

Supplementary Information S1: Search Strategies

Search strategies used on databases ACM, IEEE Explore, Scopus and PubMed

ACM (2010 - 2019). Last search date: 15 December 2019

"query": { AllField:("Immersive Virtual Reality" OR "Virtual Reality" OR "Immersive VR") AND AllField:("Older adults" OR "Seniors" OR "Elderly") }

IEEE Explore (2010 - 2019). Last search date: 15 December 2019

("Immersive virtual reality" OR "Immersive VR" OR "Virtual Reality") AND ("Older adults" OR "Seniors" OR "Elderly")

Scopus (2010 - 2019). Last search date: 15 December 2019

TITLE-ABS-KEY (("Immersive virtual reality" OR "Immersive VR" OR "Virtual reality") AND ("Older adults" OR "Seniors" OR "Elderly"))

PubMed (2010 - 2019). Last search date: 21 December 2019

((("Immersive virtual reality" OR "Immersive VR" OR "Virtual Reality"))) AND ("Older adults" OR "Seniors" OR "Elderly")

Supplementary Information S2: – Design Considerations

The following considerations were extracted from the selected papers and kept in original.

1. Onboarding and Assistance

- *Application demo & tutorial*
 - **Ahmed et al., 2018:** Afterward psychologist demonstrated the use of the game. Elderly participants were shown down how interact with objects and GUI [...] During the training session, older adults were asked to read the instructions as presented by the application.
 - **Baker, Waycott et al., 2019:** 'First Contact' was chosen as it was specifically designed by Oculus to demonstrate the capabilities of the Oculus Rift system and included a tutorial that guided the user through the basic functions of the hand controllers, HMD, and tracking sensors.
 - **Bruun-Pedersen et al., 2016:** Participant was given time to acclimatize to the HMD visuals and asked to look around to showcase the orientation property.
 - **Coldham and Cook, 2017:** Each participant was then familiarized using a demonstration program that interactively introduced the componentry of the VR system by means of a Steam VR software package, the Steam VR Tutorial
 - **Eisapour et al., 2018a:** Task instructions were recorded as verbal guidance and played in the VR program. The instructions were read in a gentle, causal, and story-telling fashion.
 - **Ijaz et al., 2016:** The game starts with an in-game tutorial which describes the different game components.
 - **Ijaz et al., 2019:** To avoid confounding spatial navigation ability with the user's ability to use the technology, we implemented an introductory tutorial (5-min long). The tutorial provides a computer-synthesized voiceover for delivering the instructions for completing the task. This reduces the workload of the facilitator and enforces a level of consistency in the information received across participants.

- **Ouellet et al., 2019:** Prior to completing the memory VR task, participants were familiarized with the virtual devices using a different version of the convenience store.
- *Introduction to equipment*
 - **Baker, Kelly et al., 2019:** This highlights a core problem related to assisting users in VR as although there was a researcher present during the session to assist the participants, they have no way of seeing focal issues directly and must simply show the participant ways to adjust the focus of the HMD and trust they will find a suitable setting.
 - **Brown, 2019:** Participant was shown the VR equipment in appropriate detail: the headset (including the attached smartphone) and hand controller. They were encouraged to ask questions to ensure their understanding of how the device worked before trying it
 - **Coldham and Cook, 2017:** Participants were invited to try out their equipment during the interactive demonstration. The demonstration incorporated the various controlling buttons, trackpads, and visual elements of the equipment and lasted for approximately 4 minutes. [...] Many participants were hesitant to engage with the VR technology used in this study. The need for participants to touch equipment beforehand, as well as familiarize themselves with headset equipment, tethering cables, and hand wands seems justified.
 - **Howes et al., 2019:** Findings from user testing of Prototype 1, also suggested that a period of familiarisation was of benefit during the introduction of novel technology to older adults.
 - **Huygelier et al., 2019:** The HMD-VR group first received an explanation about the HMD-VR device and how they could interact with the virtual environment
 - **Kovar, 2019:** The problem was that she has also the anxiety of using things which she is not familiar with. Therefore, in the beginning of the VR therapy, we had to give her extra time to get used to Samsung Gear VR device.
 - **Micarelli et al., 2019:** The patients were specifically trained in the clinic at the beginning of the protocol by an otoneurologist with expertise in HMD implementation.
- *Researchers presence throughout the experience to assist*
 - **Ahmed et al., 2018:** In practice session they could ask for the help and receive help from the psychologist directing the game but during the test session they were only allowed to ask and obtain the info regarding to use of the interface and no additional assistance.
 - **Baker, Kelly et al., 2019:** There was a researcher present during the session to assist the participants
 - **Ijaz et al., 2019:** Allow the user to have multiple controlled, momentary stops during the interaction so that users can seek support from the test facilitator.
 - **Huygelier et al., 2019:** Assistance could take the form of reminding participants what they could do in the environment, explaining participants how they could perform actions with the touch controllers, and manually assisting participants to execute these actions.
- *Assistance with equipment use*
 - **Bruun-Pedersen et al., 2016:** The researcher would place the participant's hands and feet on the handlebars and pedals of the manuped while verbally informing the participant of these actions.
 - **Ijaz et al., 2016:** Participants were assisted into the recumbent trike and the VR headset.

