International Conference on Artificial Reality and Telexistence
Eurographics Symposium on Virtual Environments (2021)
J. Orlosky, D. Reiners, and B. Weyers (Editors)

A Long-Term User Study of an Immersive Exergame for Older Adults with Mild Dementia during the COVID-19 Pandemic

Lucie Kruse[1]† and Sukran Karaosmanoglu[1] and Sebastian Rings[1] and Benedikt Ellinger[2] and Daniel Apken[3] and Thandiwe Feziwe Mangana[4] and Frank Steinicke[1]

[1] Human-Computer Interaction, Universität Hamburg, Germany
[2]Velamed GmbH, Germany
[3]gamelab.berlin, Humboldt Universität zu Berlin, Germany
[4]RetroBrain R&D GmbH, Germany

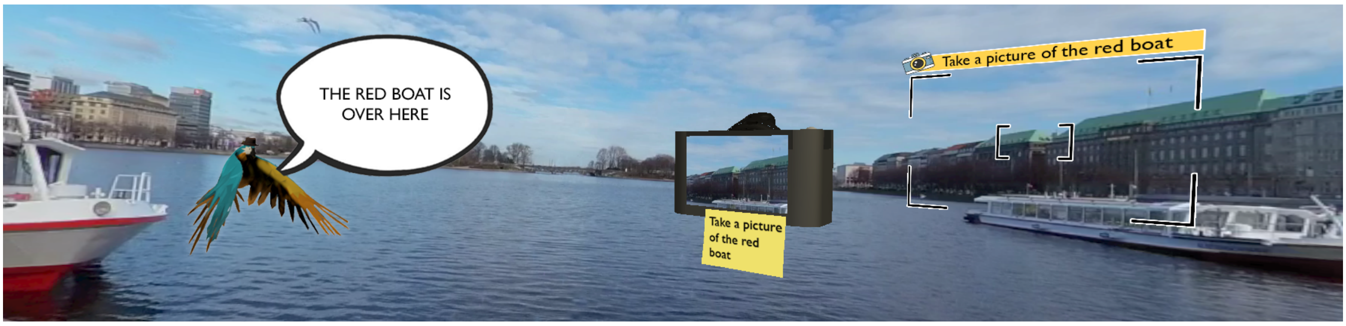

Figure 1: *A parrot guide helps the player locate the target.*

Abstract

Older adults, which are affected by neurological diseases such as dementia, often suffer from cognitive and motor deficits, and, therefore, require special care and therapy. However, especially during times of a global pandemic, they are a vulnerable high-risk group that has to be kept safe, which limits their possibilities to perform cognitive or motor training, or visit places outside their homes. We developed and evaluated a motor-cognitive exergame using a human-centered design approach, in which the older adults can virtually visit known places in their city of residence in omni-directional 3D-videos using immersive virtual reality (VR) technologies. The player's goal is to take pictures of famous landmarks with a tracked wearable that replicates a physical camera. We evaluated the game during a nine weeks user study with ten older adults with mild forms of dementia in a between-subject design: (i) five players experienced the game twice a week for 15-25 minutes, and (ii) five participants in a control group, who did not play the game. The results suggest that the overall well-being of players improved and that their game performance increased. Cognitive and physical tests indicate that the test group experiencing the game improved more than the control group. All players had positive attitudes towards the game and enjoyed the welcome change.

CCS Concepts

• ***Human-centered computing*** → *Empirical studies in accessibility;* ***Empirical studies in HCI;*** • ***Applied computing*** → ***Health care information systems;***

† We especially want to thank the Hospital zum Heiligen Geist Hamburg for their cooperation. 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). The author acknowledges the support of the Cluster of Excellence "Matters of Activity. Image Space Material" funded by the DFG under Germany's Excellence Strategy - EXC 2025 - 390648296.

DOI: 10.2312/egve.20211322

1. Introduction

With the demographics change and an aging population, dementia has become one of the most common causes for disability or neurological diseases in later life [WHO21]. Such diseases cause a decline in people's cognitive and physical abilities, restricting their autonomy. Different stages of dementia require individual care, and daily life tasks often require the help of healthcare professionals, imposing social and financial challenges for families and health systems [WHO21]. Therefore, research should address the question of how we can prevent, reduce or overcome such more frequently occurring conditions. In particular during the early stages of dementia, the WHO pointed out the importance of remaining active as long as possible and training both cognitive and physical abilities [WHO21].

Virtual reality (VR) has great potential to train cognitive and physical abilities since VR offers possibilities of creating individualized immersive training programs, which can easily be adapted [RKK*20, ECDB18a]. VR can also help to provide activities that would otherwise not be possible, e.g. visiting other countries or places [RSJ*21]. Especially for older adults with dementia living in senior living homes, the social and economic resources are limited, and the caregivers' workload is enormous. Hence, enabling activities for people with dementia such as taking a trip to the city requires a lot of preparation time, transportation and personnel. With the help of VR, people with dementia can virtually visit outside locations without increasing the workloads' of their caregivers, and especially during times of a global pandemic, without increasing their risk for infection.

In order to exploit the benefits of immersive VR technologies, we have developed *Memory Journalist VR*, an immersive VR exergame in which people with dementia can virtually visit famous places in their hometown and the capital of their country of residence. Furthermore, we provided a 3D printed replica of a camera device, with which the participants have to take pictures of specific objects or locations, stimulating their visual recognition, short-term as well as long-term memory. The game includes simple functional training activities generated by the task to take pictures, which requires users to perform head and torso rotations combined with arms-raising exercises. During a nine weeks user study, which was conducted in cooperation with a senior living home, Hospital zum Heiligen Geist, we evaluated the effects of the immersive VR exergame on physical and cognitive abilities, and psychological well-being. The evaluation was based on interviews, questionnaires and data collection during the gameplay. The fact that the study was conducted during the COVID-19 pandemic clearly empathized the importance and potential of using VR as a mean for physical and cognitive training for isolated vulnerable groups since it allowed older adults with dementia to stay active. Overall, the long-term user study was driven by the following research questions:

- Is *Memory Journalist VR* suitable for people with mild dementia, providing enjoyment, engagement and positive user experience?
- Can VR exergames improve the psychological well-being of the players during times of a global pandemic?
- Can playing a VR exergame on a regular basis be a suitable addition for maintaining or even improving cognitive and physical abilities of people with dementia?

This paper contributes to the knowledge of the effects of VR exergames on psychological, cognitive and physical well-being of people with dementia. We extend existing research by conducting a long-term study with people with dementia and their caregivers during the COVID-19 pandemic. In comparison with a control group, who did not receive any additional training, the impact of the game will be discussed. Finally, we reflect on the implications for future research, highlighting the need for immersive exergames for people with dementia, especially in times where social contact is limited.

