Validation and Implementation of Virtual Reality Serious Game for Spatial Orientation Training of Older Adults with Dementia

by

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Abstract

This thesis explores the development and evaluation of a serious game in virtual reality (VR) for neurorehabilitation and its associated challenges such as cyber sickness (CS) and benefits including the environmental and behavioral factors affecting motivation and satisfaction in rehabilitation gaming.

The VR environment chosen for neurorehabilitation was a Barn Ruins environment with an embedded game scoring to be used for neurorehabilitation. The study's objectives included designing an error-based scoring system for Barn Ruins, validating its cognition sensitivity, assessing its potential as a rehabilitation tool through an intervention study, analyzing longitudinal CS data, and identifying factors that influence older adults' motivation and satisfaction when engaging with serious games.

The Barn Ruins scoring system was found to be suitable for older adults, as it was unaffected by prior experience with gaming controllers. The game score showed a moderate negative relationship with age and a strong positive correlation with Montreal Cognitive Assessment (MoCA) scores. The intervention study revealed significant improvements in spatial learning scores over eight weeks, particularly on challenging routes.

Longitudinal analysis of CS data, spanning 14 years, highlighted age, female sex, and a history of motion sickness as significant predictors of CS susceptibility. Immersive VR environments were more likely to induce CS compared to non-immersive ones, and the use of detailed symptom-reporting methods, such as the Symptom Simulator Questionnaire (SSQ), suggested a potential nocebo effect.

Motivation and satisfaction in rehabilitation gaming were examined through the Unified Theory of Acceptance and Use of Technology (UTAUT) and Cognitive Evaluation Theory (CET). Tailored game design, autonomy, positive interactions, continuous feedback, and community engagement were identified as key factors enhancing user experience.

This research demonstrates the potential of VR-based serious games such as Barn Ruins as a neurorehabilitation tool and offers valuable insights into designing serious games that optimize engagement, minimize cybersickness, and support cognitive rehabilitation.

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Dedication

To my friends and parents who kept me sane through the journey,
and to my younger self—
you did it!

Contribution of Authors

This thesis is a “sandwich thesis” consisting of five individual manuscripts. At the time of final revisions (August 2025), the following is the status of the manuscripts:

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Ms. Rashmita Chatterjee was the first author of all the manuscripts presented in this thesis. Ms. Rashmita Chatterjee's contribution to this thesis includes forming the research questions, developing the virtual reality serious game, designing the experiments, collecting data, data analysis, writing the manuscripts and responding to reviewer's comments. Mr. James Teschuk and Ms. Ashley Verot contributed to the data coding part of processing the data and Dr. Sumeet Kalia contributed by providing statistical analysis feedback and editing the manuscript presented in Chapter 5; Dr. Kerstin Roger contributed to the development of the research concept and editing the manuscript presented in Chapter 6; Dr. Zahra Moussavi contributed to the conception and design of the research in this thesis, providing the longitudinal data presented in Chapter 5, and editing all the manuscripts.

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List of Abbreviations

AD	Alzheimer's Disease
CS	Cybersickness
HMD	Head Mounted Display
MADRS	Montgomery-Åsberg Depression Rating Scale
MCI	Mild Cognitive Impairment
MoCA	Montreal Cognitive Assessment
SCT	Spatial Cognition Training
SPA button	See Path Again button
VR	Virtual Reality
VRN	Virtual Reality Navigation

Chapter 1. Introduction

Fifty-five million people are currently living with dementia worldwide and the rate of increase in the number of cases is at an alarming 10 million per year. The World Health Organization (WHO) has reported that people over 65 make up 91% of the patient demography [1]. Dementia symptoms include topographical disorientation [2] and spatial impairments [3] from its earliest stages. For older people this is one of the main causes of dependency and disability and dementia impacts physical, psychological, social and economic aspects of not only the dementia patients but also of their family, care givers and on a broader scale society at large [1]. With the increase in mortality rates worldwide and no cure for the disease [4], there is an urgent need for interventions that can help slow down disease progression. This would allow older adults living with dementia to enjoy autonomy and avoid institutionalization for longer. Serious games and game therapy have been found to be quite useful for this purpose [5].

Serious games are any games that have a primary educational purpose before the secondary purpose of leisure and entertainment. Unlike traditional cognitive training, which may feel repetitive and disengaging, serious games provide an immersive and interactive way to stimulate cognitive functions while keeping people motivated [6]. Studies have shown that engaging in game-based interventions can enhance memory, attention, and problem-solving skills in people living with dementia [7–9]. By leveraging gamification principles, serious games can offer a structured yet enjoyable approach to rehabilitation, making them a promising avenue for cognitive interventions in dementia care.

1.1 Serious Games for Rehabilitation

Serious games for dementia care have evolved from board games to video games and virtual reality. A few board games such as Checkers, Abacus, Poker, Chess, Go have been claimed to improve cognitive abilities of dementia patients [10]. However, board games have space constraint and there is a considerable amount of randomness involved, which does not make it ideal for intervention purposes. Video games do not have this problem as they can be made to have a set goal and specific actionable tasks to achieve the goal. The proposition of using video games as serious games is based on the fact that video games are fun to play and require the use of different cognitive functions [11, 12]. However, there is a difference between the two. A serious game can be distinguished by the fact that the main aim of the designer in this case is to integrate a training objective into the game scenario [13]. It is critical to design serious games focusing on the specific needs of MCI and AD patients. For this, it is necessary to take into consideration the recommendations made in [14] to improve the human-computer interaction and another 'Game' component which is typical of serious games [13].

Compatibility, as stated in [14] necessitates considering the target populations' cognitive and behavioural characteristics and that testing should be done on the same population to check the ergonomic choices they are making. Real time *guidance* needs to be provided along with simple and readable feedback [14]. The number of game commands (max 6) and motor actions that monopolize *workload* should be limited and the amount of information on the interface should be kept to a minimum of necessary items [14]. *Adaptability* to different pathology profiles can be created by using difficulty levels and for stimulation of progressive intensity [14]. The user interface should be kept *consistent* [14] and commands, images and messages that are "familiar enough" to be understood easily need to be used. Challenges adapted to stimulate the cognitive functions targeted by the serious game have to be chosen. The term "challenges" has been used in the "Gampelay bricks" model [15]. This model defines a game challenge to be a combination of a goal ("brick game"): *Avoid*, *Destroy*, *Match*, *Create* and, the action to achieve this goal ("brick play"): *Shoot, Move, Manage, Randomize, Write, Select*. By permutation there are 24 game challenges where each challenge corresponds to an entertainment rule. The type of game will depend on the type of challenges combined. The paper in [13] recommended not to employ multiple challenges in a serious game for people with MCI and AD.

According to the definition of a serious game, there are three marketed standard serious games that have been tested on the target population of patients with Mild Cognitive Impairment (MCI) and early to moderate stages of Alzheimer's Disease (AD): MINWii (on Nintendo® Wii™) [16], Kitchen and Cooking (on tablet) [17] and X-Torp (on Microsoft® Kinect™) [18] which are based on playing a virtual keyboard, looking for ingredients and cooking and action-adventure, respectively. The paper in [13] describes these games in the context of the Gameplay bricks model and design recommendation factors like workload. For example, the X-Torp game had three challenges and players had to remember seven commands to navigate, making it a complex game for people with MCI and AD. The Kitchen and Cooking game had two challenges, and two types of actions players had to memorize, which would be easier for the MCI and AD population. The main objectives of these games were to increase positive emotions, stimulate cognitive functions and physical activity. For this thesis, the focus was on developing a serious game specifically for spatial cognition training instead. Unlike MINWii, Kitchen and Cooking, and X-Torp, this game emphasizes navigational challenges tailored to support spatial memory and orientation, which are crucial in the early stages of Alzheimer's Disease.

The design philosophy of the spatial game developed in this thesis incorporated key recommendations described above, shaping the core mechanics of the game. The spatial game had a route repetition task to a target room. It has one challenge according to the Gameplay bricks model- *Move* to *Match* which makes it ideal for MCI and AD population. The movement in the game was consciously kept minimal with joystick-like action so that the workload was low. Compatibility was checked with a usability test amongst the same population and the user interface was kept consistent with large fonts and text rather than symbols for easy understanding.

1.2 Virtual Reality

Virtual reality (VR) games are ones where a virtual world is created that can provide players audio, visual and sensory feedback like being present in the real world [19, 20], through motion sensing, tracking and so on. With the continuous developments taking place in the areas of VR and haptics, virtual reality based serious games for rehabilitation is gaining traction.

3D images are used to create the life-like and believable environments. To quantify the level of immersion a player feels in an environment, the term presence is used, which is defined as the sensation of being involved in a scene. This immersion level is heavily influenced by the VR technology's interaction paradigm. A computer display with decent computer graphics falls under non-immersive VR environments. If the computer display is much bigger, like projection screens, then it is known as a semi-immersive VR environment [21, 22]. Lastly, a fully immersive VR environment is one where the player's entire visual field is filled by the virtual environment and where actual movement of the head is replicated virtually [23] like using a head-mounted display (HMD). HMDs can be integrated with multiple tracking devices like HTC Vive [24] for different body parts for a more complete immersion.

1.3 Spatial Cognition Training

Spatial Cognition Training (SCT) plays a significant role in the rehabilitation of mild cognitive impairment (MCI) as spatial cognitive impairment can be seen in the early stages of MCI [25–27]. The training mode should be such that the subjects feel a strong sense of participation and the content should be closely related to their daily lives [28], so that there can be an easy translation of acquired skills. SCT performance in two dimensions are not similar to the requirements of everyday life, thus inducing low ecological validity of the training. For this reason, SCT needs to be implemented in three dimensions [29, 30]. Training with virtual reality based serious games meet the requirements and social needs of subjects and can be used as a way of SCT [31–33].

Over the years, there have been numerous studies and VR environment designs for spatial cognition evaluation and assessment for MCI and Alzheimer’s in the form of path learning [25, 34] and relocation tasks [35] and in various environments like virtual apartment [36], virtual city [37], virtual supermarket [33], virtual building [38, 39] to name a few. Comparatively, the amount of research in the cognition training aspect is scant.

There are a few neurorehabilitation studies for AD and MCI like a fruit harvesting game [40] to assess whether VR can engage motor and postural abilities of MCI patients, a virtual building navigation game [27] to study human navigation in a landmark-less and symmetric three-story, a virtual environment where functional real world tasks needed to be executed [41], a driving simulator [42], a racing game [43] to assess vestibular rehabilitation with VR. Out of these only the driving simulator and building navigation game are related to SCT.

Path integration in our daily lives involves functions like updating the distance, representing the speed, and updating our self-movement [44]. This would be easier to replicate with fully immersive technology as players can move about and HMDs track the movement and convert it into virtual movement. Hence, training with immersive VR has greater ecological validity. However, HMDs can also cause cybersickness in older adults [45, 46]. Hence, we did not use an HMD for the navigation game studies as our target population was older adults. We used a laptop screen for viewing the environment and used a gaming controller to move in the environment, which allows for game interaction and also involves idiothetic cues which helps with spatial learning [47].

In neurorehabilitation of people with AD and MCI, the focus has mostly been on physiotherapy, vestibular and real-world task practice [40, 43, 48]. There are only a few studies SCT as discussed above; hence, more research is needed on this topic. The reason for developing a new navigation game was to have a game that would be enjoyable for regular use and that uses gadgets that are easily accessible, and easy to use for people with MCI and AD. This is crucial for the serious game to be used as a neuro-rehabilitation tool outside the research environment.

1.4 Software and Hardware for VR

The virtual environments are designed and created on software known as game engines like Unity. A game engine has some basic key components like rendering, animation, collision detection between objects, physics, loading, graphical user interface, artificial intelligence and sound [49, 50], which are used for developing a game and essentially are the building blocks. This helps novice game developers to create games efficiently without having to know all the detailed workings of these building blocks and hence saving a lot of time. The fact that developers can focus on creating a story and aligning it to their goal, while only applying few necessary modifications to the already available software to correspond with the properties of their game, furthers the aim of interdisciplinary research like the one in discussion where a game needs to be developed for rehabilitation of AD patients.

For virtual environment to feel fully immersive, a head mounted display (HMD) is the most commonly used device. With developments in VR technology, there are many advanced and low-cost HMDs in the market which provide an increased field of view (FoV), higher resolution images, surround sound and lightweight comfortable design. All of this has improved the immersion level of virtual environments and caused the now widespread use of VR [51]. Oculus is a great example of such a product that has other unique features like minimum latency, state-of-the-art texture rendering technologies, head tracking system consisting of accelerometers, gyroscopes and magnetometers [52], all adding to an improved immersive experience. With the latest smartphones having in-built gyroscope technology, the phone itself can be used as a VR system, making the world of virtual games even more affordable and consumer friendly.

1.5 Cybersickness

The biggest drawback of VR, for which a proper solution hasn't yet been found, is cybersickness (CS). It is when a user experiences the symptoms of motion sickness that include but are not limited to eye fatigue, disorientation and nausea and, hampers the VR experience [53]. We perceive orientation and self-motion in three-dimensional space by information received from visual, proprioceptive and vestibular senses [54]. When all these inputs are synchronized, there is no problem, but when a person repeatedly receives conflicting sensory information from different sources and it is different from their expectations, it causes motion sickness [55]. Moving stimuli can also be the cause of motion sickness and when vision is the dominant sensory information being received then the sickness is termed as visually induced motion sickness (VIMS) and depending on the context it can be gaming sickness, cinema sickness or CS [56]. Many studies have claimed VIMS maybe related to vection- the perception of self-motion [57, 58]. To provide high levels of immersion, visual information is provided in such a way that the user may feel like they are moving without any or minimum vestibular input and no actual movement, which causes a higher degree of CS.

CS can be caused due to numerous factors like hardware (display type, input type, latency, FoV) [59–62], contents of the VR media (speed and visual details) [63, 64], duration [65], controllability of the content [46], and human factors like age, sex, health problems and susceptibility to motion sickness [66]. In Chapter 5, we discuss the factors we found to influence CS from longitudinal CS data collected by our lab.

1.6 Motivation and Satisfaction of Playing Serious Games

If the target population, i.e. people with MCI or AD, do not like playing the game, they will not be motivated to play the game regularly, which would defeat the purpose of the serious game. Hence, satisfaction and motivation to continue playing the game in the future are parameters through which we can quantify the success of a serious game for dementia care [67, 68]. Motivation to do an activity like going in to work every day comes from extrinsic factors like financial gain. In playing video games regularly such extrinsic factors are missing so a different source of motivation needs to be investigated. The self-determination theory focuses on intrinsic motivation [69]. Intrinsic motivation is based on the inherent satisfaction derived from action. This intrinsic motivation is the main type of motivation underlying play, and it is also relevant to playing video games. In Chapter 6, the factors that influence intrinsic motivation and satisfaction in older adults playing rehabilitation serious games are discussed.

1.7 Objectives

The goal of this study was to develop and investigate the use of a VR spatial navigation game, called Barn Ruins herein, as a neurorehabilitation tool to investigate the factors influencing CS when playing and to gain a comprehensive understanding about the environmental and behavioural factors that affect motivation and satisfaction in playing rehabilitation games.

The specific objectives of this study were to:

1. design a spatial navigation game (Barn Ruins) with an error-based scoring system.
2. validate the error-based scoring system of Barn Ruins and evaluate its cognition-sensitivity.
3. investigate the Barn Ruins' potential as a neurorehabilitation tool by conducting an intervention study.
4. analyze longitudinal CS data to identify the most important factors influencing the susceptibility to CS.
5. collate observational notes from experience of tutoring and implementing serious games to understand the factors that affect the motivation and satisfaction of older adults while playing serious games.

1.8 Report Organization

This report is divided into seven chapters including this introductory chapter which describes background, related studies and the objectives of the thesis. Chapter 2 describes the development and scoring system of the Barn Ruins in detail. This research allows to move forward to Chapter 3, discussing the Barn Ruins validation study while Chapter 4 concludes the

Barn Ruins research by outlining the intervention study conducted on Barn Ruins. Chapter 5 moves into the main side-effect of playing VR games- CS. 14-years of CS data from conducting spatial studies was analysed to investigate what factors influence the susceptibility to CS. In Chapter 6, an observational approach along with findings from literature is used to investigate the factors that influence the motivation and satisfaction of older adults while playing serious games are discussed. The last chapter, Chapter 7 summarizes the findings and suggested future work.