2. Safety

- *Researchers presence to ensure safety*
 - **Benham et al., 2019:** Immersive VR may present with adverse reactions and it is thus recommended that the VR system is used with adequate monitoring and supervision when used with older adults.
 - **Brown, 2019:** A member of the research team was always next to the participant to ensure safety.
 - **Eisapour et al., 2018a:** All tests were supervised by two trained therapists to ensure the safety and wellbeing of participants.
 - **Eisapour et al., 2018b:** (To ensure safety) An exercise therapist was in the experiment room during all sessions.
 - **Janeh et al., 2018:** Experiment involved walking but an assistant made sure participant is not tripping onver wires.
 - **Howes et al., 2018:** Close supervision was required to ensure safety for both study conditions, particularly during the VR headset study condition.
- *Having seated experience*
 - **Ahmed et al., 2018:** Playing the game while sitting on revolving chair to enjoy complete 3d environment view in VR.
 - **Benham et al., 2019:** Games requiring standing and movement were eliminated for safety. [...] Participants were reminded to remain seated throughout all sessions for safety, except one participant who attempted to engage in the activity while standing.
 - **Brown, 2019:** Each participant sat in a cushioned, swivel chair [...] None of the participants expressed that they felt physically unsteady while seated.

- **Eisapour et al., 2018b**: For safety concerns, participants were seated during each session to avoid falling.
- **Howes et al., 2019**: Many expressed that they would prefer completing the exercises with a chair for support, to improve their confidence in performing the exercises.
- **Huygelier et al., 2019**: The participants remained seated at all times [...] It is known that HMD-VR affects dynamic balance in young adults without balance disorders, making it likely that HMD-VR health applications for older adults may best be developed to be used in a seated position.
- *Stable movement platform (e.g., cycling, treadmill)*
 - **Ijaz et al., 2016**: It starts with a recumbent tricycle, which provides a safe, stable platform for physical exercise, and exerts minimal strain on the user's back.
 - **Kim et al., 2017**: Participants walked on the treadmill at the speed that was measured during the 10 m walk test to determine if they were comfortable using this speed for the duration of the treadmill trials.
- *Minimising the risk of overreaching*
 - **Baker, Waycott et al., 2019**: To minimise the risk of overreaching, researchers carefully positioned participants' wheelchairs at the beginning of each session to be in the centre of the tracking space in order to minimise the reaching that would be required.
- *Promote a sense of stability*
 - **Brown, 2019**: The chair had arms to promote a sense of stability.
- *Using exercise mats to avoid fall*
 - **Baqai et al., 2019**: The game is executed in a safe environment (with exercise mats placed in order to prevent the user from harm in case of a fall).
- *Enable participants to use their own walking aid for hand support*
 - **Howes et al., 2019**: Enable participants to use their own walking aid for hand support where required

3. Embodiment

- *User's relative height is calculated to set the game area*
 - **Baqai et al., 2019**: At the start, the user's relative height is calculated using coordinates of head and feet returned by Kinect. This is then used to setup the game arena accordingly [e.g. where the fruits on the trees are so the user can pick them up].
 - **Hodge et al., 2018**: Paid attention to the altitude of where the participant is in the environment. [...] We carefully planned the design of the environment in relation to the field of view of the participant. A key aim for us was the content to be easy for the participant to view.
- *Can see your own body parts such as arms in VR*
 - **Baqai et al., 2019**: The environment is such that if a user looks down or extends his arm outwards in front of him, he can actually see the avatar, giving it a unique VR effect.
 - **Korsgaard et al., 2019**: They were only able to see their own hands and food and not those of their meal partners.
- *Implement natural navigation mode to increase sense of presence*
 - **Ouellet et al., 2019**: It has been shown that sense of presence is higher for natural navigation mode, such as real walking.
- *Use tunneling technique to reduce risk of motion sickness*
 - **Sakhare et al., 2019**: To reduce the likelihood of nausea during locomotion, a technique known as tunneling was employed each time the virtual bike encountered an intersection requiring a turn.