2. Related Work

In this section, we summarize the previous work related to *Cognitive and Physical Training*, *Virtual Reality*, and *Exergames* for people with dementia.

2.1. Cognitive and Physical Training for People with Dementia

Dementia is a degenerative illness, which causes the impairment of several abilities including memory, learning, and problem solving [WHO21]. However, up to date there is no medical cure for dementia [BVHB*10]. Therefore, it is important to reduce the risk for and the progression of this conditions in order to enable older adults to have an independent life. Research has explored the possibilities of reducing the risk and progression of dementia in several ways, for instance, with the help of cognitive and physical training. During a 15 month long-term study, Cancela et al. showed that aerobic training can improve memory function and mobility of people with dementia [CAVS16]. A meta-analysis by Heyn et al. confirmed that exercise training can increase fitness, physical and cognitive function and lead to a positive behavior in older people with dementia [HAO04].

Nevertheless, traditional training imposes some barriers such as lack of motivation, adaptability, accessibility or required time of caregivers [SG04]. Innovative technology can overcome these challenges using systems that can motivate [GFS*08], and provide adaptive mechanics [PMBB*12]. Additionally, they provide opportunities to partially decrease the need for supervisors (e.g., by automatically guiding people through the exergame) [ECDB18b]. This is especially important during the COVID-19 pandemic, where social distancing rules have been applied in many parts of the world.

2.2. Virtual Reality for People with Dementia

Due to significant technology advancements, immersive VR technology has received considerable attention in recent years. Nowadays, VR is used in numerous application domains including health, communication, education, and entertainment. With respect to health research, VR supports two important features: (i) full stimuli control and (ii) sense of presence [GBJMACU15]. For example, cognitive training can be designed without distractions by controlling the environment and tasks [GBJMACU15]. As a result, VR has been used in many health applications for identification and rehabilitation purposes [GBJMACU15, Che11]. Regarding the COVID-19 pandemic, a survey has indicated that the usage of VR during the recent lock-downs improved both mental, and physical well-being of the general population [SM21]. We aim to extend this research with people with dementia.

For people with dementia, VR has been used for focusing on reminiscence activities to stimulate past memories [SA14, HBHM18]. Other VR applications extensively focus on physical training [ECDB18b, ECDB18a]. Similarly, VR experiences are used to provide enriching experiences [HBHM18] and to give people with dementia access to outdoor environments [TAR*19]. Also, it has been shown that long-term VR interventions can improve cognition and brain function in older adults with mild cognitive impairment [NTYK*20, TŞPU21], and that after watching short films in VR, people with dementia show more alertness [RSJ*21].

2.3. Exergames for People with Dementia

Exergames can train daily life skills in a playful way. They can provide physical training opportunities together with cognitive stimulation [VSDH*18, HGH*21, ZSL*21], which can help to reduce the risk for and progression of dementia. Games have an enormous potential to provide the added benefit of increased adherence to therapy sessions due to increased enjoyment. Prior works highlighted that exergames hold a significant potential for people with dementia to improve balance, physical, and cognitive abilities [MNM*10, SHK11]. For example, Unbehaun et al. created and evaluated four balance and coordination Kinect games [UAV*18, UVA*18a]. They showed an improvement in physical abilities including gait, coordination, mobility, balance and stability.

With respect to VR, Eisapour et al. developed different VR exergames, where the users perform upper body motions like head rotation, reaching motions, lifting both arms and rowing motions on a virtual farm [ECDB18a, ECDB18b]. The results suggest that participants achieved greater range of motion than their therapists expected. Moreover, Rings et al. [RKK*20] presented promising results in their early study showing that VR exergames can promote physical activities. Hence, using these findings, we decided to create VR exergames for people with dementia to improve their cognitive and physical abilities.

3. VR Exergame Design & Implementation

To develop *Memory Journalist VR*, we followed an HCD approach, which is described in more detail in [KRK*21]. First, we conducted semi-structured interviews with stakeholders (i.e., family members of people with dementia, clinical health experts, a physiotherapist) and employed contextual inquiry sessions with people with and without dementia. Then, based on the user requirement analysis, *Memory Journalist VR* was designed and developed. We then conducted five focus group sessions to demonstrate validity of the designed exergame. Each focus group session served as a stimuli to iterate and improve the user requirements, design, and implementation of *Memory Journalist VR*. The short-term evaluation of the exergame highlighted positive player experience for people with dementia, yielding the investigation on the long-term use.

In *Memory Journalist VR*, the player experiences 360° 3D videos of their city of residence (Hamburg) and a second famous city in their country (Berlin). While the participant plays the VR exergame, a caregiver accompanies them through the entire experience. The players take the role of a reporter, with the task to take photographs of famous landmarks for a newspaper. Our aim was to create a realistic environment to evoke the long-term spatial memories of people with dementia by providing an experience linked to their past. If the participants had not visited the places before, the help of the their caregiver permits them to play the game successfully. A custom 3D-printed camera is used as an input device to increase the realism of the experience. A virtual version of the camera is also shown in VR.

Six different locations can be shown, with three of them in each city. Each location has six different missions, e.g. taking a picture of well-known churches, towers, museums or rivers. Once the picture is taken correctly, a short newspaper article with a fictional, yet fitting headline appears (see Figure 3 middle). Some missions provide an additional difficulty by requiring an upright or zoomed-in picture. For an upright picture, the camera has to be rotated. Zoom can be achieved by moving the camera further away from the player's head. While these movements are very easy for younger and fitter players, the movements provide an important physical training for everyday life of people with physical difficulties, e.g., for lifting or placing objects [RKK*20].

A parrot is used as a narrator that presents the missions to the players. If they need help, the parrot can provide two hints. The first hint is always a textual explanation of the landmark that the players are looking for, e.g. "*We are looking for a big building with a turquoise roof*". If more help is needed, the second hint is provided optically. The parrot is flying towards the landmark saying "*[The landmark] is over here*" (see Figure 1). Overall, the use of parrots allowed both players and caregivers to solve tasks if they did not know the famous landmark. A caregiver can control the VR experience using a *Remote App* on a smartphone (see Figure 3), which was implemented as an Express `(v4)` [HS*10] web server using NodeJS `(v8.9.4)` [Dah09]. With this app, missions can be started or aborted, hints can be given and the game can be stopped.