Each manuscript has been included verbatim, preserving its original content. To avoid redundancy and improve readability, all references from the individual chapters have been compiled into a single reference list at the end of the thesis.

Chapter 2. Development of a Novel Virtual Reality Serious Game

Development of a Novel Virtual Reality Serious Game with Age Sensitive Measurement for Spatial Orientation Training

Rashmita Chatterjee and Zahra Moussavi

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Abstract

When designing a cognitive serious game for older adult, it is also equally important to design a cognitive sensitive measurement. A significant number of previous studies in this era have formulated measurements with time and distance traversed in virtual environments. Both these parameters are susceptible to decline in motor skills that come with normal aging. Hence, they may not the best parameters for cognitive assessment among older adults. In this pilot study we developed a novel virtual environment and used the concept of error measurement from our lab's previous study to come up with a new formula specific to this game for assessing spatial orientation in young and older adults. The spatial measure formula is compared with the measure of traversed distance by its power to predict participants' age. The game and its proposed spatial measure formula was evaluated using data from 10 healthy young participants (21- 39 yr old) and 10 older healthy older adults (60-79 yr old). The participants' cognitive status was tested by the Montreal Cognitive Assessment (MoCA). The results show that our proposed spatial error measurement has a medium strength correlation with age (more than that of traversed distance), which can be attributed to normal aging. Thus, while it is age sensitive, it is not affected by experience of playing video games in general. A See Path Again help button was used in the game, usage of which showed that some paths were easier to retrace than others; that might be because no mental rotation was involved in those paths.

2.1 Introduction

Pathfinding is an important skill that falls under instrumental activities of daily living (iADL) skills, i.e., transportation, handling finances, cooking; iADL is one step above Active daily activities (ADL – e.g., basic daily activities such as self-hygiene and self-care) in terms of cognitive complexity. iADL encompasses activities that allow one to live independently. Spatial navigation plays a crucial role in path finding. However, it has been shown by multiple studies that spatial navigation ability declines with age even in healthy older adults [70–76]. Spatial navigation is divided into egocentric and allocentric strategies based on the type of information recruited while remembering the space and the path. Egocentric strategy is referenced from self with set directions and distances to the goal; allocentric strategy relates the location of the goal to visual cues (e.g., a pattern on a wall, a landmark on the route). Both strategies are used during navigation, and studies have investigated how the strategies are affected by age [3, 71, 77–80]. With advancing computer technology, recent navigation studies have designed virtual environments on computer screens instead of performing the study in a real environment. Although a recent study has shown that orientation in virtual reality (VR) environments does not fully measure up to the real-world [81], the common assumption in experiments using VR environments is that decision-making related to navigation in VR is mostly transferrable to the real world [82, 83]. Nevertheless, with advances in technology and reducing the effect of motion-sickness due to moving in a VR environment [62], it is anticipated that the performances in VR and real-world to be highly correlated and transferable.

There are different types of VR experimental designs. In some navigational strategy studies [78, 79] the participant only looked at a virtual environment, which was automatically moving on a screen. This form of interaction with the virtual environment is called passive navigation and has low embodiment. On the other hand, it has been shown that idiothetic cues combined with navigational cues have higher embodiment and help form virtual bodily representations, which has been shown to aid with spatial memory [47]. Several studies have designed VR environments, in which the participant has to move in the environment: either virtually using an input device (e.g., a joystick) [42, 84, 85], or even physically (in order to reduce motion sickness) [27, 86–88].

Despite the magnitude of the efforts, the specific component of updating directional information after transitional and rotational movement has not been studied widely. Our team has previously investigated this component by designing a landmark-less VR navigational environment (VRN) [89] and developed a novel accuracy-based error score [76] to assess egocentric strategy errors in aging population; the results showed a high correlation of the navigational error with age and cognitive ability; this correlation was higher than the scores based on the time taken and distance traversed. Building upon our team's past experiences, the goal of this pilot study was to investigate the relationship between navigational strategies in findings in a different virtual environment, while providing top-down as well as first-person views of the path first and then instruct the user to repeat the path; the ultimate goal of such design is to be potentially used for neuro-rehabilitation of individuals with mild cognitive impairment. We developed a novel VR environment as a serious game, which focuses on the following navigational components: (1) translation between allocentric and egocentric representations by showing the top view of the environment first and then first-person active navigation, (2) mental rotation by having the start of route in different places.

The developed VR environment was made to look bright and sunny as the ultimate objective of the game is to be potentially used for neurorehabilitation of older adults; thus, it should also be engaging and fun to be played. Although the game can be played in immersive mode, to avoid motion-sickness in older adults, in this study the participants saw the environment on a laptop screen and were able to move around in the environment using a gaming controller (a joystick). The controller provided the idiothetic cue in the game, making it highly embodied.

2.2 Methods

2.2.1 Participants

Ten younger adults (4 males, 26.8±5.27 yr old) and ten older adults (4 males, 65±5.6 yr old) participated in this study. All participants signed an informed consent form approved by the Biomedical Ethics Board of the University of Manitoba. Five out of the ten younger participants and two out of the ten older participants had used a controller before. Montreal Cognitive Assessment (MoCA) [90] was conducted on all participants. MoCA scores were in the range of 26-30 (out of 30) amongst all participants, which imply all participants were cognitively healthy. Nevertheless, the median score of 28 was used to investigate the differences among high-MoCA scores (28 and above) and medium-MoCA scores (below 28) irrespective of age.

2.2.2 Game Environment

The goal of the game is path finding and learning the way from the starting entrance to the target room, which has a treasure chest inside the room. The VR environment consists of two regions. As depicted in Fig. 2.1a, one region is rectangular with a symmetrical layout of six rooms and one entrance, and another square region with four rooms and two entrances; the second region is not symmetric in terms of rooms locations. That makes the total count of rooms and entrances to be ten and three, respectively. The two regions are joined by an arched opening. Moving around in the game environment is achieved by a gaming controller, where translation in all directions is achieved with the right thumb joystick, and camera rotation is with the left thumb joystick. In this study, the game was played on a laptop in non-immersive mode.

2.2.3 Procedure

The experiment was designed to have two demos to learn the visuomotor task of using the gaming controller, and then 9 trial runs. The demo and trial runs were similar other than the fact that for the trial runs, the performance data (trajectory of movements, and each visited room) was recorded. For each trial run, the route was chosen randomly by choosing one out of the three entrances as the start, and one out of the ten rooms as the target. The route for each trial was unique.

There were three difficulty levels: easy, medium, difficult. The difficulty level of the routes was assigned based on the number of turns in each route. The constraint was that each entrance (Ent1, Ent2, Ent3) needed to be chosen once with each difficulty level route. The target room in each of the routes was restricted according to the entrance and difficulty level as shown in Table 2.1. Each trial had one learning and one testing phases. In the learning phase the route was first shown from top-down view with a pink line (Fig. 2.1b); then, the participant was instructed to traverse the route in first person view by following the pink line and the treasure chest would be visible inside the target room (Fig. 2.1c). In the testing phase, the participant was instructed to traverse the same route but without the pink guiding line. The treasure chest would become visible only when the participant entered the correct room. In the testing phase the participant was given two help buttons if needed: “See the Path Again” (SPA) button, with which they could repeat the learning phase for the route, and the “Go back to Start” (GBS) button, with which they could go back to the start position of the route if they get lost, but still remaining in the testing phase (Fig. 2.1d). The SPA button could however be used a total of two times in each trial.

Table 2.1. Entrance to target room difficulty level matrix

Room no. ↓	**Entrance no. →**	**Ent1**	**Ent2**	**Ent3**
1		Easy	Difficult	Difficult
2		Easy	Difficult	Difficult
3		Easy	Difficult	Difficult
4		Easy	Difficult	Difficult
5		Medium	Medium	Medium
6		Medium	Medium	Medium
7		Difficult	Easy	Medium
8		Difficult	Easy	Easy
9		Difficult	Easy	Easy
10		Difficult	Easy	Easy

2.2.4 Game Scoring Rubric

Four parameters were considered for calculating the final score of each participant' performance: 1) number of times SPA button was used, 2) number of incorrect rooms entered (IR), 3) traversed distance in each of the trials, and 4) a parameter called "totally lost", when a participant gives up the trial or gets -4.5 or more on the IR parameter (which is a minimum of three rooms and a maximum of nine rooms according to the zone penalization matrix of Table 2.2 explained in the following paragraph).

The scoring mechanism is as follows. The SPA parameter is straightforward. In each trial the SPA button could be used a maximum of twice. If it is used once in a trial there is a score of -2.

For the second time of SPA, there is a score of -3. Thus, if a participant uses the SPA button twice in a trial, they would end up with a total score of -5 for that trial. There are nine trials in each game; therefore, the total possible score for the SPA parameter for the entire game is -45.

Depending on the route, the incorrect room entered could be one where most of the path was remembered correctly and the confusion arose at the last stage, or where the path was remembered halfway correctly or the participant completely forgot and went in the other direction. Based on this logic, the layout has been divided into four zones (Fig. 2.1a), where all the rooms in one zone correspond to rooms that could be mixed up most easily. For example, while going from Ent1 to room 1, it is very likely to mix it up with rooms 2 and 6 (in the same zone) but that would not be so bad as mixing it up with room 10 (Zone D) or room 5 (Zone B). Hence, a mapping is made of the zones (Table 2.2), from the zone that is least penalized to the zone that is most penalized. A negative score of an incorrect room (IR error) entered depends on which zone it lies in and how much that zone is penalized in a specific route. If the incorrect room is in the least penalized zone, a score of -0.5 is obtained, and if it occurs in the most penalized zone then score of -2 is assigned. For the two zones in between, the penalty scores of -1 and -1.5 are assigned, accordingly. If for any trial, the IR error score goes beyond -4.5, then the IR error value will be capped at -4.5 and not calculated for any further incorrect rooms and the "Totally Lost" parameter will be -0.5. Hence, in every trial a participant can get a total possible of -4.5 in the IR parameter and -0.5 in the Totally Lost parameter; thus, for the entire game a total possible of -40.5 in the IR and -4.5 in the totally lost.

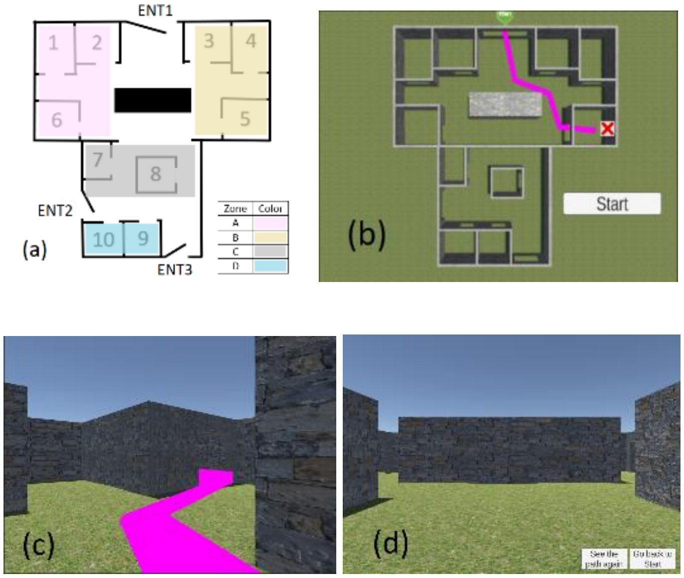

Figure 2.1 (a). The layout of the environment with 10 rooms and 3 entrances. It also marks the zones for scoring of the incorrect rooms parameter. (b). The top-down view at the start of the learning phase with the pink line to show the route. (c). First person view during the learning phase with the pink line to help guide participant to the target. (d). Screenshot of game during testing phase where the participant has to find their way to the target and has two help buttons at the bottom of screen for using when lost.

The game calculates and records the participant's traversed distance in each trial separately. Each of the 30 possible routes in the game has an ideal route distance taking into consideration the width of the corridors and widest turns at every corner. However, being unable to get a hang of the gaming controller can possibly increase the traversed distance in some trials even though a participant remembered the route and went to the correct room at the first try. Thus, a padding distance needs to be added to all the values. Considering the above overshoot distance due to unfamiliarity with game controller is important because the target audience for the game is older adults. During the game development, we tried the game on a few older adults (other than the reported participants in this study) and realized that some found it challenging to get accustomed to the controller within the first two demo trials. However, even though some of them struggled with it throughout the game, that did not translate into very varied distance scores from the ideal route distance.

Table 2.2. Zone penalizing rubric for incorrect room entered parameter

Starting door	**Zone in which target room is**	**Least penalized zone → Most penalized zone**			
Ent1	A	A	C	D	B
	B	B	C	D	A
	C	C	D	A	B
	D	D	C	A	B
Ent2	A	A	C	B	D
	B	B	C	A	D
	C	C	A	B	D
	D	D	C	A	B
Ent3	A	A	B	C	D
	B	B	A	C	D
	C	C	A	D	B
	D	D	C	A	B

Table 2.3 shows the total score for the game and the weightages of the three error parameters, See Path Again (SPA), Incorrect Room (IR) and Totally Lost errors. For each game, the participant started with a score of 100, and with each error, points were deducted according to the

game scoring rubric. The initial score of 100 was mainly for the reason that we desired all users to end up with a positive accuracy score rather than a negative score in case of many errors.

Table 2.3. Total score and parameter weightages

Total Game Score	**Parameters**		
	See path again	***Incorrect room***	***Totally lost***
100	45	40.5	4.5

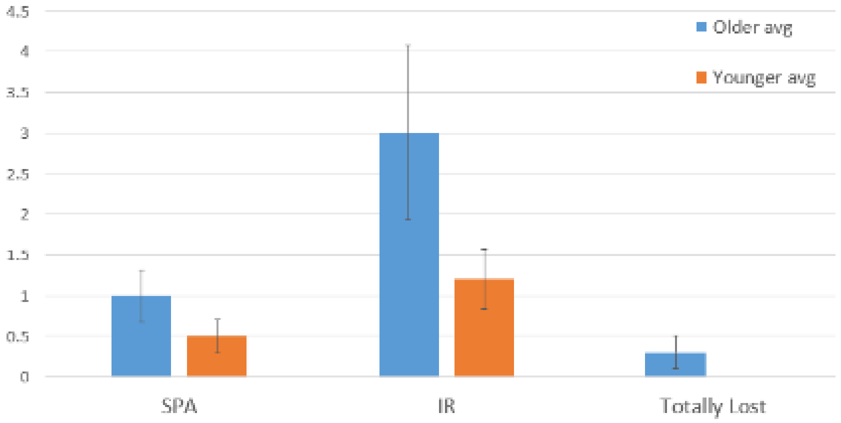

Figure 2.2. Average frequencies of the error components (the error bars show the standard errors). SPA= See path again error, IR= Incorrect room error.

2.3 Data Analysis

Independent two-tailed t-test was performed to compare the means of the distance traversed for participants experienced with playing video games with controllers and those who were not; there was statistically significant difference (t=2.89, p=0.01). Hence, traversed distance was not used for game score calculation as we did not want experience with video games to affect the score.

We investigated the frequencies of each of the errors. Fig. 2.2 shows the average frequencies of the three error components and their standard errors (SE) and Table 2.4 tabulates the descriptive statistics. Incorrect room (IR) error has much higher frequency than the others but we provided nearly equal weightage of 5 and 4.5 to See Path Again (SPA) parameter and IR parameter, respectively, because in each trial one can get up to nine incorrect rooms (4.5 upper limit divided by minimum incorrect room penalization of 0.5) but one can use SPA button only twice; using the help button is a proof that a participant has forgotten the path. Fig. 2.2 also shows that older adults depended on the SPA help button more than the younger participants. Since the target user of the game is eventually older adults with some mild dementia. it is better to have nearly equal weightage of the two types of error.

It was examined how many times the SPA help button was used for trials starting from each of the three entrances cumulatively for all the participants to see if there was a relationship between these two factors which would account for difficulty in mental rotation for a specific direction.