4. Visuals

- *Familiar and interesting scenes*
 - **Brown, 2019**: To provide an assortment of scenes that were likely to be familiar to each participant.
 - **Bruun-Pedersen et al., 2016**: The four VEs were designed by a set of governing guidelines for a structured approach to the recreational, nature-based experience of a trail-based exploration in VR.
 - **Eisapour et al., 2018a**: The farm was selected as it is familiar and interesting for most of the residents, is gender-neutral, and has a variety of activities that can be simulated. [...] Regarding the environment to implement the motions, we followed the therapists' recommendation to use a calm place that is enjoyable for most residents.
 - **Eisapour et al., 2018b**: A rural environment with a minimum number of objects to enhance familiarity and reduce the possibility of distraction to unwanted objects in the scene.
 - **Huygelier et al., 2019**: The environment is artificially made, but the scenes look natural and familiar (e.g. mountain, lake).
 - **Mol et al., 2019**: As familiar environments can have great emotional value for the elderly population [15], we tried to depict the living room with 3D models of classic and antique furniture.

- **Yang, 2019:** Game scenes can be designed as a natural environment.
- *Use minimum number of objects to avoid distraction*
 - **Eisapour et al., 2018a:** Following the simplicity principle, we decided to only present a minimal number of objects in each activity to reduce cognitive workload.
 - **Eisapour et al., 2018b:** A rural environment with a minimum number of objects to enhance familiarity and reduce the possibility of distraction to unwanted objects in the scene.
 - **Ijaz et al., 2019:** Designing for simplicity should consider reducing interface features to the minimum necessary for the task.
- *Activities that are enjoyable, relatable, and meaningful*
 - **Eisapour et al., 2018a:** The planned motions can be implemented as intuitive, meaningful, and interesting activities.
 - **Ouellet et al., 2019:** Simulating a meaningful and common day-to-day situation: shopping for common items in a convenience store.
- *Use of colour: simple, vibrant, contrasting*
 - **Ahmed et al., 2018:** (GUI) the simple and vibrant colors are used with the different attractive GUI animation.
 - **Süzer and Olguntürk, 2018:** Elderly people's abilities to distinguish unsaturated colours deteriorated gradually especially for cool hues, therefore, providing high levels of contrast for elderly people is crucial to enhance visual function.
- *Objects with proportional geometry scale to provide a sense of spatial stability*
 - **Lecavalier et al., 2018:** The environment was a small convenience store built using the same dimensions as the assessment room.
 - **Mol et al., 2019:** Objects that compose the environment were created with proportional geometry scale provides a sense of spatial stability and makes the scene elements easily understandable.
- *Navigation aid, e.g. map and compass and large map*
 - **Ijaz et al., 2016:** An onscreen compass and map point out locations of various landmarks they can cycle to, which might give them an idea of where they are. [...] Players are assisted by a compass bar across the top of the screen, and a large map that can be viewed simply by looking down.
 - **Ijaz et al., 2019:** These include distance covered, time spent, a compass bar for assisting orientation, and a white indicator to point users to the locations they can go to.
- *Avoid rotating actions*
 - **Hodge et al., 2018:** If we placed moving objects into the environment, we did not want the user to be rotating to follow the objects as this could cause them to feel sick [...] To further reduce risks of sickness or disorientation, we implemented a higher frame rate and used anti-aliasing.
- *Object positioning matched with capabilities*
 - **Eisapour et al., 2018a:** There was a considerable difference in residents' range of motion (ROM) capabilities. Customized object location is needed to avoid frustration, enable people to achieve their goals, and ensure that every user can benefit from an appropriate level of stretching. [...] Keep visual targets within the front field of view. Avoid searching that requires head motion.
- *360-degree immersion*
 - **Lecavalier et al., 2018:** For immersion, allowed the participant to rotate his/her head in a 360-degree view around the room, as well as look up and down, and interact and walk freely in the virtual environment.