We developed the game in Unity3D [Tec04]. The game ran on a computer with a GeForce RTX-2080 Ti graphics card and an i9-9900K CPU. A Valve Index head mounted display (HMD) was used, with a resolution of 1440px × 1600px per eye at 120 Hz, and a field of view of 130°. Additionally, a 3D-printed camera with an attached Vive tracker was used. The shutter-button of the camera could be pressed to take a picture in-game. For the video recordings of the environment, we used an *Insta360 Pro* camera [Ins17]. To prevent cybersickness [PCPCRF21] and for safety reasons, the camera was placed on a tripod at 120cm height from the ground, in order to replicate eye height for a seated VR experience. The game view was mirrored on a TV screen so the spectators could follow it. The players were either sitting on a stationary, rotatable chair, which made it easier for them to look around in the virtual scene, or in their own wheelchair, which had to be rotated by the healthcare professional.

4. User Study

The aim of the study was to investigate whether the developed VR exergame was able to provide a positive experience for people with

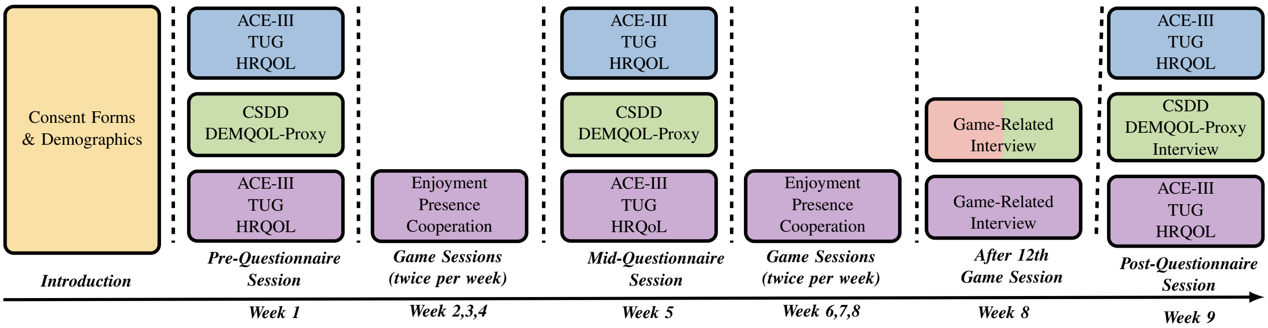

Figure 2: *The schematic procedure of the experiment. The colors represent the group of people performing the task: orange (all participants), purple (test group), blue (control group), green (caregiver), and red (healthcare professional).*

dementia in long-term use. Several studies have shown the negative impact of social isolation and the cancellation of training options on psychological, cognitive and physical well-being [RRR20, MH21, MXD*20, Abb20], which is why we and the senior living home agreed that it is important to continue our work, of course, under all hygiene standards. Furthermore, the end of the pandemic is still unknown, and positive experiences, especially at a later stage in life, are crucial for the well-being of older adults. To determine whether *Memory Journalist VR* can be this positive experience, or if it is due to external circumstances, e.g., less social distancing, less infections, or even the season of the year, we found it important to compare one group playing the game, and one group not playing the game in between-subject design. We decided against a control activity for the CG to investigate whether providing the people with dementia with a VR exergame as an addition to their normal life activities has an influence on their well-being.

The COVID-19 pandemic posed several challenges for research [DBM*20]. We took special care of all hygiene measurements, in accordance with the senior living facility. The study was carried out during the late summer months with relatively low COVID-19 infection rates in the VITALab.One [HSR*19], which is located in a separate building of a senior living facility. An outside door was open at all times, and medical masks were worn. Between each participant, the HMD, controllers and surfaces they touched were cleaned and disinfected. A healthcare professional was responsible for putting the HMD on the participant's head, so the researchers did not get close to them to ensure social distancing.

The study is part of a project with multidisciplinary researchers, which also includes an ethics expert. Additionally, we held a so-called ELSI workshop to discuss and reflect on ethical, legal, societal, privacy and security issues prior to the study. The knowledge gained during this workshop was integrated into our work procedure. Furthermore, the ethics expert visited us during one of our earlier prototyping sessions, where they experienced the game and the interaction of the people with dementia with the game, and discussed the ethical problems and indications of the study. We then incorporated their feedback once again. In cooperation with the senior living home, we determined safety protocols for both, mental stress, as well as physical stress or dangers due to the COVID pandemic. For example, stop markers were developed with caregivers to peacefully end the experience in a case of emotional distress or disorientation. The legal representatives of the participants were informed about the study and signed a consent form, and of course the participants themselves participated out of their own will, and were free to stop whenever they wanted.

4.1. Participants

10 participants (7 female, 3 male) diagnosed with mild dementia were recruited from the senior living facility. At the beginning of the study, people with dementia were randomly assigned to the TG (4 female, 1 male) and the CG (3 female, 2 male). The average age of the participants was 82.8 ± 5.49 years (TG: 83.6 ± 7.42 years, CG: 82 ± 2 years). The study was conducted with a healthcare professional (female, 52 years) participating in the game. Also, the responsible caregivers of all users (N=16, 14 female, 2 male, 48.06 ± 12.84 years, 11.75 ± 10.48 years of experience) participated in the questionnaire sessions to inform us about them.

4.2. Procedure

The study took place over the course of 9 weeks, with 6 weeks playing the game twice per week, and 3 weeks of questionnaire sessions. The procedure can be seen in Figure 2. We chose to have the questionnaire sessions in separate weeks to rule out any short-term effects of the game on cognitive, physical and psychological states of the participants. After the last questionnaire session, each of the players received a printed newspaper with the pictures that they took during the game as a thank you.

4.2.1. Questionnaire Sessions

Several standardized questionnaires were used to assess cognitive, physical and psychological changes. Because some people with dementia might have difficulties in answering questionnaires [UVA*18b, CST*20, KSKW13], we also used proxy measures that were answered by the responsible caregivers. A senior home employee filled out Addenbrooke's Cognitive Examination III (ACE-III, A-B-C sub-versions for each session, max. score 100) with all participants [HSH*13]. For a self-reported HRQoL rating, a customized single-item from the Dementia Quality of Life (DEMQoL) questionnaire was employed ("*Thinking about all of*

Figure 3: *Left: An older adult playing the game, with the healthcare professional assisting him. The experimenter guides the game with a remote control from their phone. Middle: A newspaper article that appears when a correct picture is taken. Right: An older adult playing the game by herself, with the healthcare professional using the remote control.*

the things: your feelings, memory and everyday life, how would you rate your quality of life overall?" on a 4-point scale) [SLB*07, KF07]. The participants' mobility was measured with the Timed Up and Go Test (TUG) [PR91]. At the same time, an experimenter interviewed the caregivers of all participants. Caregivers answered DEMQoL-Proxy and Cornell Scale for Depression in Dementia (CSDD) for the participants [AAYS88,WWVR13,SLB*07,KF07]. Because of changing work schedules, the caregivers were not the same throughout the sessions (See limitations).