Analysis of variance (ANOVA) was used to investigate whether experience of playing controller-based video games had any effect on participant game scores. Experience of using a controller before was used as the grouping variable and game score as the dependent variable.

Pearson correlation coefficient was calculated between the game scores, distance parameter and participant age to examine if spatial performance denoted by the game score and distance parameter have an age effect.

To compare the power of the game score and the distance parameter, a regression model was used to predict the age of each participant using the game score and distance parameter. To evaluate the significance of the regression model, R squared test was used. This provides a measure of how well the variation in the dependent variable (age) can be explained by variation in the independent variable (game score and distance parameter).

For all statistical tests, $p<0.05$ was used as the level of significance.

2.4 Results

After studying the data from both groups of participants, the padding value for the distance parameter was considered as five units. Anything over that was considered as wandering before getting to the target. All the participant trial distances were compared with their ideal path distance and it was noted for each participant in how many trials out of the nine they wandered before getting to the target and that number was used as the distance parameter value for each participant.

The SPA help button was used a total of 15 times in the 180 total trials amongst 20 participants. It was used six times in trials starting at Ent1, seven times for trials starting at Ent2 and twice for trials starting at Ent3, showing that participants overall found it less difficult to retrace the path when the trials started at Ent3. The ANOVA on game scores with experience of playing video games with a controller produced no statistically significant difference between the groups experienced with gaming controllers and not experienced ($F=4.34$, $p>0.05$), supporting that the formulated game score is not affected by experience.

The results of the dependent variables, game score and distance parameter for older and younger adults age group are tabulated in Table 2.5. As can be seen, there is a slow decremental pattern of game score with age and a slow incremental one of distance error with age. From the Pearson correlation coefficients provided in Table 2.6, it can be seen that both the game score and distance parameter have statistically significant ($p<0.05$) medium strength relationship with age;

that shows an effect of age on these measurements. However, traversed difference was not found to be statistically significantly different between the two age groups (older adults versus younger adults); nor it was significant when we grouped them based on their MoCA scores (high-MoCA score and medium-MoCA). These results were expected as all the enrolled participants in this study were healthy adults with normal MoCA score of 26 or more; hence, it was expected not to find any statistically significant difference in game performance but a medium negative relationship of game score and age, accounting for healthy aging.

Table 2.4. Descriptive statistics of error components

Descriptive Statistics	**See path again error**		**Incorrect room error**		**Totally lost**	
	Older Adults	***Younger Adults***	***Older Adults***	***Younger Adults***	***Older Adults***	***Younger Adults***
Mean	1	0.5	3	1.2	0.3	0
Standard error	0.3	0.2	1	0.4	0.2	0
Minimum	0	0	0	0	0	0
Maximum	1	1	12	4	2	0

Table 2.5. Results of age group on the two main measurements

Age Group	**Game Score**	**Distance Error**
Older Adults	94.9 ± 4.88	3.9 ± 2.74
Younger Adults	97.85 ± 2.44	2 ± 1.34

Table 2.6. Pearson correlation coefficient between all variables (p<0.05)

	Game Score	**Distance Error**
Game Score	**-**	**-**
Distance Error	-0.496	-
Age	-0.486	0.481

The regression model for predicting age from the independent variables was statistically significant F(1,18)= 5.557058, $p<0.05$, $R^2 = 0.236$. The backward stepwise regression method was used and it was found that the distance parameter was not a significant predictor of age, whereas game score can be used to predict the age and accounts for 23.6% of the variance of the age variable.

2.5 Discussion

The data having been taken from gameplay in a novel VR environment further validates our team's previous study [76] on proving the reliability and age sensitivity of an error measurement not including distance, which is otherwise the standard measurement system in the domain of spatial orientation in VR studies. Our proposed measure is based on the frequency of using a help button to see the path again and number of incorrect rooms entered. The Totally Lost parameter is a subset of the incorrect rooms parameter as the definition of being totally lost has been given as: when incorrect room parameter penalization reaches its upper limit of 4.5 for a single trial. The help button allowed the participants to declare that they had forgotten the path, alongside with formulating a logic for when a participant is lost. It was interesting to observe that younger adults tended not to use the help button, and were confident of their memory even when they were lost. On the other hand, most of the older adults were not confident on their memory and used the help button much quicker whenever they went a little astray. This would be something to look at when older adults with dementia will be recruited to play the game, whether it is a similar trend or more or less than cognitively healthy older adults.

Results from this study showed that the distance parameter is affected by whether a participant has had prior exposure to playing with a controller or not. Thus, the traversed distance should not be considered for the scoring formula of the game. Our proposed formulated game score does not include the traversed distance as a parameter.

Participants' performance with regards to the two navigational components of the game was also observed. It was noted that irrespective of age some participants spent more time studying the allocentric representation (top-view of the game) whereas others immediately moved to the egocentric representation (first person active navigation). To have a more definitive statistics of navigation strategies, a post test strategy questionnaire needs to be added to the process in the future. In regards to mental rotation of the environment, it was observed that it was overall easier for participants to retrace their paths when starting at Ent3. On looking at Fig. 2.1a and b as to how the environment is shown in the game, it can be seen that Ent3 is the only trial start point that does not need mental rotation to remember the path; Ent2 needs a rotation of 90° and Ent1 needs one of 180°.

The future goal would be to test this game on dementia patients and see if there is a relationship between ability to find the target, cognitive status and stage of dementia and if playing it over time improves their ability to find the target. Having a larger sample size of participants will also provide feedback on what aspects of the game need improvement or more ease of use; those can be worked on to make it more target audience-oriented.

2.6 Post Publication Remarks

The Barn Ruins game was designed with a user-centered approach to assess spatial navigation in older adults, particularly those with Alzheimer's disease. A key innovation introduced in this chapter is the error-based scoring system (adapted from VRNHouse [76]), which emphasizes navigation errors over time or distance to better reflect cognitive performance. However, a limitation of this system is that the penalty weights for different errors were selected heuristically based on design logic and early testing, without formal empirical validation.

Another important consideration is the potential impact of unfamiliarity with the gaming controller on participant performance. While the game was iteratively tested with older adults during development, some individuals found it difficult to adapt to the controller within the first few trials. Since many older adults have limited prior experience with gaming controllers, difficulty using the device may increase cognitive workload and introduce noise into spatial performance data. It may also reduce user satisfaction and participants might not want to keep playing the game when Barn Ruins is used as an intervention. We changed the way the gaming controller was used from two thumbsticks to one in the next study. A more thorough discussion of controller usability and the adaptations made can be found in Chapter 3 under Game Environment (3.3.1). Usability observations from this study were also used to inform key points for practice in Chapter 6 to improve motivation and satisfaction while playing serious games.

Chapter 3. Evaluation of the Spatial Virtual Reality Game (Barn Ruins) for Alzheimer's Disease

Evaluation of a Cognition-Sensitive Spatial Virtual Reality Game for Alzheimer's Disease

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Medical and Biological Engineering and Computing, 1–11. https://doi.org/10.1007/S11517-024-03270-1/

Abstract

Spatial impairment characterizes Alzheimer’s disease (AD) from its earliest stages. We present the design and preliminary evaluation of "Barn Ruins," a serious virtual reality (VR) wayfinding game for early-stage AD. Barn Ruins is tailored to the cognitive abilities of this population, featuring simple controls and error-based scoring system. Ten younger adults, ten cognitively healthy older adults and ten age-matched individuals with AD participated in this study. They underwent cognitive assessments using the Montreal Cognitive Assessment (MoCA) and the Montgomery-Åsberg Depression Rating Scale (MADRS) before gameplay. The game involves navigating a virtual environment to find a target room, with increasing levels of difficulty. This study aimed to confirm the cognitive sensitivity of the Barn Ruins' spatial learning score by studying its relationship with Montreal Cognitive Assessment (MoCA) scores. MoCA scores and spatial learning scores had a correlation coefficient of 0.755 ($p<0.001$). Logistic regression further revealed that higher spatial learning scores significantly predicted lower odds of cognitive impairment (OR = 0.495, 95% CI [0.274, 0.746], $p < 0.005$). The initial results suggest that the game is effective in differentiating performance among participant groups. This research demonstrates the potential of the Barn Ruins game as an innovative tool for assessing spatial navigation in AD, highlighting areas for future validation and investigation as a training tool.

3.1 Introduction

Alzheimer's disease (AD) causes wayfinding and path integration impairments from its earliest stages [36, 91–93]; these are among the first ten warning signs of AD [94]. Wayfinding is the navigation process of using all environmental cues to find one's way to the destination in both familiar and unfamiliar spaces [95]. Path integration can be thought of as the conversion of the perception of movement into a continuous sense of location combined with the recognition of landmarks [96]. These processes help with daily activities such as finding the way back to home from a store, which is considered an instrumental activity of daily living (iADL). Regularly playing serious games has been shown to be effective in slowing cognitive decline [5, 8, 9, 27, 42, 97]. For example, playing navigational games as an intervention can potentially help improve real-life navigation skills, hence enabling individuals with AD to walk around their neighbourhood more confidently. However, before a serious game can be used as an intervention, it is crucial to evaluate the game's scoring system to ensure that it measures what it is aimed for. The focus of this paper is to perform a preliminary evaluation of the efficacy of our recently designed serious virtual reality (VR) game [98] for strengthening spatial orientation training.

The proposition of using VR games as serious games is based on the fact that VR games are engaging to play and require the use of different cognitive functions [11, 99]. A serious game can be distinguished from other video games by the fact that the main aim of the designer is to integrate a training objective into the game scenario [100] rather than only entertainment. As spatial orientation impairment is one of the first signs of AD [3], we aimed to develop a serious game focusing on spatial orientation for individuals with AD.

For navigational game scoring systems, the common parameters are distance traversed, time taken to complete trials and number of successful trials [34, 101, 102]. Our research group's prior work on error-based scoring systems for navigation tasks [76] showed that the formulated error score was able to better categorize different age and cognition groups than the commonly used temporal and distance parameters. This also aligns with the fact that a decline in cognitive and perceptual skills with the progression of AD can confound temporal and distance parameters during navigation tasks [103, 104]. Hence, the scoring system of a navigation game should consider the number of unsuccessful trials, number of trials successful with trial-and-error, type of error and number of errors within a successful trial in finding a designated target.

The Barn Ruins spatial game [98] that is evaluated in this paper focuses on wayfinding and path integration using the following environmental components: (1) a landmark-less, symmetrical environment, similar to office and hospital corridors; (2) multiple regions with distinct edges marking boundaries between the regions; (3) a top view map shown at the beginning of the task; and (4) different starting point options. At two entrances (ENT1 and ENT2 in Fig. 3.1a), the top view map and the environment were designed to be misaligned. This would make wayfinding more difficult, as the player would have to mentally rotate the top view map while trying to find the target room. All these components have been found to affect wayfinding [105]. We believe these aspects make the game sensitive to cognition, as spatial cognition significantly declines with both natural aging and the progression of AD but at different rates [3, 32, 39, 71, 106–110].

We evaluated the scoring system of our Barn Ruin game among individuals with AD by comparing their scores with those of age-matched cognitively healthy individuals and younger controls. The predictive power of the game scores of the participants for their cognitive status, measured by the Montreal Cognitive Assessment (MoCA), was also investigated.

3.2 Methods

3.2.1 Participants

A total of 30 adults aged 20-88 years were recruited for the study. This included ten younger adults (5 males, 26±3.34 yrs.), ten cognitively healthy older adults (3 males, 70.7±5.3 yrs.), and ten individuals with AD (7 males, 77.8±5.9 yrs.). Individuals with AD who were diagnosed with AD by a neurologist or neuropsychiatrist were recruited from our research group's current longitudinal study cohort. Cognitively healthy older adults were recruited from among the caregivers of the AD participants. Younger adults were recruited from among University of Manitoba graduate students. All participants had normal or corrected-to-normal hearing and vision. The MoCA [90] was administered to all participants as a measure of cognitive status. A MoCA score of 25 and above is generally considered to indicate cognitive health, scores between 16 and 25 indicate mild cognitive impairment, scores between 10 and 15 indicate moderate cognitive impairment, and scores below 10 indicate severe cognitive impairment. The Montgomery-Asberg Depression Rating Scale (MADRS) [111] was also used for each participant as a measure of depression level, as it is normally considered a confounding variable in statistical analysis. People with MADRS scores of 0-6 are considered nondepressed, while those with MADRS scores of 7-19 and 20-34 are considered mild and moderate depression, respectively; those with MADRS scores above 34 are considered severe depression.

The eligibility criteria for participating in this study were that the age of participants should be between 18 and 40 years for younger adults and between 65 and 85 years for older adults, with a MoCA score > 25. The participants in the AD group must have had a MoCA score between 6 and 25. All participants signed an informed consent form approved by the Biomedical Research Ethics Board (BREB) of the University of Manitoba, and all the study procedures complied with the BREB's guidelines and regulations [HS25611 (B2022:079)].

3.3 Barn Ruins game

3.3.1 Game Environment

The aim of the Barn Ruins game is wayfinding using route repetition. The player learns the path from the entrance to a target room with a treasure chest inside with the help of a guiding line. The player then must find their way to the treasure chest without the guiding line. The VR game environment is the same as that used in our previous exploratory study [98], a virtual field consisting of two connected regions. As shown in Fig. 3.1a, one region is rectangular with six rooms and one entrance in a symmetrical layout, and another square region is asymmetric in its room layout. This region has four rooms and two entrances. The playing field has a total of ten rooms and three entrances. The two regions are connected by an archway, which can be considered a boundary between the two regions.

Player movement in the VR barn ruins environment is executed via a gaming controller, as in the prior study. However, the previous exploratory study utilized a two-joystick control format, consisting of a right thumb joystick for translation and a left thumb joystick for rotation. This control format was challenging for some cognitively healthy older adults and was found to be extremely difficult for individuals with AD. In accordance with the recommendation from Ben-Sadoun et al. [13] to reduce motor demands and decrease attentional load for participants with neurodegenerative conditions, the control format was changed to a one-handed system. Participants only needed to manipulate the right thumb stick on the gaming controller to move in the desired direction within the virtual environment. To ensure familiarity, all participants were given two practice trials using the gaming controller, and the new one-handed control format was intuitive enough for all participants to effectively navigate the virtual barn ruins during the testing trials. In this study, the game was played on a laptop in non-immersive mode (without a VR headset), with the joystick movement providing idiothetic cues.

3.3.2 Game difficulty levels

In Barn Ruins, there are three entrances and ten rooms, yielding a total of 30 possible routes. The 30 routes are categorized into three levels of difficulty: easy, medium, and difficult. The difficulty levels are based on the number of turns it takes for the player to reach the goal. Nine routes, one from each difficulty level for each entrance, were then randomly selected for data collection for each participant. For this study the trials were presented to the participant in a random sequence of difficulty levels to avoid learning effect. The entrances are placed in different orientations so that for Ent1 and Ent2, the top view map is misaligned in reference to the starting point by different degrees. If the player starts from ENT1, it is misaligned by 180° since they see the top view map upside down. If the player starts from ENT2, the top view map is misaligned by 90° in reference to the viewpoint at the starting point. This makes some mental rotations necessary. If the player starts from ENT3, no mental rotation is required since the top view map is aligned to the viewpoint at the start.

3.3.3 Game Trials

In each trial, there is a learning phase and a route-repetition phase (Fig. 3.2). During the learning phase, the route is initially presented in a top-down view with a pink guiding line (Fig. 3.1c). Participants are allowed as much time as they want to observe the top-down view. Once they are ready, they are placed at the entrance in first-person view with the pink line visible and are instructed to follow the pink line to the treasure chest. During the route-repetition phase, they are again placed at the entrance in first-person view, but this time without the pink guiding line. They are instructed to find their way to the same room with the treasure chest. In this phase, however, the treasure chest is not visible from outside the room until the participant fully enters the room. There are two help buttons available on the screen during the route-repetition phase: the *See the Path Again* and the *Go back to Start* buttons. The *See the Path Again* button can be used by the participant to repeat the learning phase of the route, while the *Go back to Start* button can be used to restart the route-repetition phase if they feel disoriented. In the scoring of the game, using the *See the Path Again* button has a penalty, whereas *Go back to Start* button does not. The participants are not informed of this and are encouraged to freely use the help button they think they need.

