the experience?
- **Privacy:** What kind of data is collected by the hardware manufacturers of the devices we use, how can we prevent this?
- **Security:** How is the data stored and transferred to authenticated partners?

To elaborate on these implications we invited experts from each area of expertise to our University to discuss their respective topic with our projects partners. We also invited them to our play sessions and received feedback immediately after each prototyping session. Further workshops are planned in the following years to go into detail on new issues that have or might arise.

2 IMPLEMENTATION

2.1 Requirements

For this exergame, we mainly focus on three aspects of the therapists' involvement. They are planning the daily routine of the patients, doing biography work when interacting with a patient and managing their workload. Daily life at the hospital is clocked for dementia patients and especially therapists. Appointments need to fit into a regular 30 minutes to 1 hour time slot leaving enough time for travel and arrival at the community room. Events, which do not meet these requirements are unlikely to find wide acceptance as a regular, everyday activity. Even our surveys, interviews and preliminary studies needed to fit these time slots to ensure a smooth process.

Biography work, meaning keeping track of patients interests, hobbies and biography, is usually done at all times. Group sessions however make it difficult to both memorize newly gained information until it is jotted down and also to stimulate patients into talking about themselves. At other times, the therapist might be in a one on one situation with the patient, but their task (medication, planning, ...) is more significant.

Finally, in group playing sessions of the previously described Kinect exergames we could observe therapists to be very busy with inciting quiet or secluded players into playing the game (this is desired by the patients), or encouraging the current players into giving their best and repeating the instructions. This falls in line with the feedback they gave us, that they expect a new type of therapy game to make interaction with the patients simpler. They would also appreciate it, if the exergame could at least in part take charge of the encouragement whilst playing and deal with errors more noticeably for the patients.

2.2 Prototype

We developed the prototype of the application using the Unity development Engine [3] which allows for rapid prototyping and on the fly changes. We used the Valve Index head-mounted display[4]. It features a $1440x1600$ resolution per eye and a refresh rate of up to $144Hz$ with a $130°$ field of view. In early prototyping stages, we valued the controllers straps, which holds them at the palm of the player, without them needing to keep their hands closed. Before, we had issues when instructing them to pick up, place, and toss objects. Finally we create our own device which the patients use to control the game in the shape of an older photo camera, that our partner 3D printed. We connected it using a Vive tracker, which connects to the Valve Index tracking hardware inherently.

The design of our controller is the result of the requirement analysis and multiple focus-group interviews conducted with healthy inhabitants of the hospital. Shape and button placement were revamped after prototyping sessions with older adults with light dementia or mild cognitive impairment (MCI). We will explain more about the design and mechanics of the exergame in chapter 3. Through monthly prototyping sessions at a living lab in a community room of the hospital, we reiterated our prototype using the feedback we received. Figure 1 shows an early prototyping session at the hospital, where we introduced the camera controller for the first time.

Figure 1: An older adult at the living lab community room tests our exergame using an early version of our camera controller. The screen in the back will be used by the clinicians for monitoring and taking part in the patient's experience.

While the patient is immersed in the VR experience, the clinician is responsible for the patient's safety and well-being. Thus, the clinician cannot, at the same time, also wear a head-mounted display, because they need to be able to react if the patient where to loose balance or have a sudden urge to run away. The VR experience must also react to the patients current state, pointing them to new tasks when quite, and holding back when the patient is explaining something or busy observing the scenery. Since the caretakers are usually very familiar with their patients' idiosyncrasies, they should be the ones in charge of the flow of the VR experience. Therefore, we created a remote control mobile app in consultation with the clinical experts, which gives them full control over events we agreed are necessary to control the exergame in a meaningful way. The remote control is implemented in the form of a NodeJS Express[5] web server, run through the Unity exergame application. Mobile devices in the same network can access the remote control dashboard, which is shown in figure 2. The game and the device communicate through a TCP connection and web-sockets for transfer in both directions. We opted for this design, since we needed the remote to be very accessible for all clinicians and adapting to changes in the game throughout the development process. Buttons on the remote are changed depending on the game state, so that the clinician always knows his current options, and what occurs when they are triggered.