Additionally, two types of semi-structured interviews were conducted: a game-related interview and a follow-up interview. The questions can be found in the supplementary material. The game-related interview took place directly after the 12th game session. This interview aimed to obtain information regarding the game experience of the players, and the impact of the game on their well-being. A follow-up interview was conducted in the post-game questionnaire session with all caregivers. The purpose of this interview was to observe the possible long-term effects of the VR exergame on the well-being of the participants, and to compare it to that of the CG.

4.2.2. Game Sessions

Each game session consisted of 15-25 minutes of game play and three questions afterwards. In a tutorial, the players received their camera, and were asked to press the shutter button to take their first picture. Since we used a 3d printed replication of a well-known camera, the older adults intuitively knew how to use it. Afterwards, a scene with one of the six different locations started. The participants had some time to look around and recognize where they were. Then the healthcare professional started the first mission, which asked the participant to take a picture of a specific location or landmark in the virtual scene. During the game, we recorded the position of the 3D-printed camera, and the reaction times.

Each game session presented three different locations with four different missions each. The locations and missions were shuffled randomly in a counter-balanced way. When four missions were completed, the scene changed to a different location. As soon as 12 missions were done, or the players decided that they wanted to stop, the game ended. Then, the participants were asked about their enjoyment, presence and cooperation with the caregiver. Enjoyment and cooperation scores were acquired via custom single-item measures on a 7-point Likert scale (respectively "*I enjoyed this game experience.*" and "*I enjoyed the teamwork with the experimenter.*"). For presence, a single question from the Slater-Usoh-Steed Presence Questionnaire was asked ("*I had a sense of being at [the place].*" on a 7-point Likert scale) [SUS94].

5. Evaluation

This section covers the qualitative and quantitative results. We employed mixed-method data analysis and focused on both quantitative and qualitative data. Due to the small sample size and drop-outs from the study within the given COVID-19 restrictions, we did not focus on statistically significant differences on quantitative measures, but will report trends that emerge from the data. For detailed results, please refer to the supplementary material.

For the qualitative evaluation, we used steps from both reflexive and codebook approaches of thematic analysis [BC06, BC21]. The main researcher decided on four categories focusing on our research questions before the analysis: psychological, cognitive, and physical well-being, and player experience. The interview data was then coded inductively under these deductive priori categories.

5.1. Dropouts of Participants

Two TG participants could not participate for the first two sessions because their house was on lock-down, and each participant missed one or two game sessions because of doctor's appointments, sickness, or quarantine regulations. During the mid-questionnaire session, there was a lock-down imposed due to COVID-19, so data for one participant from the TG and one from the CG are missing. From the CG, one participant had an accident shortly before the mid-questionnaire session and stopped participating (CG_2). We also note that one player dropped out after the mid-questionnaire session according to their own wishes (TG_1).

5.2. Psychological Well-Being

We observed a decreasing trend for CSDD scores, indicating lower depression for the TG (pre: 4.2 ± 3.03; mid: 2 ± 2.45; post 0 ± 0).

For the control group, the CSDD values showed a decrease from pre (1.8 ± 1.64) to mid (1 ± 1.15), but indicated an increase later (post:1.6 ± 1.14). DEMQoL and HRQoL did not show any trends.

The interviews showed that the psychological well-being of the TG participants was affected in various positive ways. First, in terms of mood: "*I would say [TG_3's] mood afterwards was euphoric, in contrast to depressed before*"-Cargiver of TG_3 (CTG_3). Second, joy of life: it has improved over the course of the study, which is stated by multiple caregivers: "*[TG_5] has fun and it is a great change to [TG_5's] daily life, especially in times of Corona where the offer of care is very limited*"-CTG_5 and "*[TG_4] is always happy when [TG_4] is picked up and we say 'Today we are going to [play the VR exergame]'*"-CTG_4. A large improvement was shown for TG_3, who showed signs of delusion before the study started. CTG_3 reported that "*This has decreased noticeably, we hear this very rarely now*". A third aspect were social interactions. While some players, e.g. TG_3 normally were rather reluctant to talk to others, CTG_3 reported that "*when [TG_3] comes back, [TG_3] also talks about it. Well, [TG_3] had a smile on their face and said 'wow, that was so!'*". CTG_5 also said that "*[TG_5] is looking forward to these dates, and afterwards we can greatly talk about it*".

5.3. Cognitive Well-Being

The cognitive task during the game was to finish all missions as quickly as possible. The mean time spent in VR for each session was 16 minutes. On average, participants needed 18.5 seconds ($SD = 12.5s$) to fulfil a mission after receiving new instructions. Since we would be expecting a learning effect due to the repetition of the exercises, we have superimposed a fitted exponential curve to support the improvements in our players ($f(x) = 23.49 \cdot e^{-0.009413x}, R^2 = 0.5090$).

The total ACE-III scores of the TG rose steadily between the sessions, (pre: 60.4 ± 15.96, N=5; mid: 61.25 ± 17.29, N=4; post: 64.75 ± 13.6, N=4). For the CG, the mean total scores were 68.2 ± 17.28 in pre (N=5), 80.33 ± 1.53 in mid (N=3) and 76.5 ± 10.85 in post (N=4). It can be seen in Figure 4 that on average, the participants from the TG improved their score more than the CG. However, we note that given the dropout status of some participants, these scores should be evaluated at an individual level. Especially TG_3, who had a low score of 33 in the pre-session, improved to 46 in the post session, equaling an improvement of 39%. In the interviews, the impact of the COVID-19 pandemic on cognitive abilities of people with dementia was emphasized several times. CTG_3 explained that "*the problem is that we could not do so many groups [for cognitive training]*", which might be a reason for declining cognitive abilities. CTG_2 also stated that "*The cognitive stimulation gets worse now, that is also because no activities take place. We notice this in our inhabitants in general, that cognitive [abilities] decrease a little and the forgetfulness gets more in focus now*". The caregivers saw the VR exergame sessions as an opportunity to provide cognitive stimulation for participants during COVID-19. Further, a caregiver explicitly indicated that one player showed signs of improved memory because of *Memory Journalist VR*: "*It is a small improvement. I think so, yes. [...] I even think this has improved positively*"-CTG_3. Additionally, caregivers stated that the mood and abilities of the participants depended on the day (CCG_1, CTG_2, and CTG_5), which might help to understand underlying reasons of our varying quantitative results.