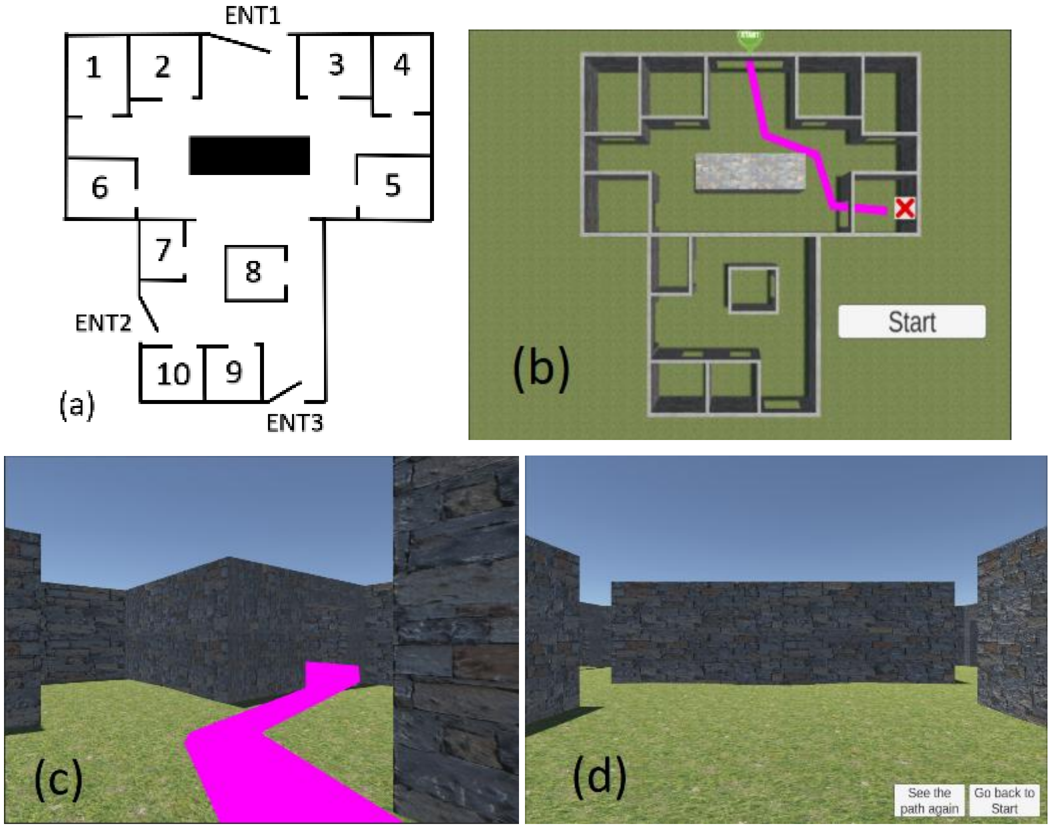

Figure 3.1. Illustration of the "Barn Ruins" game (a). The layout of the environment with ten rooms and three entrances. (b). The top-down view at the start of the learning phase, with the pink line showing the route. (c). First-person view during the learning phase with the pink line to help guide participants to the target. (d). Screenshot of the game during the route-repetition phase, where the participant had to find their way to the target and had two help buttons at the bottom of the screen for use when lost. Adapted from [98].

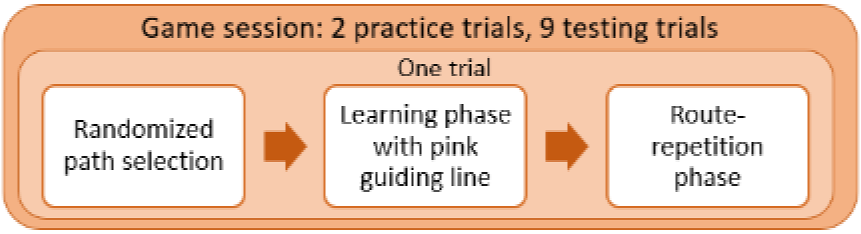

Figure 3.2. Illustration of the steps in a full game session.

Table 3.1. Difficulty level of the trial according to the entrance and room chosen to place the treasure chest.

Room no. → **Entrance no. ↓**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Ent1	Medium	Medium	Medium	Medium	Easy	Easy	Hard	Hard	Hard	Hard
Ent2	Hard	Hard	Hard	Hard	Medium	Medium	Easy	Easy	Easy	Easy
Ent3	Medium	Medium	Medium	Medium	Hard	Hard	Hard	Easy	Easy	Easy

3.3.4 Scoring

Each trial has a raw score out of ten. Three error parameters are deducted from the initial ten points for each trial. The parameters are *See Path Again* error, *Incorrect Room* error and

Totally Lost. The *See Path Again* error is based on how many times a participant used the *See Path Again* button. The *Incorrect Room* error is a weighted deduction based on how close the incorrect room is to the target room. The *Totally Lost* error is when a participant goes to more than four incorrect rooms (rooms are weighed differently depending on proximity to the target room), and they try to find the target room by trial and error. Details of each parameter can be found in the exploratory study paper [98]. The raw score for each trial is then converted into a trial spatial learning score, which is weighted by the difficulty level of the trial path according to Table 3.1. The difficulty level easy is assigned as level 1, the medium difficulty level is assigned as level 2, and the hard difficulty level is assigned as level 3. The trial spatial learning score formula is as follows:

$$\text{Trial spatial learning score} = \text{Level}^{*}\ (\text{raw trial score}/10) \qquad (1)$$

The participant's scores over the 9 trials were combined into a single score called Spatial learning score (out of 18) using equation (1). As there were three easy trials, three medium trials and three hard trials in each full game, the game spatial learning score was out of 18 for each participant.

3.4 Study Procedure

For each participant, the MoCA and MADRS assessments were performed before they played the game. Prior to logging the scores of the games, participants were given two practice trials of the game to familiarize themselves with the visuomotor activity of using a gaming controller to navigate a virtual environment and then had nine testing trials. The practice trials and testing trials were similar, with the exception that performance data (i.e., visited rooms and instances of help button usage) were recorded for the testing trials.

3.5 Data Analysis

The spatial learning score was normally distributed within each participant group. Hence, analysis of variance (ANOVA) was used to investigate differences in the spatial learning scores of younger adults, cognitively healthy older adults and individuals with AD. The participant category was used as the grouping variable, and the spatial learning score was used as the dependent variable. Tukey’s pairwise honestly significant difference (HSD) test was performed as a post hoc test. ANOVA was also performed with MoCA scores as the dependent variable to validate the participant categorization of individuals with AD.

To examine the power of spatial learning scores to explain the variation in MoCA scores, a linear regression model was used with MoCA score as the dependent variable and spatial learning score as the independent predictor variable. The MADRS score was also added as an independent variable to the second block of the regression model in the enter method. This was done to test whether the MADRS influenced spatial learning and MoCA scores. Before conducting the regression, the Pearson correlation coefficient was calculated between the MoCA score and spatial learning score to determine the relationship direction and strength. To evaluate the significance of the regression model, the R-squared test was used.

To test the sensitivity of the spatial learning score in detecting cognitive health a logistic regression was done followed by graphing the ROC curve, computing the Area Under the ROC Curve (AUC) and confusion matrix, sensitivity and specificity calculations. For this logistic regression, the continuous variable MoCA scores was converted into a binary variable called Brain Health. The cognitively healthy older adults (MoCA>= 24) were marked as Healthy and the people with AD (MoCAs between 13 to 22) were marked as Impaired. This new variable

Brain Health was used as the dichotomous dependent variable in the logistic regression and spatial learning score was the continuous independent variable.

A heatmap was generated to present the spatial learning scores according to the starting entrance and difficulty level to visualize whether mental rotation plays a role in spatial learning. ANOVA was calculated for each participant category separately to investigate whether there were significant differences in spatial learning scores because of different degrees of mental rotation of the game environment map.

The statistical analyses were done using a combination of IBM SPSS Statistics 27 and RStudio. For all the statistical tests, $p<0.05$ was considered to indicate statistical significance.

3.6 Results

Table 3.2 provides the baseline statistics of the study participants in the different groups. Figure 3.3 graphically presents the means of the spatial learning scores and MoCA scores of all three groups. The range of MoCA scores among all 30 participants was 13-30. Among the cognitively healthy older adults, one participant had a MoCA score of 24 (borderline between healthy and cognitive impairment) but was not diagnosed with any cognitive impairment and was living an independent life; therefore, we included them in the cognitively healthy group. This specific participant also had moderate depression according to their MADRS score; it is known that depression influences the executive/attention subtasks of the MoCA test [112]. This was indeed the case for that participant who lost two scores on the executive task of the MoCA. Table 3.2 provides the detailed population demographics of the study participants.

ANOVA of the MoCA scores of the three groups revealed a statistically significant difference ($F=39.33$, $p<0.001$). As expected, Tukey's pairwise HSD showed that individuals with

AD had lower MoCA scores than cognitively healthy older adults [p<0.001, 95% CI (5.33, 10.66)] and lower MoCA scores than younger adults [p<0.001, 95% CI (5.83, 11.16)]. There was no difference in the MoCA scores between the older and younger healthy adult groups [p=0.882, 95% CI (-2.16, 3.16)]. ANOVA of the MoCA subcategories revealed that the abstraction, delayed recall, and orientation subcategories exhibited statistically significant between-group differences, as outlined in Table 3.2.

ANOVA of spatial learning scores revealed a significant difference between the groups (F=14.056, p<0.001), as expected. Tukey's pairwise HSD showed that individuals with AD had lower spatial learning scores than both cognitively healthy older adults [p=0.01, 95% CI (0.62, 4.98)] and younger adults [p<0.001, 95% CI (2.44, 6.8)]. There was no significant difference in the spatial learning scores between the cognitively healthy older adults and younger adults [p=0.114, 95% CI (-3.56, 3.96)].

3.6.1 Relationship between MoCA scores and spatial learning scores

The Pearson correlation coefficient between spatial learning scores and MoCA scores was 0.755 (p<0.001) (Fig. 3.3), indicating a strong positive relationship between the two scores. The regression model to examine the strength of spatial learning scores in explaining variation in MoCA scores was statistically significant [F (1,28) = 37.15, p<0.001, R^2 = 0.597], meaning that spatial learning scores could explain 59.7% of the variance in the MoCA scores of our dataset. When MADRS score was added to the regression model as the confounding variable, it explained only 0.2% of the spatial learning score variance, with a p value of 0.776; hence, the MADRS score was excluded from the regression model due to its very small effect.

Table 3.2. Baseline characteristics of the participants. *p<0.05, **p<0.001, ns= nonsignificant. All values are presented as the mean (SD).

Participant Groups	Younger Adults (n=10) [Group1]	Cognitively Healthy Older Adults (n=10) [Group2]	People with AD (n=10) [Group3]	ANOVA p value	Significant post hoc	
					Group1 vs Group3	Group2 vs Group3
Age (years)	26 (3.39)	70.7 (5.31)	77.8 (5.94)	**	**	*
MoCA (out of 30)	27.6 (1.5)	27.1 (1.79)	19.1 (3.44)	**	**	**
MoCA subcategories						
Visuospatial/Executive (out of 5)	4.8 (0.42)	4.5 (0.7)	4 (1.3)	ns	-	-
Naming (out of 3)	2.8 (0.42)	2.9 (0.32)	2.5 (0.53)	ns	-	-
Attention (out of 6)	5.8 (0.42)	5.8 (0.42)	5.6 (0.69)	ns	-	-
Language (out of 3)	1.8 (1.13)	1.9 (0.74)	1.7 (0.82)	ns	-	-
Abstraction (out of 2)	1.9 (0.31)	1.9 (0.31)	0.9 (0.87)	**	*	*
Delayed Recall (out of 5)	4.7 (0.95)	4.4 (0.96)	0.1 (0.31)	**	**	**
Orientation (out of 6)	5.8 (0.42)	5.7 (0.48)	4.2 (1.32)	**	**	**
MADRS (out of 60)	6.5 (8.19)	3.3 (7.36)	4.5 (4.27)	ns	-	-
Spatial learning score (out of 18)	17.8 (0.3)	15.98 (2.12)	13.18 (2.64)	**	**	*
Spatial learning score parameters						
Number of times See Path Again button used	0 (0)	1.6 (1.71)	3.6 (2.07)	**	**	*
Number of times Totally Lost	0 (0)	0.5 (0.85)	2.8 (1.62)	**	**	**

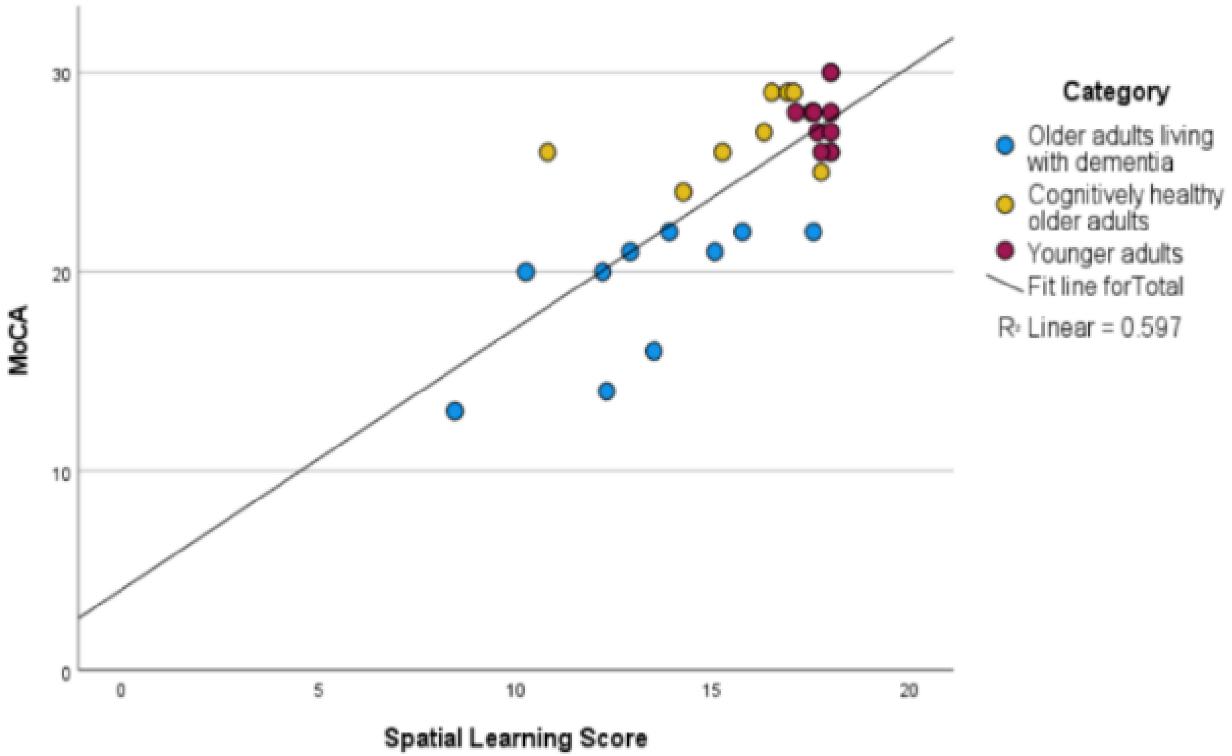

Figure 3.3. Scatter plot of the Montreal Cognitive Assessment (MoCA) scores and spatial learning scores categorized according to participant group.