[3]https://unity.com/

[4]https://store.steampowered.com/valveindex

[5]https://expressjs.com/de/

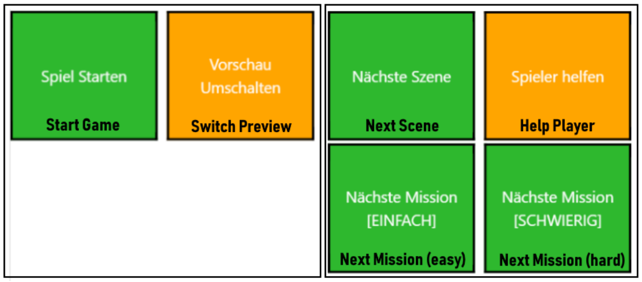

Figure 2: View of the mobile remote control app at different stages of the game. Black text shows the translation of the buttons. Left image shows options before the start of the game. Right image shows options mid game. Note especially the orange "Help the player" button, which tells the game to present the player with a hint, in case the task is not fully understood after introduction.

Not pictured in 2 are the red "escape" buttons, which are necessary to immediately start a soft or hard termination of the software, depending on the urgency. A soft exit would be necessary if the patient gets bored or feels himself to be in a shortage of time (which we observed on multiple occasions). In this case, the game would run an exit sequence, which fluently brings ends the game. A hard exit case would arise if the player experiences motion sickness, blurry vision or has other immediate complaints.

3 Exergame Application

In our VR therapy exergame the participants are immersed in a 360° 3D Recording in the vicinity of famous landmarks. These locations have been requested by a majority of the participants in our interview sessions, since they remember being there earlier in their life and want to continue to visit there. For prototyping we created two minute 360° 3D recordings at these locations by placing a *Insta360 Pro* camera[6] on a tripod with 120*cm* height. We chose this height after measuring the eye height above ground of our participants when they were sitting since we also included people with wheelchairs. Only rural scenes where included during prototyping for reasons of accessibility. Other locations the patients requested where mountains, rivers and forests which they remember from their holiday trips.

The patients play the role of a reporter for a local newspaper and are tasked to photograph landmarks. We chose this task because it met the requirements of being easily understood by patients with dementia and nothing new needs to be learned. Any task where the patients would need to learn something new is unfit for people with dementia and would require a lot of guidance from the clinicians. All parts of our exergame are results of our requirement analysis and thoroughly evaluated in multiple play sessions.

The game begins with a brief audio-visual explanation of the player's role and tasks. The camera controller is introduced and handed over by the clinician when prompted by the VR assistant. After receiving the camera, the player is immersed in the 360° 3D video and can explore his surroundings whilst listening to an introduction to the current area. When the clinician sees that the patient is ready to continue, he activates an easy or hard mission and the VR guides starts explaining the task via a short story. After the explanation has finished, the player is reminded of the task with a sticky note attached to the camera, as well as a floating frame which shows the field of view of the camera as seen in Figure 3. When the camera is pointed at the requested landmark and triggered, a newspaper article with the image appears in front of the player. This materializes the work in a comprehensible representation for the player, and makes both patient and therapist understand, that the task has been accomplished (see Figure 4). If the player photographs other areas, they would still see the picture, but the final article would not be visible. This is also an important game mechanic, which reduces frustration, since the player can take as many pictures as desired.

Every scene also features hidden "Easter eggs", which when first found by a patient stimulate the conversation between both actors, since especially the patient is surprised. Examples include moving objects such as pigeons or persons. If those are photographed, it also can cause a newspaper article.

After the completion of the actual tasks, the clinician is asked to decide whether to start an optional objective, which prolongs the experience but might be interesting for the player. In general, the clinician is always in control of where the player currently is (e.g. which 360° video scene is loaded). Navigation in form of teleportation between scenes is built into the storyline, and the player is only moved to a different scene when the clinician presses the according button on the remote control.

At the end of the experience, the clinician receives a summary of all pictures the patient has made over the course of this session, and can review these together with the player. This makes it easier for the patient to process the VR experience after removing the glasses, and making a connection between the virtual and real world. Further data is stored about the performance or movements of the patient for later analyses. At the same time, the clinician can evaluate what parts of the experience are remembered by the player, and ask for details regarding the discussions they had while solving different tasks.