5.4. Physical Well-Being

Movement of the 3D-printed camera was evenly distributed around the y-axis, which means that the players rotated on their chair and took pictures in every direction. The movement intensity of the camera supports the functionality of our exergame. Most movement was done close to the head of the player, holding the camera close to their eyes. The biggest training was the act of zooming, for which the camera had to be moved away from the players' head. The mean total distance that the camera, and therefore the player's hand, travelled during one session was 26.4 meters ($SD = 7.64m$). Additionally, a training effect of the participants can be observed in less scattering of range of motion in the last three weeks of playing, compared to the first three weeks. This is a typical learning effect, as the players needed less movement to fulfill the task, meaning they get more precise.

All participants except for CG_5, who was sitting in a wheelchair, participated in TUG. Mean times for the TG decreased, starting from $29.93s \pm 29.74s$ in pre (N=5), $25.63s \pm 22.49s$ in mid (N=4) and decreasing to $21.3s \pm 16.14s$ in post (N=4). Times for the CG also decreased, with $26.22s \pm 16.96s$ in pre (N=4), $18.43s \pm 6.68s$ in mid (N=3) and decreasing to $16.24s \pm 5.92s$ in post (N=3). The improvements can be seen in Figure 4 (left). TG improved by 42.7% and CG improved by 14.71%. Looking at the individual results, TG_4 improved the most by 47%, almost needing half as long in the post-game session, as in the pre-game session.

In our study, we observed that players had varying physical abilities. For example, TG_4's caregiver explained that "*Sometimes TG_4 is picked up in their wheelchair, sometimes they walk by themself with their walker*". This might be a reason for their improving score. The second topic was pain, or the absense of it. The caregiver of TG_3 reported: "*before [the study started], they had extreme shoulder pain. [TG_3] had an accident, long ago, and now [TG_3] does not complain about it anymore.*"-CTG_3. While holding the physical camera was considered a good training by most older adults, TG_1 reported difficulties due to a shoulder injury that they received when using their walker. This was also a reason for them to drop out from the study. From the CG, only the caregiver of CG_2 reported that CG_2's physical well-being was worse due to their accident, while all other control group caregivers reported no physical change during the study period.

5.5. Player Experience

The player experience stayed high throughout the game sessions, with a little lower scores in the very first and around the middle of the game sessions (mean values for enjoyment: 5.61 ± 0.59; presence: 5.3 ± 1.16; cooperation: 5.88 ± 0.25).

The qualitative findings of the game-related interviews also support the quantitative findings by showing high player experience for the players. For example, TG_2 reported that "*[The game] was fun. I liked to come here*", and that there was "*no boredom at all. [There] was always something to see*". The high player experience is further supported by the healthcare professional: "*the joy we brought*

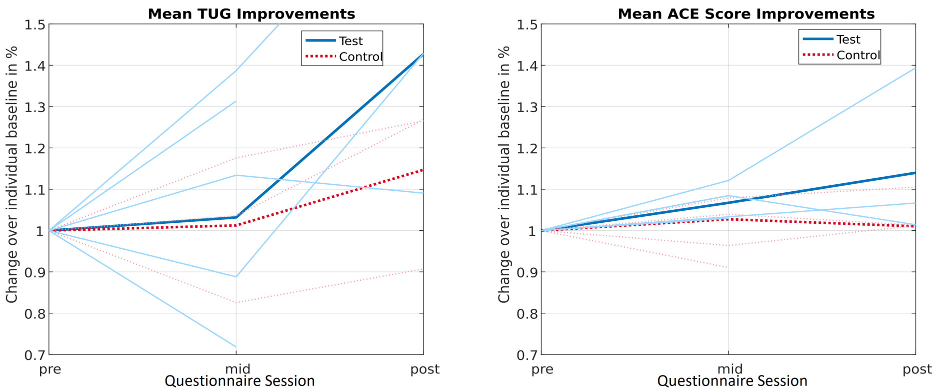

Figure 4: *Left: TUG improvements. Right: ACE-III improvements. Bold lines show the mean value, thin lines the individual changes. The pre-session is used as an individual baseline for each participant.*

to [TG$_3$]. That was great. [...]". Further she pointed out the feeling of accomplishment: "*[TG$_3$] came into the room scared, then we sat [them] on the chair and [they] said "I hope I can do this". And when [TG$_3$] saw the pictures, total enthusiasm and totally relaxed. No fear, and no fear to fail at all. [...] It was like this until [the last session]*". More generally, she evaluated: "*I see how much you achieve and how much fun [the older adults] have. [...] We make them really happy and I think that is wonderful*". The healthcare professional also explicitly pointed out the possibilities of this VR exergame: "*I found [the game] super good, because everyone that has a person suffering from dementia at home or takes care of them knows what an effort it is to travel to [the center of] Hamburg or to other cities.*", emphasising how the exergame can achieve this is seconds.

Furthermore, the realism of the virtual world was praised by many participants, yielding a feeling of presence: "*I am shaking. Birds everywhere! This is so real. I sometimes ducked my head [laughing]*"-TG$_3$. Moreover, the VR exergame created a feeling of curiosity: "*I felt well there. [I liked that] there were different motives. It was always interesting*"-TG$_4$ and "*the game was something new. And if it is new, it is interesting. It is something different. You talk to other people, you see other things, new pictures*"-TG$_5$. The healthcare professional emphasized the repeatability of the VR exergame, indicating that some participants could play the game even longer: "*I think [TG$_3$] could have easily played not just 10 minutes, but half an hour or 45 minutes and she would still have been enthusiastic*", and "*[TG$_5$] would have liked to keep playing, she would also have been a candidate where you could say half an hour, 45 minutes*". All participants reported that they would recommend the game to others, and when we asked TG$_3$, they answered: "*I already did!*".

TG$_1$ -who only played until the 6th session– stated that they "*liked [the game], yes, yes. [It] was good, good video captures. [...] It was quite an experience if you see it like that*". However, they also reported it got boring after a while because they already knew all the places to visit. All other participants did not have any suggestions on improvements. TG$_4$ said: "*I think you have done this game in the optimal way.*"

6. Discussion

Below, we discuss the findings focusing on our research questions.

6.1. Psychological Well-Being

Our results in the mid-game questionnaire session show a decreased quality of life. This was probably caused by severe COVID-19 restrictions including a full lock-down of one of the houses. Previous research has found similar decreases of perceived quality of life due to such isolation measures [HGT*21, MXD*20]. In contrast to the CG, the psychological well-being of the TG showed improvements. Especially in times of COVID-19, when all other group activities were cancelled, the individual game sessions gave the players something to look forward to, and something aside from their daily routine. In addition to the positive short-term effect of improved psychological well-being while the people with dementia played, we observed a positive mid-term effect over the course of the study. This empathizes the importance of situation adjusted activities for people with dementia in senior living homes. We argue that *Memory Journalist VR* can contribute to the well-being of older adults with mild dementia, especially in later times, when more caregivers are trained to use the system.