The logistic regression model revealed that higher spatial learning scores significantly predicted lower odds of cognitive impairment, as indicated by a statistically significant odds ratio (OR = 0.495, 95% CI [0.274, 0.746], $p < 0.005$). Cognitive impairment was measured by Brain Health which was binarized from MoCA scores as outlined in the Data Analysis section. The ROC curve is shown in Fig. 3.4 with an AUC of 0.90. Table 3.3 presents the confusion matrix for a threshold of 0.35. At this threshold the model had a sensitivity of 0.7 and specificity of 0.95. The corresponding Spatial Learning Score cut-off, determined from the logistic regression probability formula using β_0= 10.1 and β_1= -0.703 was calculated to be to be 15.3 out of 18. As shown in Table 3.3, this means that with the cut-off of 15.3 for the Spatial Learning Score, we were able to correctly categorize 19 out of 20 Healthy data points and 7 out of 10 Impaired data points, providing an accuracy of 87%. Given the combined strength of these metrics, it can be said that the Spatial Learning Score is cognition sensitive.

Table 3.3. Confusion matrix for threshold value of 0.35 with a corresponding spatial learning score of 15.3 out of 18.

Threshold=0.35		Brain Health		Total
		Actual Impaired	Actual Healthy	
Spatial Learning Score Prediction	Impaired (Positive)	7	1	8
	Healthy (Negative)	3	19	22
	Total	10	20	30

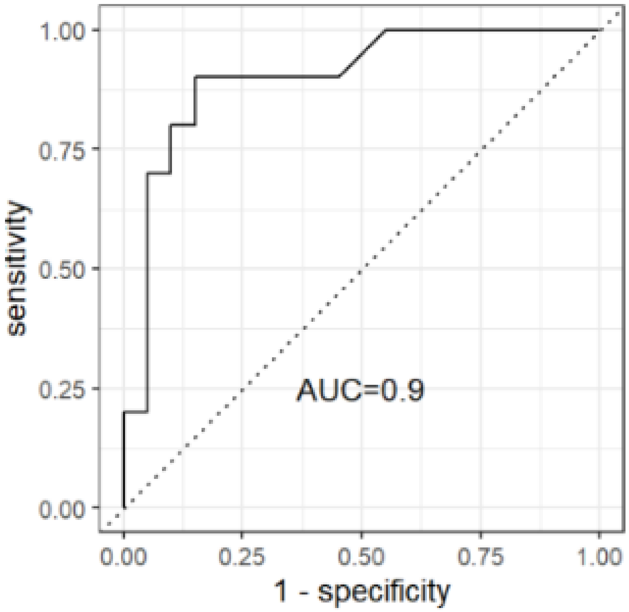

Figure 3.4. ROC curve demonstrating the capacity of the Spatial Learning Score to predict Brain Health. The AUC is 0.90 and at a threshold of 0.35, sensitivity is 0.70 and specificity is 0.95, with a corresponding Spatial Learning Score threshold of 15.3 out of 18, underscoring its effectiveness as a cognition-sensitive scoring method.

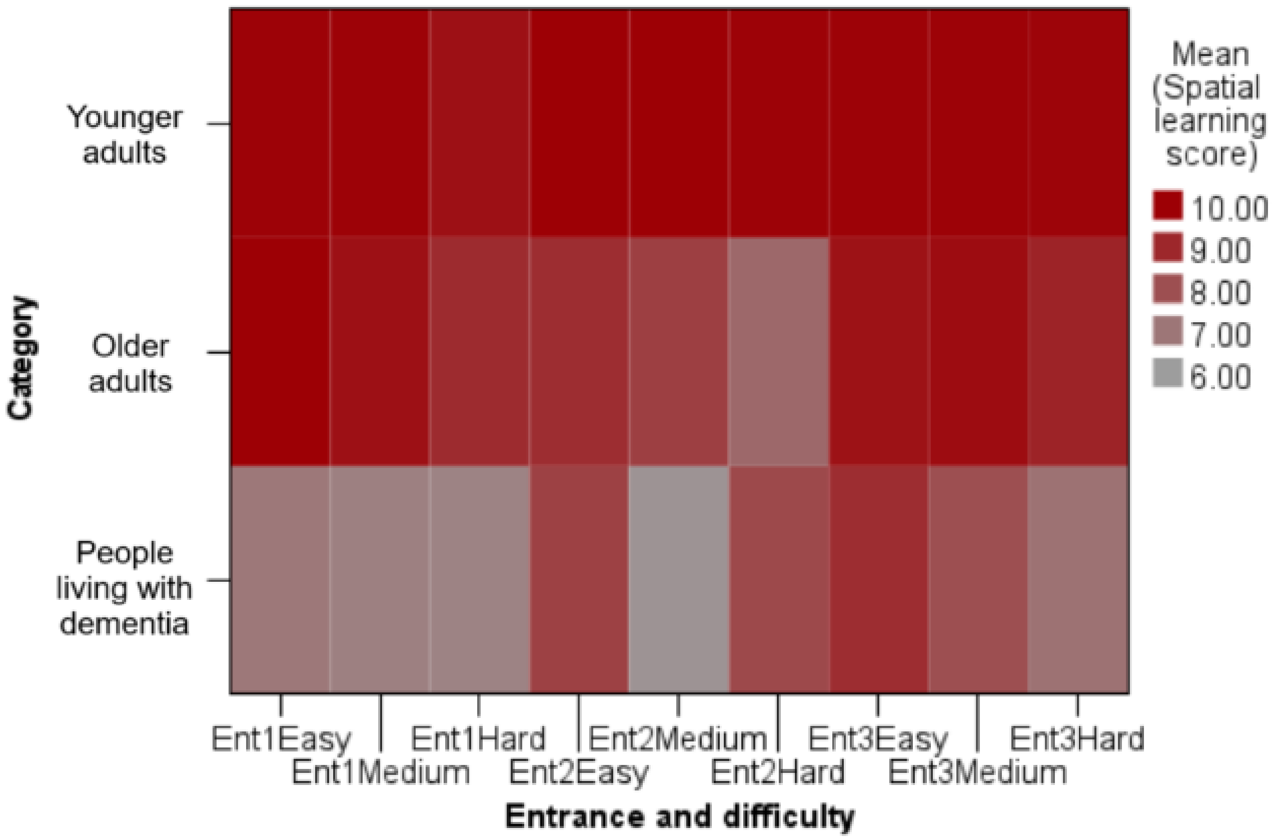

Figure 3.5. Heatmap of trial spatial learning scores according to participant category and starting entrance and difficulty level.

3.6.2 Effect of Mental Rotation on the Spatial Learning Score

Mental rotation was incorporated into the game by having the entrances oriented in different directions. Figure 3.5 shows that mental rotation affects spatial learning scores. Every group received the best scores in the Ent3 starting trials, which did not require any mental rotation. For trials that required mental rotation (starting at Ent1 and Ent2), spatial learning scores decreased with age, especially for individuals with AD. Accordingly, ANOVA revealed that for younger adults and individuals with AD, there was no significant difference in the spatial learning score based on starting entrance. For the cognitively healthy older adult group, there was a statistically significant difference between spatial learning scores for the Ent1, Ent2 and

Ent3 starting trials (F=5.013, p=0.009). Tukey's pairwise HSD showed that starting at Ent2 had significantly lower spatial learning scores for cognitively healthy older adults than starting at Ent1 [p=0.017, 95% CI (-2.41, -0.19)] and Ent3 [p=0.023, 95% CI (-2.36, -0.14)].

3.7 Discussion

Overall, these results show that the developed Barn Ruins game and its spatial learning scoring system are sensitive to a wide range of cognitive statuses, measured by MoCA scores, from cognitively healthy to mild and moderate levels of cognitive impairment. The strong correlation with MoCA scores reinforces the game's effectiveness in capturing cognitive nuances, with spatial learning score explaining 59.7% of the variance in MoCA scores. For every one-unit increase in Spatial Learning Score, the odds of cognitive impairment decreases by 50.5%. This cognition sensitivity in the scoring system will be useful when the Barn Ruins is used as a training tool in the future, to provide feedback on cognitive improvements.

The younger adult group had relatively lower Language and Naming subcategory scores of the MoCA test. This is probably because a large percentage of the younger adults were international students for whom English was not their native language, and the MoCA was conducted in English for all participants. For example, during naming the animals, a couple younger adults were able to name it in their native language but not in English. There was no significant difference between the MoCA and spatial learning scores of younger adults and cognitively healthy older adults. This is logical because the MoCA and the Barn Ruins spatial navigation game are used to assess cognitive impairment. However, the spatial learning score of healthy older adults was lower than that of younger adults. This finding is congruent with the results of other studies that have shown that spatial navigation abilities decline with age even in cognitively healthy adults [71–73, 76, 93].

Depression levels, as measured by MADRS scores, did not significantly influence the variation in spatial learning scores. This can be attributed to the fact that all participants in this study, with the exception of one, exhibited either no depression or very mild depression. The range of MADRS scores observed in our participants was not sufficient to have a substantial impact on task performance. The data corroborate this finding, indicating that within the observed range, depressive symptoms did not meaningfully affect task performance in the Barn Ruins.

3.7.1 Using help buttons

The Barn Ruins game score was formulated using error frequencies in a similar manner to our research group's previous error-based score [76]. The three spatial learning parameters were the number of times the *See the Path Again* button was used, the number of incorrect rooms and *Totally Lost*, which was when the participant was trying random rooms because they had forgotten the way. The *See the Path Again* button parameter indicates how much the participant felt they needed help, whereas the *Totally Lost* parameter, through checking the number of incorrect rooms, indicates how lost the participant truly got. Interestingly, the younger adults did not use the *See the Path Again* button at all. When they went into an incorrect room, they were still confident of their memory and found the correct target room without any additional help. Cognitively healthy older adults, on the other hand, used the *See the Path Again* button whenever they became stuck, not having much confidence in their memory. However, this group had a relatively lower *Totally Lost* average. Individuals with AD needed the *See the Path Again* button most often, even on easy level routes for a few participants, and they had a relatively high *Totally Lost* average. These findings match previous research reporting that individuals with AD have greater spatial impairments than age-matched cognitively healthy older adults [93, 109, 113]. When individuals with AD play Barn Ruins as an intervention game (in our future study), it will be interesting to investigate whether the dependency on help buttons decreases proportional to the reduction in the *Totally Lost* parameter or whether they feel more confident in playing the game regularly with less use of help buttons but without any reduction in the *Totally Lost* parameter.

3.7.2 Mental rotation and navigation strategy preference

Mental rotation was also incorporated into the Barn Ruins game, such as visualizing a map and mentally rotating it according to the user's current position, which is a crucial step in navigation. We had three starting entrances oriented in different directions to allow for different degrees of mental rotation. We observed through lower spatial learning scores that it became difficult for older adults, especially individuals with AD, to learn a route when they had to rotate the mental map representation in their head. This finding is consistent with previous studies on mental rotation [114, 115]. In future intervention studies, we will observe whether participants improve in all or only some degrees of mental rotation.

The current Barn Ruin game is structured such that the participant sees the top-down view first and then navigates in first person; this structure has been able to provide some insight into what type of navigation a participant prefers. Some participants spent much more time in the top view and vocally memorized the path from the top-view map, which shows that they preferred map-based navigation. Some did not spend more than a second looking at the top view and went straight into the first-person navigation mode, which shows their preference for path integration. This was only an observation, and in a future study, it would be interesting to objectively note this strategy preference for all participants and see if there is a correlation with their performance in routes including mental rotation.

3.7.3 Comparing the Barn Ruins game with similar paradigms

We believe that the Barn Ruins game scoring may offer comparable and, in some cases, enhanced capacity to detect cognitive variation relative to other virtual reality spatial tasks in terms of accuracy, specificity, Pearson's correlation coefficient and R^2. Our error-based scoring was adapted from VRNHouse scoring method [76] and had congruent result of errors increasing with decrease in cognitive performance. However, the strength of correlations between MoCA score and task performance was notably higher in our study r(Barn Ruins)= 0.75 vs r(VRNHouse)= 0.3. Additionally, the MoCA predicting capacity of Barn Ruins (R^2=0.597) was substantially greater than that of VRNHouse (R^2=0.13).

Magno et al., 2024 [116] in their meta-analysis found the Virtual Supermarket Program (VSP) to have impressive metrics in the category of virtual reality game-based tests for screening mild cognitive impairment in older adults. VSP had high sensitivity and specificity of 0.85 and 0.8 respectively and a correlation coefficient of 0.645 between VSP score and MoCA [117]. The Barn Ruins score's correlation with MoCA of 0.75 is stronger than VSP with an exceptionally high specificity of 0.95. The Barn Ruins' higher-than-average specificity (0.95) demonstrates strong accuracy in correctly excluding participants without cognitive impairment. However, its sensitivity of 0.7, while lower, is still within a reasonable range. For comparison, novel digital solutions in cognitive assessment, as reported by Magno et al. [116], tend to have sensitivities of at least 0.78 and specificities ranging from 0.5 to 0.9, depending on the design and targeted cognitive domains. This suggests that the Barn Ruins game performs competitively in terms of specificity, though sensitivity is somewhat lower compared to certain other tools in the field.

It is important to note that the Barn Ruins game is intended to be used as a future training tool, where a higher R^2 value becomes particularly relevant. The Barn Ruins game demonstrates an R^2 of 0.597, indicating that as participants improve in the game, these improvements are likely to reflect real gains in cognitive ability, as measured by MoCA. This strong predictive capacity underscores the game's potential for effectively tracking cognitive progress over time.

3.8 Conclusion

This research aimed to evaluate the effectiveness of the Barn Ruins navigation game in assessing spatial navigation abilities in individuals with AD. The findings in this paper indicate that the game's spatial learning score strongly correlates with MoCA scores, suggesting that the game is sensitive to cognitive impairments characteristic of early-stage AD. This finding suggests that this sensitivity could be useful as a training tool where cognitive changes over time need to be measured.

Importantly, the study demonstrated that Barn Ruins effectively differentiates performance among younger adults, cognitively healthy older adults, and individuals with AD. This difference is important because it validates the game's scoring system, which considers error-based parameters rather than solely relying on temporal and distance metrics.

3.9 Study Limitations and Future Directions

As we only recruited people who were interested, convenience sampling can cause sampling bias. Due to the limited sample size, the results do not provide high statistical power; hence, there is a greater possibility of type I or type II errors. The Barn Ruins game in this study provided a relatively low sensitivity of 0.7. This reduced sensitivity may be attributed to the heterogeneous and non-linear progression of Alzheimer's disease (AD) across participants. Cognitive decline in AD patients does not follow a uniform trajectory, and cognitive performance, as measured by MoCA, may not fully capture the early or varying degrees of impairment. In some cases, participants clinically diagnosed with AD may still have MoCA scores that fall within the normal range, leading to under detection of impairment in the game. This discrepancy highlights the challenge in correlating clinical diagnosis with cognitive performance at different stages of the disease.

The current study was a pilot study to evaluate the scoring system and investigate whether this game holds up in measuring general cognitive health while focusing on spatial cognition measurement. Our future work will test this game as an intervention for improving spatial navigation. Some of the differences in the groups that were not visible in this study might be more prominent when in a future longitudinal study, the repeated sessions will require long-term learning. This might highlight changes in spatial learning abilities that are not evident in a single session of playing a serious game. In the current version of the game, the top-down view and the first-person view navigation strategies are combined. We are interested in how individuals perform on the Barn Ruins game by using each strategy separately. We will investigate this by breaking down the game into two sessions, one for each strategy, to see if one is better than the other for individuals with AD.

3.10 Post Publication Remarks

It is important to recognize that this was a pilot study, and as such, the sample size was limited. While the results provide valuable preliminary insights, the findings should be interpreted with caution. To ensure more robust statistical inference and generalizability, future studies should include a larger number of participants in each group.

Another notable limitation concerns the age difference between the cognitively healthy older adults and people with AD. On average, the cognitively healthy group was approximately seven years younger than the AD group. Given that cognitive decline can occur even within the normal aging process, this age disparity may have introduced a confounding variable, potentially influencing the observed group differences. The absence of age-matched control participants makes it difficult to fully disentangle the effects of AD from those attributable to typical aging.

Future evaluations using the Barn Ruins game should prioritize the recruitment of age-matched control groups. Doing so will better isolate the specific impact of Alzheimer's disease on spatial navigation performance, allowing for more accurate interpretation of the game's diagnostic and therapeutic potential.