Figure 3: Instructions of the current mission are displayed on the camera and in line with the cameras field of view. Hence, they are visible both when the patient holds the camera close to their eyes, and when they extend their arms all the way.

4 Current Study

Evaluating changes in cognitive performance of patients with dementia is difficult, since the effects of the disease depend on the person's daily condition and varies with the time of the day. Performance is expected to be better in the morning, and often worsens

[6]https://www.insta360.com/product/insta360-pro

Figure 4: Two examples of newspaper articles, which are visible after taking a picture of a landmark after solving a task. Left image shows a wide-angle shot accomplished by contracting the arms. Right image is zoomed in when the participants stretch out the camera and their arms.

in the afternoon and evening hours [2]. Progression of dementia is usually measured in years, but since the projects funds are limited and the hospital is running multiple studies at once, we currently run a two-month study first.

In our current design, we will observe eight patients with diagnosed light dementia during our study for two months. Half of the group will be observed as our control group while the other half plays our exergame once a week for the duration of the study. For evaluation of the patients' cognitive condition, we use the Montreal Cognitive Assessment (MoCA) [8] and Addenbrooke's Cognitive Examination (ACE-R) [7]. Both are commonly used in literature and both are able to differentiate on a scale and suggest the current stage of the dementia disease between MCI and diagnosed dementia. Due to the above-mentioned reasons, these values might not give us the best indicator on how the exergame is influencing the disease, but we can compare the performance in the exergame with their current state of mind. Before and after every session we will receive feedback from the clinician, as of how the patients' well-being changed in the week between the appointment, and after experiencing the VR exergame.

Using the "Timed Up and Go" test [10] we also evaluate changes in the patients balance and mobility after every playing session. We hypothesize, that shifting the center of mass through the exercises in our game will improve their performance over the course of the two-month study. Further, we will record the patients' personal experience through questionnaires and compare their opinion with that of their attending clinicians.

Data is recorded anonymously during each session. Participants receive a random QR code at the beginning of the study, which the clinician scans using the remote control mobile app every time the participant uses the exergame. We collect the participants head and camera controller movements (velocity, position) as well as eye tracking data and all mission events. For the study we will switch the headset for an *HTC Vive Pro Eye*[7] which has a built in eye tracker. (We valued the *Valve Index* in prototyping, because of the magnetic face cushion, which can be quickly removed for cleaning in between participants.) Those are start and ending times, precision and search space in relation to the actual targets position. We hypothesize that the movements of the camera controller become more steady, and that extending the arms in the "zooming" exercise is more pronounced. We further expect tasks to be solved quicker due to improved physicals, superior clinician-patient teamwork and recognition.

5 Conclusion and Future Work

In this paper, we presented a VR exergame, which we developed for older adults with dementia together with their therapist to improve cognition through everyday exercise and complement continual biography work by cooperative experience. We described the challenges, requirements and implementation as well as ongoing user study, which we would like to discuss in the workshop with other participants.

Our long-term goal is that the exergame is played regularly by multiple patients under supervision by clinicians and therapists.

Using the collected data through these sessions, we want to work together with the hospital and clinical experts to create early diagnosis tools for older adults with risk of dementia. We will also have to find applicable answers to ethical questions, such as to when we are allowed or obligated to inform patients of impending disease.

Additionally we are working on designing new procedures that allow us to perform studies over a longer time span. This is largely complicated by the availability of clinicians and the difficulty to match them with the schedule of patients, which are in line of the study. If we find candidates willing to participate in a longer 2 years study, we will tie this in on the end of the first two months, but we only expect a small pool of candidates willing to commit to this time span.

[7] https://www.vive.com/de/product/vive-pro-eye/

Acknowledgments

This work was funded by the German Federal Ministry of Education and Research (BMBF) as well as the German Research Foundation (DFG), the European Union's Horizon 2020 research and innovation program and the Federal Ministry for Economic Affairs and Energy (BMWi).

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