6.2. Cognitive Well-Being

The quantitative results of the TG's ACE-III scores were higher than the CG's. Due to COVID-19, cognitive training groups had to be reduced and the individual caregivers' workload was too high to provide a lot of individual training. *Memory Journalist VR* and the cognitive training associate with it may have led to the TG's higher scores. Furthermore, people with dementia's mood and cognitive abilities vary from day to day, and a positive mood can lead to a better cognitive performance [LRS*13]. As discussed above, the game improved the participants' psychological well-being and we assume that this might also have positively influenced their cognitive well-being. On the other hand, it is unclear whether these effects would also be shown under normal circumstances. This needs to be tested in future studies.

Even though the short-term memory is limited for people with dementia, the game was remembered by all of our participants, who talked about it to their neighbors and caregivers, or made comments about looking forward to the game session. Additionally, their speed in finding the required landmarks improved, hinting for some form of remembrance. Especially those participants with a lower cognitive score in the pre-session improved by playing the exergame. This implies that the training aspect of this game is most suitable for them. Therefore, we argue that playing *Memory Journalist VR* has the potential to maintain and improve cognitive skills.

6.3. Physical Well-Being

During the game play, players successfully fulfilled the required movements to take a picture, even though some of them needed assistance to rotate on their chair. This implies that even though the movements are easy for younger and fitter people, our participants had to make an effort to perform them.

In TUG, it could be seen that almost all participants from both groups increased their speed between the sessions. While this could be a simple training effect of repeating the test itself, the TG's improvement was larger. Similar to the results for cognitive training, the players with the highest physical problems improved most. This implies that even a low-intensity activity in VR can maintain or improve physical abilities. One player complained of shoulder pain before the study, but did not do so anymore afterwards. This might be due to the physical training they received, but of course, a more detailed examination is necessary to confirm this.

While we employed the TUG test too measure physical well-being, we argue that it is not always applicable for people with dementia due to varying physical conditions (e.g., when using wheelchairs). Future studies should either employ inclusion criteria for participation or consider these variances and thereby use different measurements for physical well-being.

6.4. Player Experience

All players reported that they liked the game and that it was fun to play for them, which replicated previous findings in the usage of exergames [ECDB18b, RKK*20]. Although all our participants had mild dementia, their short-term memory abilities varied. Especially the participants with worse short-term memory were enthusiastic every time they played the game, while it became boring or too slow for those who remembered it after a few sessions. We argue that playing the game regularly is the most suitable for people with increased dementia symptoms, while infrequent playing sessions will invoke feelings of joy even for users that remember the game and the videos. Therefore, future development should add more variety and videos from other places to make the game less repetitive for everyone. Furthermore, it should be noted that the participants did not indicate the need for any improvements, but this might also be due to their difficulties in expressing themselves. This again empathizes the importance of integrating caregivers into the development process for VR exergames.

6.5. Limitations

One obvious limitation was the group size, with five people in each group. COVID-19 restrictions and health problems of the participants additionally made the quantitative analysis less meaningful. However, this also implies that future studies should be aware of the challenges of conducting long-term studies with this special user group, in particular under pandemic circumstances.

Another limitation is that the control group did not perform any activity while the TG played the game twice a week. It is important to note that our exergames should not be seen as a replacement for traditional therapies, but as an extension, as indicated by Zeng et al. [ZPLG18]. Our current study design empathized how important it is to provide additional activities for older adults, especially in times of social distancing and if their traditional activities are not possible. Additionally, control activities like actually going outside to take pictures are not possible under the current circumstances but could be compared in future studies.

The caregivers (who performed CSDD and DEMOqL-proxy measures) were different in the questionnaire sessions; this decreases the comparability of these metrics across questionnaire sessions. Future studies should avoid these variances, though the personal connection between caregivers and people with dementia needs to be taken into account.

7. Conclusion

We have developed and evaluated a VR exergame for people with dementia, which provides the possibility of participating in outside activities again, provides cognitive stimulation, and encourages them to perform functional physical movements. Even though our user study had a relatively low number of participants, the quantitative findings of the work indicate a higher cognitive, physical and psychological well-being for the TG compared to the CG. Particularly the participants with more difficulties benefited from the additional training. Over the course of the study, presence, enjoyment, and cooperation values remained high, indicating high long-term engagement with this VR exergame.

Furthermore, our qualitative findings indicate that the immersive exergame can help to improve and maintain cognitive, physical and psychological well-being and can, to some degree, counteract the negative impact that the COVID-19 pandemic had on the participants. The meaningfulness of the game, which gave the participants a relevant task, a distraction from their daily life and which left them with a feeling of accomplishment, was pointed out. The game was also a relief for caregivers and family, helping them with the provision of meaningful activities in a time where most exercise groups were not possible anymore.

We want to highlight the importance of using VR technology not only for the standard users, but also for older adults and people with dementia. Especially during the pandemic, we believe that VR technology has the potential of participating in activities that are otherwise not possible, e.g. visiting different places, and it thereby has the potential to decrease the negative effects of social isolation. We argue that it is important to integrate new training methods into senior living homes as they can be seen as a good addition to traditional activities; especially when one-on-one or group training cannot take place. Most importantly, the positive impact of the experience on psychological well-being was obvious in the participants' reactions and interview findings.

References

[AAYS88] ALEXOPOULOS G. S., ABRAMS R. C., YOUNG R. C., SHAMOIAN C. A.: Cornell scale for depression in dementia. *Biological psychiatry 23*, 3 (1988), 271–284. 5

[Abb20] ABBASI J.: Social isolation—the other covid-19 threat in nursing homes. *Jama* (2020). 4

[BC06] BRAUN V., CLARKE V.: Using thematic analysis in psychology. *Qualitative research in psychology 3*, 2 (2006), 77–101. 5

[BC21] BRAUN V., CLARKE V.: Can i use ta? should i use ta? should i not use ta? comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches. *Counselling and Psychotherapy Research 21*, 1 (2021), 37–47. 5

[BVHB*10] BLANKEVOORT C. G., VAN HEUVELEN M. J., BOERSMA F., LUNING H., DE JONG J., SCHERDER E. J.: Review of effects of physical activity on strength, balance, mobility and adl performance in elderly subjects with dementia. *Dementia and geriatric cognitive disorders 30*, 5 (2010), 392–402. doi:10.1159/000321357. 2