Chapter 4. Barn Ruins as a rehabilitation tool for older adults with MCI

Barn Ruins virtual reality-based serious game as a rehabilitation tool for older adults with mild to moderate cognitive impairment: A pilot study

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Abstract

This study evaluates the potential of a serious game, called Barn Ruins, as a spatial learning rehabilitation tool for older adults with mild to moderate cognitive impairment (MCI). The game's user navigates a maze environment on a laptop screen using a gaming controller (a joystick). It progresses through easy, medium, and hard routes, and has an error-based spatial learning score. The intervention spanned eight weeks, during which participants played the game for 30 minutes, three times a week. Pre- and post-intervention assessments were conducted using two independent and validated spatial orientation measures: VRNHouse as the primary and the Clock Orientation Test as the secondary outcome.

Seven participants (86.3 ± 4.9 years, 2 males) completed the study. Although no statistically significant changes were observed in VRNHouse or Clock Orientation Test scores, 71.4% of participants improved or maintained their performance in the primary outcome measure, while 66.7% demonstrated improvement or stability in the secondary measure. Analysis of spatial learning scores within the Barn Ruins game revealed significant improvements over time ($p = 0.0046$, *Kendall's W = 0.42*), particularly in easy ($p = 0.023$) and hard ($p = 0.01$) routes. Performance on medium routes fluctuated, suggesting greater difficulty with these trials.

Post-hoc comparisons revealed that by Weeks 7 and 8, participants' overall spatial learning scores were significantly higher compared to those in Week 1. Notably, easy routes exhibited a ceiling effect after Week 4, while harder routes showed consistent improvement after Week 5.

Despite modest results in independent outcome measures, the game's significant performance gains suggest its utility in improving spatial skills. Future research with larger samples is needed to validate these findings. These findings highlight the potential of the Barn Ruins game as a novel rehabilitation tool for enhancing spatial learning in older adults with MCI.

4.1 Introduction

There is an increasing prevalence of mild cognitive impairment (MCI) among older adults. Spatial memory is impaired in many MCI individuals [35, 109, 118]. Finding innovative approaches for neurorehabilitation that can effectively address cognitive deficits while enhancing overall well-being is necessary for this population. Serious games and game therapy have been found to provide a good solution for cognitive rehabilitation [18, 27, 42, 108, 119–121]. The proposition of using video games as serious games is based on the fact that video games are fun to play and require the use of different cognitive functions [11, 99]. A serious game can be distinguished from a video game by the fact that the main aim of the designer is to integrate a training objective into the game scenario [13] rather than only entertainment. With recent technology advancements, serious games for cognitive rehabilitation (neurorehabilitation) have been designed in virtual reality (VR). Virtual environments allow for easier control over study parameters in comparison to real-world study environments. For navigation in VR, a recent study found that moving around VR environments does not provide the same cues as a real environment [81]. However, common consensus from studies is that the decision-making process related to navigation in virtual environments translate well to real environments [82, 83].

In neurorehabilitation of older adults living with dementia, the focus has mostly been on physiotherapy, vestibular and real-world task practice [40, 43, 48]. There are only a few studies on spatial cognition rehabilitation [27, 42, 122, 123]; hence, more research is needed on this topic. The reason for using a new navigation game was to have a game that would be enjoyable for regular use and that uses gadgets that are easily accessible, and easy to use for people with MCI. This is crucial for the serious game to be used as a neuro-rehabilitation tool outside the research environment.

The objective of this paper was to investigate whether playing the previously developed and validated serious game, “Barn Ruins” [121], regularly over an eight-week period would help to improve spatial navigation.

4.2 Methods

4.2.1 The intervention

The Barn Ruins game was used as the neurorehabilitation tool in this intervention study. It is a spatial navigation game that requires participants to remember their way to a treasure box in a maze environment. The game setup includes a laptop screen for display and a gaming controller for player movement (Fig. 4.1a). We used a laptop screen instead of a head-mounted display to avoid cybersickness. The VR environment is a field consisting of two connected regions. As seen in Fig. 4.1b, one region is a symmetrical rectangular with six rooms and one entrance, and another asymmetric square region with four rooms and two entrances. The playing field has a total of ten rooms and three entrances. Each trial has a learning phase that first displays the pink line to the treasure box from the top as seen in Fig. 4.1b and then the participant follows the pink line using the gaming controller in first-person view as seen on the laptop screen in Fig. 4.1a. Then there is a route-repetition phase in first-person view where the participant must find the treasure box themselves without the pink line.

The game has easy, medium and hard routes and one full game has nine trials—three at each difficulty level. For the intervention, we always started with the easy routes and went up to the hard ones. The scoring of the game was using an error-based method of visiting incorrect rooms, using help buttons and/or getting totally lost in the environment. The easy trials were scored out of 1, the medium ones out of 2 and the hard ones out of 3. The total score obtained from the Barn

Ruins game for one day was standardized to 1; it is called Spatial Learning Score herein. The higher this score is, the better performance in the game.

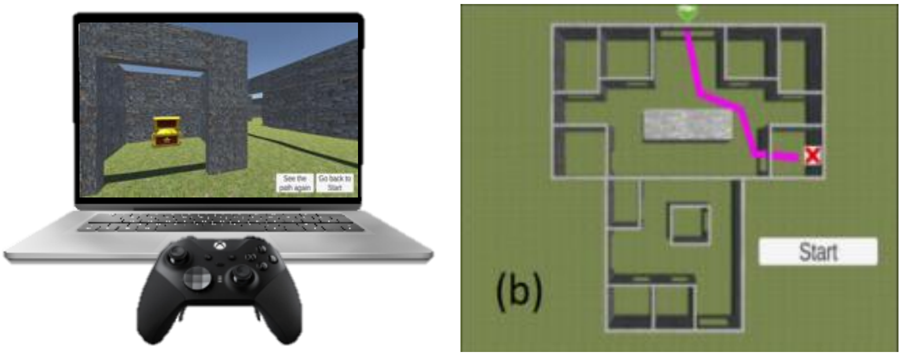


Figure 4.1. Illustration of the "Barn Ruins" game (a). The game setup of the laptop and gaming controller and a first-person view of the game on the screen. (b). The top-down view at the start of the learning phase, with the pink line showing the route.

4.2.2 Assessments

VRNHouse [76] as the primary outcome measure and Clock Orientation Test [124] as the secondary outcome measure were used as pre and post assessments for the intervention. Both of these tests are independent of the Burn Ruin game; therefore, they can assess the far-effect of the game. The VRN House is a cubic three-storey building. Each of its four sides has six windows in two left and right-side columns. For each trial, an X mark is randomly placed on one of the windows as the target. The building is then rotated for participants to view all the sides and locate the X mark. Once the building is rotated a full circle and participants see the front wall again, they are asked to recall the location of the X mark by remembering the floor, whether it was on the left or right column of the wall, and which wall of the building it was on. This is called the localization stage of the VRN, and it has a total score of 18 [108]. The VRNHouse has been validated with repeated measures on 319 50+ years old individuals as a cognitive measure for spatial orientation assessment [76, 125].

The Clock Orientation Test [124] is an egocentric orientation assessment that requires the participant to imagine that they are standing in the middle of a clock and and have to imagine rotating around the centre of the clock for the various tasks. One task involves determining the relative position of a number based on the participant's current orientation. For example, "If you are facing the number 6, which number is to your left". Another task is a pointing task, where the participant is asked to point to the positions of various numbers on the clock face based on their relative locations to the number the participant is currently facing. For example, "Imagine you are facing the number 2, can you point where the number 5 would be". The tasks get more complex across the assessment and requires mental imagery, rotation and egocentric processes which are all also needed in the Barn Ruins game. Hence, we considered the Clock Orientation Test to be an independent and suitable assessment for this intervention study.

4.2.3 Participants

Volunteer older adults over the age of 75 with MCI were recruited from a retirement living facility (Lindenwood Retirement Living facility). Cognitive impairment was measured by the scores of the Montreal Cognitive Assessment (MoCA) [90]. Our inclusion criteria were to be of age 60-99 years, mild to moderate cognitive impairment, no or minimal depression and fluency in reading and understanding English. Depression was measured by the Montgomery-Åsberg Depression Rating Scale (MADRS), where scores between 0 to 6 are considered no or minimal depression. A diagnosis of Parkinson's disease, Huntington disease, bipolar disorder, significant speech aphasia and/or major depression/anxiety were considered as exclusion criteria. We assessed MoCA for 12 volunteer older adults residing at the facility, out of which 10 met the inclusion criteria and were enrolled into the study. However, one of them withdrew from the study before the intervention started because the study schedule was demanding for them. Two other participants withdrew after starting the intervention program— one because they did not like the Barn Ruins game and one because of experiencing cybersickness. At the end, we analyzed the data of seven participants (86.3±4.9 yrs., 2 males). The detailed participants' demographics is presented in Table 4.1. Figure 4.2 provides a flowchart of the number of participants at each stage of the study. All the participants signed an informed consent form approved by the Biomedical Research Ethics Board (BREB) of the University of Manitoba, and all the study procedures complied with the BREB's guidelines and regulations [HS25611 (B2022:079)].

Table 4.1. Participant demographics

Characteristic	**Mean ± SD**
N	7 (2 males)
Age	86.3 ± 4.9
MoCA	17.7 ± 4.1
MADRS	1.7 ± 1.7

VRNHouse and the Clock Orientation Test were first assessed for each participant at the baseline (Week0). Then the participants played 30 minutes of the Barn Ruins game each day for three days a week for eight consecutive weeks. At the beginning, it took them longer to play the game, but by the end of the study, participants were able to play two full games in 30 minutes. On the first day of the intervention and the third day of every week, we had the participants play the full game at least once so that we had game data from all the difficulty levels at multiple time points for better performance analysis. On Week9, we assessed all the participants again on VRNHouse and Clock Orientation Test as the post-intervention assessments.

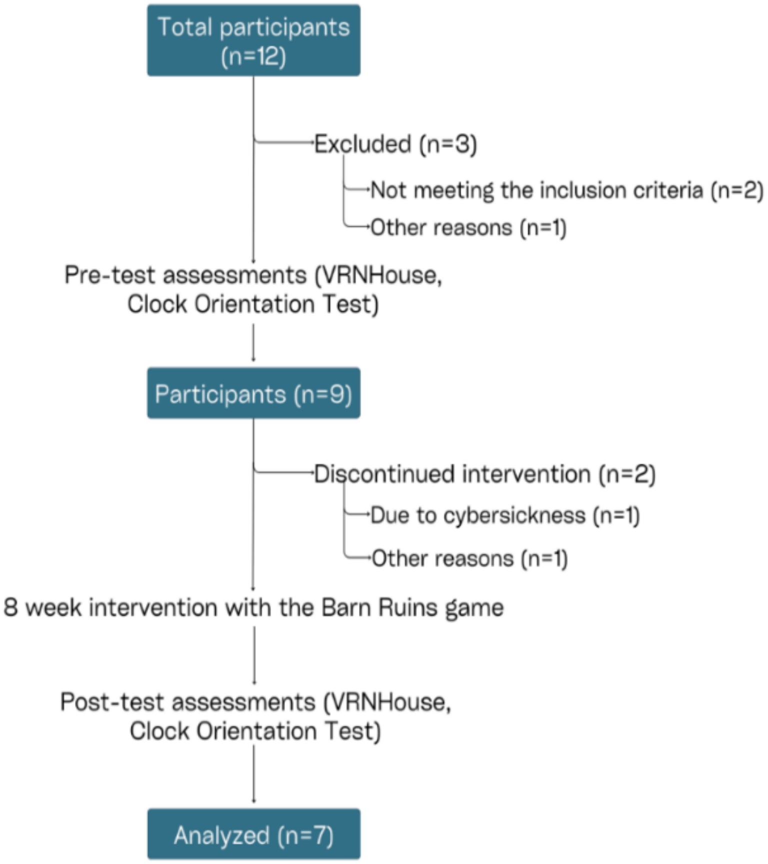


Figure 4.2. Flow chart of number of participants at each stage of the study.

4.3 Data Analysis

As the sample size was small, non-parametric tests were used for all analyses. Pre- and post-intervention assessment scores of VRNHouse and Clock Orientation Test were analysed using Wilcoxon signed rank test as the data was paired. Friedman test for repeated measures was used to investigate differences in Spatial Learning Scores over time and Kendall's W was used to calculate the effect size. Post-hoc pairwise comparison was performed using Nemenyi-Wilcoxon-Wilcox, in which the p-values were adjusted using the single-step method to adjust for multiple comparisons. The analysis was done on the total Spatial Learning Score and separately on the Easy, Medium and Hard level trials as well because we aimed to investigate whether there were different learning rates for the difficulty levels.

4.4 Result

The VRNHouse and Clock Orientation Test were conducted pre and post intervention to investigate if there were any spatial skill improvement in a task other than the Barn Ruins game. One participant was not able to do the Clock Orientation Test; hence, the analysis was done with sample size of six for Clock Orientation and with seven for VRNHouse. Table 4.2 provides the mean and standard deviation of the pre- and post- intervention scores of both the assessments and also the Wilcoxon signed rank test results. The Wilcoxon signed rank test was not significant for both the pre-post VRNHouse scores ($V = 15.5$, $p\text{-value} = 0.87$) and pre-post Clock Orientation Test scores ($V = 9$, $p\text{-value} = 0.78$). Despite the non-significant results of the VRNHouse score analysis, it should be noted that five out of the seven participants showed improved scores, but two participants showed a significant lower score at post assessment; thus, outweighing the improvements observed in the other five participants as illustrated in Fig. 4.3a. Nevertheless, the fact that five out of seven participants demonstrated improvement in the primary outcome measure represents a 71.4% success rate, highlighting the potential effectiveness of the Barn Ruins task in enhancing spatial skills. The success rate here has been defined as performance improvement or maintenance. In the Clock Orientation Test, two participants' performance decreased at post assessment and one participant's score remained the same during pre and post assessment. However, a point to note is that it is not the same two participants that decreased in Fig. 4.3a and 4.3b. The secondary outcome measure, Clock Orientation Test had a success rate of 66.7%.