5. Audio

- *Ambient sounds*
 - **Hodge et al., 2018:** Environments were completed with a set of ambient sounds: i.e., wind, waves crashing, and birdsong.
 - **Lecavalier et al., 2018:** Irrelevant conversations were presented via the headgear in order to mimic a noisy environment.
 - **Ouellet et al., 2019:** Ambient verbal noise – a conversation between two customers – was presented dichotically through the HMD during the whole task. This was done to increase the ecological validity of the task by reproducing a task completed under distracting conditions.
 - **Sakhare et al., 2019:** Prior to the last task, a choice of music was provided, as music has been shown to be the most important factor associated with enjoyment of exercise (Wininger and Pargman, 2003).
- *Audio feedback*
 - **Baqai et al., 2019:** Successful collection of the fruits is indicated by sound to the user
 - **Ijaz et al., 2016:** There are also audio cues that indicate when landmark is nearby and when a wrong guess is made.
 - **Liao et al., 2019:** In the VR context, participants would imitate the virtual character and adjust their movements based on the simultaneous visual and auditory feedback.

- **Yang, 2019:** Sound effects can achieve effects such as situation shaping, feedback experience, and action perception.
- *Audio instructions*
 - **Eisapour et al., 2018a:** Provide verbal instructions that bring users into the scene and task, in a gentle, casual, and storytelling fashion.
 - **Eisapour et al., 2018b:** We added verbal (pre-recorded) scenario-specific instructions that played over the earphones to guide users in each task.
 - **Ijaz et al., 2019:** The tutorial provides a computer-synthesized voiceover for delivering the instructions for completing the task. This reduces the workload of the facilitator and enforces a level of consistency in the information received across participants.
- *Spatial audio*
 - **Baker, Kelly et al., 2019:** Several participants commented that they were not aware of the direction of the speaker's voice, despite the prototype employing spatial audio software.
 - **Mol et al., 2019:** Spatial audio technology was also used to provide a sense of where sounds are coming from in 3D space.

6. Realism

- *Authentic tasks*
 - **Coldham and Cook, 2017:** Authentic tasking [...] To test the usability of VR under authentic scenarios [...] There was strong post-experience agreement with the idea that an authentic task such as interacting with Google Earth virtual reality maps held value for elderly people.
- *Human-like manner avatars*
 - **Baker, Kelly et al., 2019:** Behavioural anthropomorphism, which encompasses their avatars' ability to speak, move, and act in a human-like manner in social VR.

7. Personalization

- *Familiar elements*
 - **Hodge et al., 2018:** [Personalized VR for one participant] a concert hall with her favourite singer performing onstage.
 - **Ijaz et al., 2016:** Social interaction should be limited to people that are already well known
 - **Mol et al., 2019:** We opted for a simple and comprehensible story to facilitate the contextualization of the elderly player [2]. Through pre-recorded voice dialogues, the girl or granddaughter talks to the player.
 - **Mol et al., 2019:** The game environment lies within the living room of grandparents' house and has a decoration more focused on the 60s and 70s.
 - **Mol et al., 2019:** Young avatars can be more believable and attractive to the elderly audience, appearing to them adorable, innocent and also making them remember their own children or grandchildren [17].
 - **Yang, 2019:** The reason why the game is based on Little Red Riding Hood is because the seniors are familiar with this story, and because the image of Little Red Riding Hood is a child, it will be more intimate for the elderly
 - **Yang, 2019:** The oldest songs can be used in the music selection of the game. It is best to be familiar with the songs of the elderly.
- *Pick applications based on participants' interests or needs*
 - **Baker, Waycott et al., 2019:** All other software was chosen during the study to respond to specific participants preferences or needs.
 - **Benham et al., 2019:** Games were continuously downloaded throughout the study as the researcher learned of participants' occupational interests.
- *Customizable platform*
 - **Ijaz et al., 2019:** The platform should be customizable to accommodate new memory test protocols with personalized features.
 - **Ijaz et al., 2019:** The joystick controller's speed and interaction with VR environment were made slow to match common competencies of the aged participants; these may have to be adjusted for visitors in clinics, particularly those with musculoskeletal complaints or neurodegenerative diseases that limit movement or are characterized by tremor such as Parkinson disease. Simultaneously, it is possible that users with better computer skills may find the design not matching their competency level and experience disinterest.