[CAVS16] CANCELA J. M., AYÁN C., VARELA S., SEIJO M.: Effects of a long-term aerobic exercise intervention on institutionalized patients with dementia. *Journal of science and medicine in sport 19*, 4 (2016), 293–298. 2

[Che11] CHERNIACK E. P.: Not just fun and games: applications of virtual reality in the identification and rehabilitation of cognitive disorders of the elderly. *Disability and rehabilitation: Assistive technology 6*, 4 (2011), 283–289. doi:10.3109/17483107.2010.542570. 2

[CST*20] CZECH E., SHIBASAKI M., TSUCHIYA K., PEIRIS R. L., MINAMIZAWA K.: Discovering narratives: Multi-sensory approach towards designing with people with dementia. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (2020), pp. 1–8. doi:10.1145/3334480.3375209. 4

[Dah09] DAHL R.: Nodejs, May 2009. URL: https://nodejs.org/en/. 3

[DBM*20] DOURADO M. C. N., BELFORT T., MONTEIRO A., LUCENA A. T. D., LACERDA I. B., GAIGHER J., BAPTISTA M. A. T., BRANDT M., KIMURA N. R., SOUZA N. D., ET AL.: Covid-19: challenges for dementia care and research. *Dementia & neuropsychologia 14*, 4 (2020), 340–344. 4

[ECDB18a] EISAPOUR M., CAO S., DOMENICUCCI L., BOGER J.: Participatory design of a virtual reality exercise for people with mild cognitive impairment. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (2018), pp. 1–9. doi:10.1145/3170427.3174362. 2, 3

[ECDB18b] EISAPOUR M., CAO S., DOMENICUCCI L., BOGER J.: Virtual reality exergames for people living with dementia based on exercise therapy best practices. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (2018), vol. 62, SAGE Publications Sage CA: Los Angeles, CA, pp. 528–532. doi:10.1177/1541931218621120. 2, 3, 8

[GBJMACU15] GARCIA-BETANCES R. I., JIMÉNEZ-MIXCO V., ARREDONDO M. T., CABRERA-UMPIÉRREZ M. F.: Using virtual reality for cognitive training of the elderly. *American Journal of Alzheimer's Disease & Other Dementias® 30*, 1 (2015), 49–54. doi:10.1177/1533317514545866. 2

[GFS*08] GAMBERINI L., FABREGAT M., SPAGNOLLI A., PRONTU L., SERAGLIA B., ALCANIZ M., ZIMMERMAN A., RONTTI T., GRANT J., JENSEN R., ET AL.: Eldergames: videogames for empowering, training and monitoring elderly cognitive capabilities. *Gerontechnology 7*, 2 (2008), 111. 2

[HAO04] HEYN P., ABREU B. C., OTTENBACHER K. J.: The effects of exercise training on elderly persons with cognitive impairment and dementia: a meta-analysis. *Archives of physical medicine and rehabilitation 85*, 10 (2004), 1694–1704. doi:10.1016/j.apmr.2004.03.019. 2

[HBHM18] HODGE J., BALAAM M., HASTINGS S., MORRISSEY K.: Exploring the design of tailored virtual reality experiences for people with dementia. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (2018), pp. 1–13. doi:10.1145/3173574.3174088. 3

[HGH*21] HASSANDRA M., GALANIS E., HATZIGEORGIADIS A., GOUDAS M., MOUZAKIDIS C., KARATHANASI E. M., PETRIDOU N., TSOLAKI M., ZIKAS P., EVANGELOU G., ET AL.: A virtual reality app for physical and cognitive training of older people with mild cognitive impairment: Mixed methods feasibility study. *JMIR Serious Games 9*, 1 (2021), e24170. 3

[HGT*21] HANNA K., GIEBEL C., TETLOW H., WARD K., SHENTON J., CANNON J., KOMURAVELLI A., GAUGHAN A., ELEY R., ROGERS C., ET AL.: Emotional and mental wellbeing following covid-19 public health measures on people living with dementia and carers. *Journal of Geriatric Psychiatry and Neurology* (2021), 0891988721996816. 7

[HS*10] HOLOWAYCHUK T., STRONGLOOP, ET AL.: Nodejs express, 2010. URL: http://expressjs.com/. 3

[HSH*13] HSIEH S., SCHUBERT S., HOON C., MIOSHI E., HODGES J. R.: Validation of the addenbrooke's cognitive examination iii in frontotemporal dementia and alzheimer's disease. *Dementia and geriatric cognitive disorders 36*, 3-4 (2013), 242–250. 4

[HSR*19] HILDEBRAND K., STEINICKE F., RINGS S., KÜMMEL C., WESBERG P., VILLWOCK J.: Vitalabs-a multi-stage platform for the evaluation of virtual therapies. In *Proceedings of the IEEE VR Workshop on Applied VR for Enhanced Healthcare (AVEH)* (2019). 4

[Ins17] INSTA360: Insta360 pro, 2017. URL: https://www.insta360.com/product/insta360-pro. 3

[KF07] KNORR C., FRÖHLICH L.: What determines health related quality of life (hrqol) in patients with dementia and their caregivers. *Neurodegenerative Diseases 4* (2007), 127. 5

[KRK*21] KARAOSMANOGLU S., RINGS S., KRUSE L., STEIN C., STEINICKE F.: Lessons learned from a human-centered design of an immersive exergame for people with dementia. *PACM on Human-Computer Interaction 5*, CHI PLAY (2021), (accepted). 3

[KSKW13] KINDELL J., SAGE K., KEADY J., WILKINSON R.: Adapting to conversation with semantic dementia: using enactment as a compensatory strategy in everyday social interaction. *International Journal of Language & Communication Disorders 48*, 5 (2013), 497–507. doi:10.1111/1460-6984.12023. 4

[LRS*13] LOHMAN M. C., REBOK G. W., SPIRA A. P., PARISI J. M., GROSS A. L., KUEIDER A. M.: Depressive symptoms and memory performance among older adults: results from the active memory training intervention. *Journal of aging and health 25*, 8_suppl (2013), 209S–229S. 7

[MH21] MACDONALD B., HÜLÜR G.: Well-being and loneliness in swiss older adults during the covid-19 pandemic: The role of social relationships. *The Gerontologist 61*, 2 (2021), 240–250. 4

[MNM*10] MULVENNA M. D., NUGENT C. D., MOELAERT F., CRAIG D., DRÖES R.-M., BENGTSSON J. E.: Supporting people with dementia using pervasive healthcare technologies. In *Supporting people with dementia using pervasive health technologies*. Springer, 2010, pp. 3–14. 3