Table 4.2. Pre and post intervention assessment scores [mean±sd)]

Assessment	**Pre-intervention score**	**Post-intervention score**	**Wilcoxon signed rank test statistic (V)**	**p-value**
VRNHouse (n=7)	10.9 ± 3.7	11 ± 3	15.5	0.87
Clock Test Orientation (n=6)	6.8 ± 2.7	7.5 ± 2.8	9	0.78

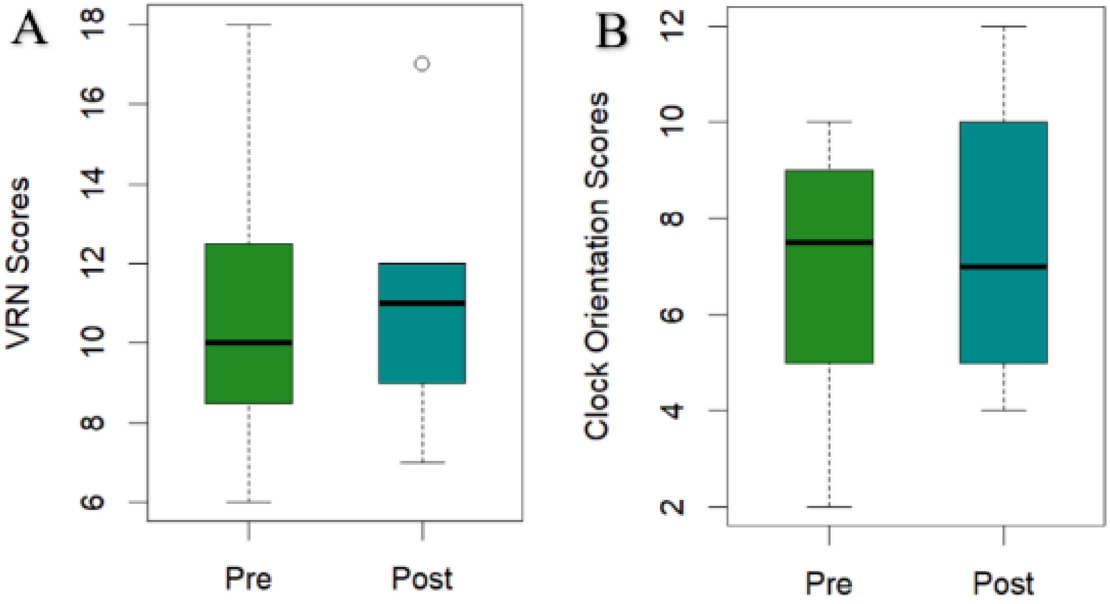


Figure 4.3. Comparison of pre-test and post-test assessment scores for (a) VRNHouse and (b) Clock Orientation Test

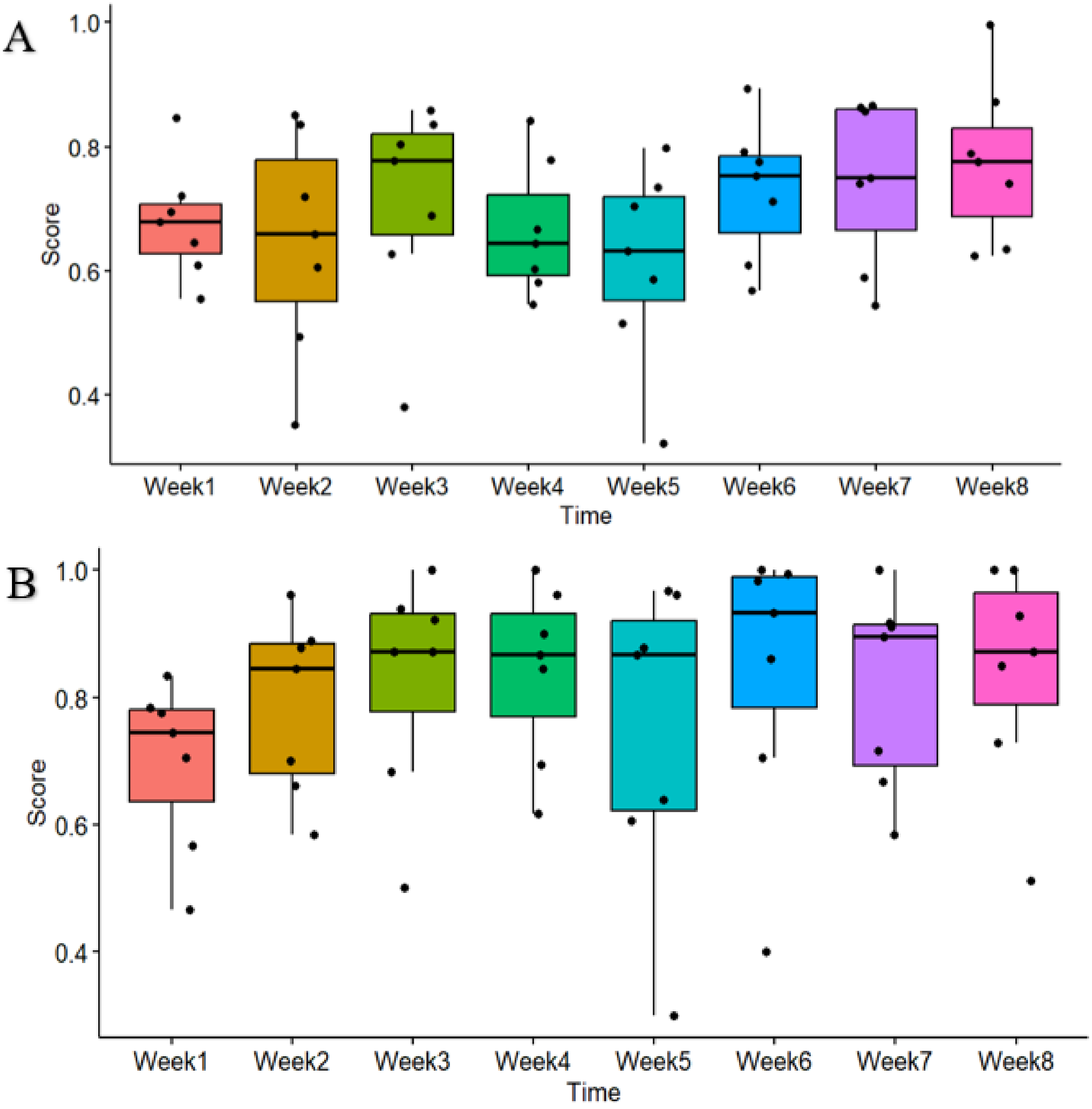
The Friedman test was conducted on the Barn Ruins spatial learning score over the eight weeks of intervention to see if performance improved in the game itself. There are visible trends of improvement in the boxplots of Fig. 4.4 a, b and d. The medium routes boxplot (Fig. 4.4c) shows that learning was most difficult for these routes as the scores across the weeks fluctuate largely without an upward trend. There were significant differences across the eight weeks in the total spatial learning score ($\chi^2(7) = 20.48$, $p = 0.005$, Kendall’s W= 0.42) and the spatial learning scores of the easy routes($\chi^2(7) = 16.24$, $p = 0.023$, Kendall’s W= 0.33) and hard routes ($\chi^2(7) =$

18.38, *p* = 0.01, Kendall's W= 0.38) with moderate effect sizes. The spatial learning score of the medium routes did not have significant differences across the eight weeks, matching the visual conclusions from Fig. 4.4c.

Table 4.3. P-values of the post-hoc pairwise comparisons of total spatial learning scores across the eight weeks using Nemenyi-Wilcoxon-Wilcox (* p<0.05)

	Week1	**Week2**	**Week3**	**Week4**	**Week5**	**Week6**	**Week7**
Week2	0.99	-	-	-	-	-	-
Week3	0.66	0.93	-	-	-	-	-
Week4	0.99	1	0.99	-	-	-	-
Week5	1	1	0.73	0.99	-	-	-
Week6	0.79	0.98	1	0.99	0.85	-	-
Week7	0.047*	0.19	0.89	0.36	0.06	0.79	-
Week8	0.047*	0.19	0.89	0.36	0.06	0.79	1

Post-hoc pairwise comparisons of the weeks were performed for the total spatial learning score and the scores of the easy routes and hard routes separately. As seen in Table 3, Week7 and Week8 had a significantly different spatial learning score from that of Week1; combined with the boxplot in Fig. 4.4a we can see that participants overall performed significantly better in Weeks 7 and 8 in comparison to Week 1. Similary, post-hoc comparisons for the easy routes showed significant differences in spatial learning scores between Week1 and Week4 (*p= 0.04*), Week1 and Week6 (*p= 0.024*) and Week1 and Week7 (*p= 0.047*). These results combined with Fig. 4.4b shows that the spatial learning score improved significantly by Week4 compared to Week1 and then stabilized. Post-hoc comparisons for the hard routes showed that Week2 and Week8 had signficant differences in spatial learning scores (*p= 0.047*) and so did Week5 and Week8 (*p= 0.016*). As seen in Fig. 4.4d, Week2 and Week5 scores are lower than the rest. In the hard routes the scores fluctuate till Week5 and then improvement is more steady.


A
1.0
0.8
0.6
0.4
Score
Week1
Week2
Week3
Week4
Week5
Week6
Week7
Week8
Time
B
1.0
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Score
Week1
Week2
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Week7
Week8
Time

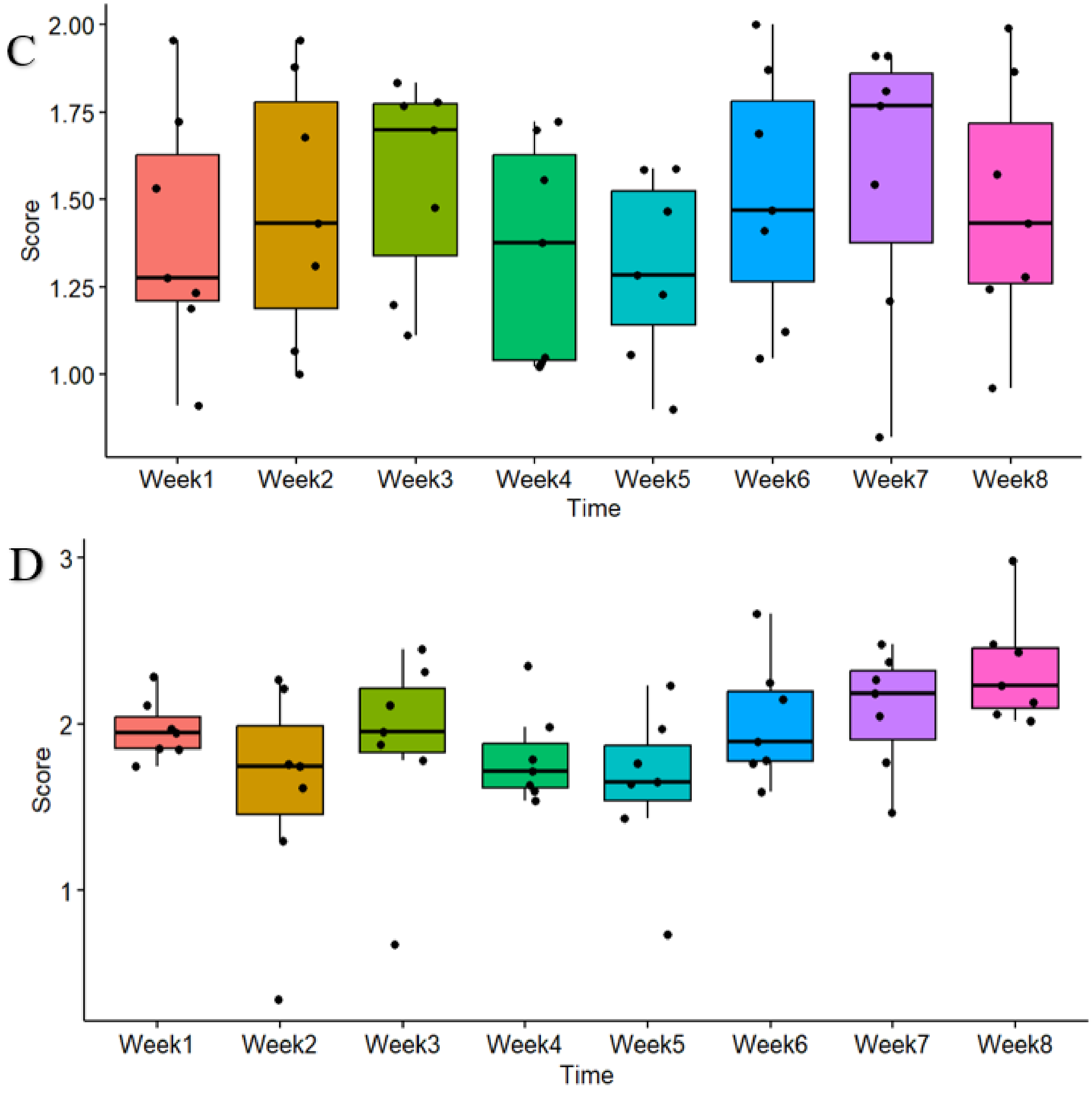

Figure 4.4. Boxplots of Barn Ruins spatial learning scores averaged across all participants over eight weeks plotted separately for (a) total score, (b) score in the easy routes, (c) score in the medium routes and (d) score in the hard routes.

4.5 Discussion

Overall, the results of this study, show that the Barn Ruins game has the potential to be used as a spatial learning rehabilitation tool for people with MCI. VRNHouse and Clock Orientation Test were used to investigate the far-effects of the intervention as these assessment tasks required similar skillsets (e.g. mental rotation and egocentric orientation) that were learnt during the Barn Ruins neurorehabilitation, and yet independent. The role of mental rotation and egocentric orientation in spatial cognition and its impairment have been established in prior research [109, 126, 127].

On playing the Barn Ruins game for eight weeks, even though the independent assessments did not have significant far effects, there was a 71.4% success rate in improving performance in the primary outcome measure, VRNHouse, and a 66.7% success rate in improving and maintaining performance in the secondary outcome measure, the Clock Orientation Test. Within the Barn Ruins game itself, between Week1 and Week8 we observed significant improvements in the total spatial learning score, showing spatial performance improvement.

The significant near-effect spatial improvement among MCI participants was congruent with results from [122]. This previous study [122] also had an 8-week intervention and post hoc results showed a significant difference between the first and last session in average of distance error. Another study [42] had an intervention of spatial learning via a driving simulator for 2 two weeks, 5days/week; their results did not show significant near effect improvement in the driving simulator but showed an upward trend in spatial learning score of the driving simulator similar to the results of the current study. Both these previous spatial intervention studies had significant far effects— in [122] using Weschsler Adult Intelligence Scale-Revised Block Design Test

(WAIS-BDT) and in the driving simulator study [42] using VR Morris Water test (total time and normalized correct trajectory), which was not significant in the current study using VRNHouse and Clock Orientation test. Possible reasons could be the small sample size or that these assessments were not well-suited to effectively measure the spatial learning outcomes from the Barn Ruins. In future intervention studies with the Barn Ruins, more commonly used spatial assessments should be used alongside the current ones.

On investigating the learning progress in the Barn Ruins closer by looking at the levels separately, we observed that learning took place differently in the different levels. The easy routes had a ceiling effect Week4 onwards as can be seen in Fig. 4.4b and from the results of the Friedman post-hoc comparisons. This makes sense as the easy routes had very few turns in some routes and participants found it easy to memorize those routes; by Week4 nearly all the participants were doing near perfect on those routes. The routes were randomly chosen; hence, we can say the improvement in scores is from spatial skill improvement and not from memorizing the routes from previous sessions. The ceiling effect in simpler spatial tasks has been documented in previous research. For instance, a study on spatial ability instruments observed ceiling effects among sophomore engineering students, indicating that the test was not sufficiently challenging to differentiate higher levels of spatial ability [128].

The spatial learning scores in medium routes had more variability between the participants and between the sessions (days). For some participants these routes felt easy and for some others hard as they verbally expressed their feedback. Thus, it was not surprising that spatial learning in the medium routes was inconsistent across the participants.

In comparison, the hard trials had much less variability. It was difficult for all participants as scores rarely went up to the maximum score; thus, we can conclude there was no ceiling effect in these routes. There was a steady progression in spatial learning in these routes.

4.5.1 Study Limitations and Future Directions

The main limitations of this study were its very small sample size and lack of a control group due to challenges in study participant recruitment. Ideally the study should have a larger sample size, and a control group matched in age, sex and cognitive status to truly investigate the benefits of the Barn Ruins game neuro-rehabilitation intervention. As we only recruited people who were interested, convenience sampling can cause sampling bias. Due to the limited sample size, the results do not provide high statistical power; hence, there was a greater possibility of type I or type II errors, and the results should be interpreted with caution.

Aside from larger sample size, an interesting addition would be to investigate how the level of impairment, measured by MoCA scores, influences the rate of learning.

4.6 Post Publication Remarks

The spatial learning scores for the medium-difficulty routes, shown in Figure 4.4c, exhibit substantial variability both between participants and across weeks. This is evident from the spread of the boxplots and the distribution of individual data points, with no clear upward or downward trend over time. For some participants, medium routes appeared relatively easy—as reflected in consistently high scores—while for others, the same routes posed a greater challenge. This subjective variability was supported by participants' verbal feedback during sessions, with reports ranging from straightforward to confusing.

Despite some visual fluctuations, the Friedman test revealed no statistically significant difference in scores across the eight weeks. This lack of significance suggests that, overall, participants' spatial learning on the medium routes did not follow a consistent trajectory over time. One possible explanation is the heterogeneous cognitive profiles of the participants, which became more apparent in the medium-difficulty routes. While the easy routes were manageable for all participants and the hard routes posed challenges for most, the medium routes fell into a grey area—some participants found them intuitive, while others struggled. This divergence in perceived difficulty likely contributed to the variability in performance, between individuals.

Additionally, variability across sessions could be influenced by route-specific characteristics within the medium category itself. Although routes were classified as medium based on prior pilot testing, it is possible that some were inherently more challenging than others due to layout complexity, number of turns, or similarity between rooms. Since routes were randomly assigned across sessions, it is plausible that participants encountered more difficult medium routes on certain days, further contributing to score fluctuations. Finally, external factors such as daily variations in mood, fatigue, or engagement may also have affected task performance in this longitudinal design.