8. Usability

- *UI should be simple, intuitive*
 - **Eisapour et al., 2018a:** A guiding premise is that the interface should be designed to be as simple and intuitive as possible to minimize users' workload on attention, comprehension, memory, and motor systems, as these are generally impaired for older adults.
- *Using large fonts, large objects, signage (proper labels)*
 - **Ijaz et al., 2019:** Taking elementary usability considerations into account such as larger font and object sizes, we also designed the interface by identifying and incorporating guidelines for older users.
- *Getting feedback about game design*
 - **Howes et al., 2019:** Images of screen grabs from the game were shown to the users in small groups of 2–3, and they were given the opportunity to provide feedback on their perceptions of the game design, colours, clarity and ease of reading of the text.
- *Use haptics as a form of feedback*
 - **Eisapour et al., 2018a:** It was also recommended to add vibration on hand controllers as feedback to inform the completion of an action.
- *Confirm user selection with virtual pointers*
 - **Ouellet et al., 2019:** Virtual pointer [...] To avoid errors by accidentally pressing the button, the participant is asked to confirm the selection by pressing a validation button [...] It was appropriate to implement a two-step response strategy (select then validate) in the VR task, regardless of the participant's age.
- *Avoid multiple menu navigation*
 - **Brown, 2019:** The VR software was already cued to the primary screen that showed the menu of the study's video options. This was done so that the participant would not have to navigate through the various prerequisite menus. (This consideration surfaced in a pilot study conducted by the principal investigator [PI] the prior year, as many of older adults encountered challenges with navigating multiple menu options).
- *Minimizing the use of controller*
 - **Eisapour et al., 2018b:** All the interactions with objects in VR were conducted by hand and head motions without the need to press any buttons. Interaction with virtual objects without needing to push any buttons is highly recommended for PWD to match their learning and workload capacity.

9. Engagement

- *Game levels with increasing difficulties*
 - **Ijaz et al., 2016:** This game has four levels, which increase in difficulty as the landmarks become less well-known and more distant from each other.
 - **Plechata et al., 2019:** The vSST had four consecutive levels of increasing difficulty.
- *Offer rewards*
 - **Sakhare et al., 2019:** To optimize engagement and motivation, participants were asked to select a reward after the 1st, 2nd, and 3rd conditions. This included the selection of a basket to go on the virtual bike, an animal companion to ride in the basket, and a song genre to listen to while riding.
 - **Yang, 2019:** more tasks are achieved, more beautiful scenes will be opened.
- *Making realistic and activity-based game*
 - **Ahmed et al., 2018:** Game should be very realistic, and activity based. Activity describes their action, tools, goals and impact on user.

10. Minimizing Side Effects

- *Minimizing stress*
 - **Ahmed et al., 2018:** Time is very important factor and give pressure to elderly while playing a game, so in our game very fair and lot of time is running out for every task.
 - **Ijaz et al., 2019:** To achieve a sense of control and avoid stressful interaction, the system should be optimized to provide users with a sense of autonomy and choice.
- *Avoid over-exertion*
 - **Ijaz et al., 2016:** We need to be careful that players do not over-exert themselves, so the contest is not a race [...] Both modes require physical effort to move about the environment, but neither punish players for taking a relaxed pace.
 - **Yang, 2019:** Try to make sure that the game time is not too long, and you need to give the seniors a break [...] meditation room for player to rest temporarily.
- *Motion that is under control of the observer*

- **Huygelier et al., 2019:** We used an HMD-VR application with motion that is under control of the observer to minimize the chance of observing certain cybersickness symptoms.
- *Check if the users are ok*
 - **Bruun-Pedersen et al., 2016:** During sessions, participants were asked casually into their experience (for example “how do you feel” or “how is it (the HMD) to wear”). While this could very well result in a break in presence, it was deemed necessary to make sure that participants did not involuntarily sustain their involvement while experiencing VR sickness.
- *Explaining transition to put participants at ease*
 - **Eisapour et al., 2018a:** The research team took care to clearly describe what was happening so the participants could feel more at ease, particularly with transitions.
- *Familiarization to reduce anxiety*
 - **Kovar, 2019:** The problem was that she has also the anxiety of using things which she is not familiar with. Therefore, in the beginning of the VR therapy, we had to give her extra time to get used to Samsung Gear VR device.