[MXD*20] MENG H., XU Y., DAI J., ZHANG Y., LIU B., YANG H.: Analyze the psychological impact of covid-19 among the elderly population in china and make corresponding suggestions. *Psychiatry research 289* (2020), 112983. 4, 7

[NTYK*20] NGEEMASARA THAPA HYEJIN PARK J., YANG H., KIM H., SON M., JANG J., LEE H., PARK: The effect of virtual reality (vr)-based intervention program on brain and cognition in older adults with mild cognitive impairment (mci). *Alzheimer's & Dementia 16* (2020). doi:https://doi.org/10.1002/alz.042835. 3

[PCPCRF21] P CAMPO-PRIETO J. M., CANCELA G., RODRÍGUEZ-FUENTES: Immersive virtual reality as physical therapy in older adults:

present or future (systematic review). *Virtual Reality* (2021). doi:10.1007/s10055-020-00495-x. 3

[PMBB*12] PIROVANO M., MAINETTI R., BAUD-BOVY G., LANZI P. L., BORGHESE N. A.: Self-adaptive games for rehabilitation at home. In *2012 IEEE Conference on Computational Intelligence and Games (CIG)* (2012), IEEE, pp. 179–186. 2

[PR91] PODSIADLO D., RICHARDSON S.: The timed "up & go": a test of basic functional mobility for frail elderly persons. *Journal of the American geriatrics Society 39*, 2 (1991), 142–148. 5

[RKK*20] RINGS S., KARAOSMANOGLU S., KRUSE L., APKEN D., PICKER T., STEINICKE F.: Using exergames to train patients with dementia to accomplish daily routines. In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play* (2020), pp. 345–349. 2, 3, 8

[RRR20] RADWAN E., RADWAN A., RADWAN W.: Challenges facing older adults during the covid-19 outbreak. *European Journal of Environment and Public Health 5*, 1 (2020), em0059. 4

[RSJ*21] ROSE V., STEWART I., JENKINS K. G., TABBAA L., ANG C. S., MATSANGIDOU M.: Bringing the outside in: The feasibility of virtual reality with people with dementia in an inpatient psychiatric care setting. *Dementia 20*, 1 (2021), 106–129. 2, 3

[SA14] SIRIARAYA P., ANG C. S.: Recreating living experiences from past memories through virtual worlds for people with dementia. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2014), pp. 3977–3986. doi:10.1145/2556288.2557035. 3

[SG04] SCHUTZER K. A., GRAVES B. S.: Barriers and motivations to exercise in older adults. *Preventive medicine 39*, 5 (2004), 1056–1061. doi:10.1016/j.ypmed.2004.04.003. 2

[SHK11] SÜTTERLIN S., HOSSMANN I., KLINGHOLZ R.: *Demenz-Report: Wie sich die Regionen in Deutschland, Österreich und der Schweiz auf die Alterung der Gesellschaft vorbereiten können*. DEU, 2011. 3

[SLB*07] SMITH S., LAMPING D., BANERJEE S., HARWOOD R., FOLEY B., SMITH P., COOK J., MURRAY J., PRINCE M., LEVIN E., ET AL.: Development of a new measure of health-related quality of life for people with dementia: Demqol. *Psychological medicine 37*, 5 (2007), 737–746. 5

[SM21] SIANI A., MARLEY S. A.: Impact of the recreational use of virtual reality on physical and mental wellbeing during the covid-19 lockdown. *Health and Technology 11*, 2 (2021), 425–435. 3

[SUS94] SLATER M., USOH M., STEED A.: Depth of presence in virtual environments. *Presence: Teleoperators & Virtual Environments 3*, 2 (1994), 130–144. 5

[TAR*19] TABBAA L., ANG C. S., ROSE V., SIRIARAYA P., STEWART I., JENKINS K. G., MATSANGIDOU M.: Bring the outside in: Providing accessible experiences through vr for people with dementia in locked psychiatric hospitals. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (2019), pp. 1–15. doi:10.1145/3290605.3300466. 3

[Tec04] TECHNOLOGIES U.: Unity real-time development platform, August 2004. URL: https://unity.com/. 3

[TŞPU21] TORPIL B., ŞAHIN S., PEKÇETIN S., UYANIK M.: The effectiveness of a virtual reality-based intervention on cognitive functions in older adults with mild cognitive impairment: a single-blind, randomized controlled trial. *Games for Health Journal 10*, 2 (2021), 109–114. 3

[UAV*18] UNBEHAUN D., AAL K., VAZIRI D. D., WIECHING R., TOLMIE P., WULF V.: Facilitating collaboration and social experiences with videogames in dementia: Results and implications from a participatory design study. *Proceedings of the ACM on Human-Computer Interaction 2*, CSCW (2018), 1–23. doi:10.1145/3274444. 3

[UVA*18a] UNBEHAUN D., VAZIRI D., AAL K., LI Q., WIECHING R., WULF V.: Mobiassist-ict-based training system for people with dementia and their caregivers: Results from a field study. In *Proceedings of the 2018 ACM Conference on Supporting Groupwork* (2018), pp. 122–126. doi:10.1145/3148330.3154513. 3

[UVA*18b] UNBEHAUN D., VAZIRI D. D., AAL K., WIECHING R., TOLMIE P., WULF V.: Exploring the potential of exergames to affect the social and daily life of people with dementia and their caregivers. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (2018), pp. 1–15. doi:10.1145/3173574.3173636. 4

[VSDH*18] VAN SANTEN J., DRÖES R.-M., HOLSTEGE M., HENKEMANS O. B., VAN RIJN A., DE VRIES R., VAN STRATEN A., MEILAND F.: Effects of exergaming in people with dementia: results of a systematic literature review. *Journal of Alzheimer's Disease 63*, 2 (2018), 741–760. doi:10.3233/JAD-170667. 3

[WHO21] WHO: Dementia, 2021. URL: https://www.who.int/news-room/fact-sheets/detail/dementia. 2

[WWVR13] WONGPAKARAN N., WONGPAKARAN T., VAN REEKUM R.: Discrepancies in cornell scale for depression in dementia (csdd) items between residents and caregivers, and the csdd's factor structure. *Clinical interventions in aging 8* (2013), 641. 5

[ZPLG18] ZENG N., POPE Z., LEE J. E., GAO Z.: Virtual reality exercise for anxiety and depression: A preliminary review of current research in an emerging field. *Journal of clinical medicine 7*, 3 (2018), 42. 8

[ZSL*21] ZHANG H., SHEN Z., LIU S., YUAN D., MIAO C.: Ping pong: An exergame for cognitive inhibition training. *International Journal of Human–Computer Interaction* (2021), 1–12. 3