Chapter 5. Cybersickness in Virtual Reality

Cybersickness in Virtual Reality: Insights from 14 years of Multi-Study Analysis of Influential Factors and Measurement Methods

Rashmita Chatterjee, James Teschuk, Ashley Verot, Sumeet Kalia, Zahra Moussavi

Submitted to *Human Factors*

Abstract

Objective: To retrospectively examine cybersickness (CS) challenges encountered over 14 years of conducting virtual reality (VR) experiments amongst older adults and describe patterns of symptom reporting across VR types, participant characteristics, and assessment methods.

Background: VR is increasingly used for cognitive rehabilitation in older adults, but cybersickness limits its adoption. The prevalence and nature of cybersickness in this population during VR rehabilitation remain unclear. This study retrospectively analyzes CS recorded as routine safety measures in cognitive rehabilitation VR studies.

Method: Data were compiled from 664 participants who played immersive and non-immersive VR-based navigational serious games. CS were documented through either Simulator Sickness Questionnaires (SSQ) or informal verbal reports by assessors. Analyses were conducted to explore symptom prevalence by age, sex, VR modality, and reporting method.

Results: CS occurred in both immersive and non-immersive settings, with immersive VR eliciting more frequent and severe symptom reports. Older adults and female participants were more likely to report symptoms. Differences in reporting method were notable: structured SSQ questionnaires captured a greater number of symptoms per session compared to informal verbal assessments.

Conclusion: Cybersickness remained a consistent challenge in these long-term VR studies, despite deliberate design choices to minimize risk for older adults. These findings highlight the need for tolerable, user-centered VR experiences and consistent symptom assessment protocols, as discomfort can persist even in carefully optimized VR environments.

Application: This work provides experience-based insights into managing CS in VR research in aging populations, and highlights considerations for future VR health interventions and usability studies.

5.1 Introduction

Virtual reality (VR) technologies have expanded rapidly in recent years, moving beyond entertainment into fields like physical therapy [129], cognitive rehabilitation [8, 27, 130], assessment [38, 108, 116], and mental health interventions [131, 132] for diverse populations. Among older adults, VR has shown promise for enhancing spatial cognition, supporting memory rehabilitation [12, 42], and improving overall engagement in care settings.

However, as our research group has observed while working with aging populations over more than a decade, cybersickness (CS)—a form of motion sickness induced by VR technology—remains a significant barrier to successful implementation. CS can manifest through symptoms like dizziness, nausea, oculomotor discomfort, and headache [133], and risk and severity of CS are influenced by both user-related factors and characteristics of the VR system itself, including level of immersion, interaction style, and display modality.

VR technology can vary in its immersion level and is categorized into fully immersive, semi-immersive, and non-immersive, each offering a different intensity of user involvement and sensory engagement. For fully immersive VR technology head-mounted displays (HMDs) are considered, whereas semi-immersive VR technology employs large screens or projected environments. Non-immersive or low-immersive [134] technology uses laptop or PC screens with low to no immersion in the environment. One can still interact with the non-immersive technology using gaming controllers and joysticks.

In aging populations, evidence surrounding CS susceptibility in immersive environments is mixed. Some studies suggest older adults experience less CS than younger adults in immersive environments [135–137], while others report higher sensitivity in older age groups [46, 138, 139]. Notably, literature on the effect of old age on cybersickness in non-immersive VR environments, like desktop applications, is even sparser despite these formats being common in clinical and research settings with older adults. Margrett et al. [140] in their systematic review of extended reality use in older adults, noted that 80% of the included studies used immersive headsets, highlighting a clear research imbalance. Brooks et al. [141] reported higher CS rates in older adults using a semi-immersive three-screen setup, and the study in [134] compared immersive, semi-immersive, and desktop setups; though, the latter study involved only younger adults. In real-world motion sickness, Golding [142] identified age-related effects, but equivalent low-immersion VR data are scarce. These inconsistencies highlight the need for further research examining cybersickness in older adults across both immersive and non-immersive VR formats, particularly given the growing use of these technologies in clinical and cognitive rehabilitation settings.

To err on the side of caution, while developing VR-based cognitive rehabilitation tools for older adults, our research group designed VR applications to minimize cybersickness risk based on emerging literature. Recommended mitigation strategies including self-controlled locomotion [143], low maximum virtual locomotion speeds to reduce sudden accelerations [144], and a narrowed central field of view [144, 145] were considered in our research group's VR applications. In addition, routinely adapted session protocols, hardware choices and assessment methods over time were considered to manage participants' discomfort and ensure the studies' completion. This is an important consideration when interpreting symptom reporting patterns in the present analysis, as the navigational VR tasks were purposefully optimized to reduce CS risk.

This paper presents a retrospective synthesis of CS data gathered over 14 years of conducting VR studies. Rather than testing hypotheses, this manuscript descriptively examines patterns in CS reporting across 664 participants, exploring how factors such as age, sex, motion sickness history, and reporting method influenced symptom prevalence. Importantly, we also reflect on the methodological challenges encountered in symptom elicitation and data consistency, offering practical considerations for future VR research with aging populations.

5.2 Methods

5.2.1 Overview

The VR studies in this paper, conducted between 2011 and 2024, were originally designed to examine spatial navigation abilities, cognitive function, and intervention feasibility using VR-based tasks. While primary objectives of these studies did not focus on cybersickness, symptoms were consistently monitored as a routine safety and tolerability measure. Resulting symptom data, gathered through structured questionnaires and informal verbal reports, provide a valuable dataset for reflecting on the practical challenges of managing CS in long-term VR studies involving aging populations. While participants' age ranged from 4 to 92 years, 56% (372 participants) of the total sample were 60+ years, providing a substantial basis for focusing this analysis on older adult experiences.

5.2.2 VR Games and Studies

Cybersickness symptoms were recorded during participants' interactions with three VR applications developed for spatial navigation research: VRNHouse [76], Virtual Hallway [146], and Barn Ruins [98]. All three applications involved maze-like route-finding or wayfinding tasks where participants were asked to navigate through virtual environments to reach designated target locations while remembering and retracing paths. The VR applications varied in display modality, input device, and level of immersion.

In the VRNHouse and Virtual Hallway studies, participants navigated using a customized manual wheelchair joystick, referred to as the VRNChair [87] as an input device. Participants moved in the modified manual wheelchair to navigate within the VR environment. The Barn Ruins study employed a standard Xbox-compatible gaming controller for navigation input. All participants completed tasks while seated regardless of VR format.

Immersive VR sessions used Oculus Rift DK2 head-mounted display which had an OLED panel with a resolution of 960×1080 pixels per eye, a 75 Hz refresh rate, an approximate 100° field of view, and adjustable interpupillary distance. Non-immersive sessions were presented on a 15.6-inch laptop display with 1920×1080 resolution, 60 Hz refresh rate and IPS LCD panel. Participants in immersive condition experienced stereoscopic 3D environments, while those in non-immersive condition viewed the same environments rendered on a flat screen in monoscopic 2D. The decision to use immersive or non-immersive environments was typically based on participant preference, tolerability, and study-specific design constraints. This research complied with the American Psychological Association Code of Ethics and all studies were approved by the Biomedical Research Ethics Board of the University of Manitoba. Informed consent was obtained from each participant prior to the experiments.

5.2.3 The dataset

Cybersickness data were collected between 2011 and 2024 via either the SSQ [133] or informal verbal reports. The SSQ rates the severity of 16 symptoms to produce a total CS score. In some of our studies, the study assessors gathered symptom information through unstructured verbal inquiry during or after VR sessions, typically asking about symptoms like dizziness, nausea, or headache, without standardized phrasing or checklists.

Data was adopted from the above three discussed VR spatial games, used in both immersive and non-immersive formats according to user preference. Four CS data categories were created according to symptom reporting method and immersion condition: *Questionnaire-immersive, Questionnaire-nonimmersive, Verbal-immersive, and Verbal-nonimmersive.* Age and sex were recorded for all participants.

A total of 664 participants (55.1 ± 19.8 years; 248 males) contributed data. Table 1 summarizes participants' number in each of the above four categories. Forty-six participants experienced both immersive and non-immersive sessions, with the non-immersive session always occurring first — at least 7 months and often 3–5 years before their immersive session. In immersive sessions, 15 participants had both SSQ and verbal data; these were grouped with verbal data for user factor analyses and with questionnaire data for other analyses. Repeated sessions were completed by 23 participants (14%) in Verbal-immersive and 115 (24.7%) in Verbal-nonimmersive datasets, ranging from 2–5 sessions over up to six years. Repeated sessions data handling is detailed in *Data Preparation*.

Table 5.1. Number of participants in each category of data

	Immersive VR Games (n=201)	Non-immersive VR Games (n=509)
Questionnaire (N, %)	21 (10.5%)	43 (8.4%)
Both (N, %)	15 (7.5%)	—
Verbal (N, %)	165 (82%)	466 (91.6%)

5.2.4 Converting assessor notes to CS data

Cybersickness symptoms documented through verbal reports were retrospectively coded into predefined categories for this synthesis. The 16 symptoms from SSQ [133] were used as primary categories. Additionally, a binary variable, "experienced cybersickness," was created and coded as 1 if any of these 16 symptoms were reported.

Three additional participant-related factors identified in the literature were also coded from the assessor notes when present: "Sleep problems" (including chronic sleep issues or poor sleep the night before a session), "Previous motion sickness" (any reported history of motion sickness, vestibular disorders, or dizziness/vertigo), and "Negative emotions" (self-reported or assessor-noted anxiety, stress, frustration, or diagnosed affective conditions during the session). These were selected based on prior research linking them to CS risk [66, 147–151] and their availability in session documentation. Health information was gathered informally at session start, with questions about general health and motion sickness routinely asked, while details on sleep and emotional state were frequently reported by participants spontaneously and hence used as exploratory factors.

Coding was conducted in two stages to enhance consistency and accuracy [152]. First, two coders (RC and JT) independently coded the presence or absence of experienced CS (κ=0.97) and the three additional factors across all verbal data. In stage two, a separate pair (JT and AV) independently classified CS-positive cases into the 16 SSQ symptom categories, covering 36 Verbal-immersive and 41 Verbal-nonimmersive sessions. Discrepancies were resolved through consensus.

An attempt to code symptom severity was made but abandoned due to inconsistent terminology and informal documentation practices over the 14-year period. Consequently, only symptom presence (yes/no) was coded for verbal data.

Table 5.2 provides all the Cohen's kappa (κ) values for the different CS symptoms for the Verbal-immersive and Verbal-nonimmersive data. Not all the above-mentioned symptoms were experienced. Symptoms like difficulty focusing, difficulty concentrating in the immersive data and fatigue in the non-immersive data had low initial interrater reliability because in some cases the notes were ambiguous whether the symptoms were caused by playing the game or by external factors. The sweating symptom kappa was assigned as 0 initially because there was only one data point that mentioned "cleaned the sweat of the hand" and the two coders had coded it differently. The consensus on that was it would be categorized as sweating.

The consensus process resolved other such discrepancies, resulting in a more reliable and consistent coding of the data. Post-consensus the Cohen's kappa was 1 for all the symptoms.

Table 5.2. Cohen's kappa (κ) for stage 2 of initial coding of Assessor notes

Immersive (n= 36)

Symptom	N (%)	κ
General Discomfort	3 (8.3%)	0.64
Fatigue	4 (11.1%)	0.87
Difficulty focusing	2 (5.5%)	0.53
Nausea	16 (44.4%)	0.72
Difficulty concentrating	4 (11.1%)	0.63
Blurred vision	2 (5.5%)	1
Dizzy (eyes open)	14 (38.8%)	0.94
Vertigo	3 (8.3%)	1
Stomach awareness	2 (5.5%)	0.64

Non-immersive (n= 41)

Symptom	N (%)	κ
General Discomfort	3 (7.3%)	1
Fatigue	8 (19.5%)	0.85
Sweating	1 (2.4%)	0
Nausea	14 (34.1%)	0.89
Dizzy (eyes open)	20 (48.7%)	1

5.2.5 Data Preparation

To ensure comparability across the diverse studies included in this retrospective dataset, several adjustments were made. In the Questionnaire-immersive dataset, repeated sessions existed for some participants, performed using different input devices [62]. The order of input devices was randomized to avoid carry-over effect in the study [62]. To maintain consistency, only data from sessions conducted using the VRNChair input device were retained for analysis. In the Questionnaire-nonimmersive dataset, ages and SSQ scores from repeated sessions were averaged.

A Symptom Count variable was created to enable comparisons between questionnaire and verbal data, as verbal reports lacked severity ratings and total SSQ scores. Symptom Count is the total number of distinct cybersickness symptoms reported in a session.

For repeated sessions in Verbal-immersive and Verbal-nonimmersive datasets, age and Symptom Count were averaged. Binary variables like Sleep problems and Negative emotions were considered 0/1 for absent/ present. For repeated sessions the binary values were averaged, with a threshold of 0.5 to classify presence. If the mean value for a participant exceeded 0.5, the factor was considered present. Any record of Previous Motion Sickness across sessions was treated as confirmation of its presence, given its status as a stable characteristic.

After these adjustments, the resulting datasets were independent within the four categories: Questionnaire-immersive, Questionnaire-nonimmersive, Verbal-immersive, and Verbal-nonimmersive. Available variables by dataset are summarized in Table 2.

Table 5.3. Availability of participant-related factors and cybersickness data across different data collection categories and VR technologies.

Factors	Questionnaire-immersive	Questionnaire-nonimmersive	Verbal-immersive	Verbal-nonimmersive
CS presence	✓	✓	✓	✓
Age	✓	✓	✓	✓
Sex	✓	✓	✓	✓
SSQScore	✓	✓		
Symptom frequency	✓	✓	✓	✓
Sleep problems			✓	✓
Previous motion sickness			✓	✓
Negative emotions			✓	✓

5.3 Data Analysis

Analyses were conducted separately for immersive and non-immersive VR sessions due to differences in technology, display characteristics, and participant experiences. To examine whether verbal cybersickness (CS) reporting was associated with user-related factors, multiple logistic regression analyses were performed, with presence/absence (1/0) of CS as the binary outcome. Predictors included age (per 10-year increment), sex, motion sickness history, sleep problems, and negative emotions. Separate models were run for immersive and non-immersive datasets. Correlation matrices and variance inflation factors (VIF) confirmed no multicollinearity among predictors.

To assess differences in symptom severity between immersive and non-immersive conditions, a Mann-Whitney U test compared SSQ scores from the questionnaire data (due to non-normal distributions by Shapiro-Wilk test: Immersive $W = 0.87$, $p < 0.05$; Non-immersive $W = 0.75$, $p < 0.05$). For verbal data, a Chi-square test of independence was conducted, excluding 46 participants with data in both conditions to preserve independence. A McNemar's Exact test was applied to this paired subsample.

To compare reporting methods, Mann-Whitney U tests examined differences in symptom count between questionnaire and verbal reports within immersive and non-immersive subsets. Normality assumptions were violated (confirmed by Shapiro-Wilk tests) in both immersive (Questionnaire: $W = 0.89$, $p < 0.05$; Verbal: $W = 0.49$, $p < 0.05$) and non-immersive subset (Questionnaire: $W = 0.78$, $p < 0.05$; Verbal: $W = 0.29$, $p < 0.05$). All analyses were conducted in RStudio (v4.3.1) using a nominal $\alpha = 0.05$, with results interpreted descriptively given the exploratory, retrospective nature of this work.

5.4 Results

5.4.1 Observed Associations Between User-Related Factors and Cybersickness Symptoms

To explore how user-related factors were associated with the occurrence of cybersickness (CS) symptoms, multiple logistic regression analyses were conducted on subsets of the verbal data. In the Verbal-immersive dataset, a subset of 117 sessions with complete information on user-related factors was analyzed. Demographic characteristics for both this subset and the full Verbal-immersive dataset are presented in Table 3. It is important to note that due to the opportunistic nature of data capture for sleep problems and negative emotions, regression analyses including these variables were considered exploratory.

5.4.1.1 Verbal-immersive user-related factors subset

As shown in Table 4, a history of motion sickness was associated with greater odds of reporting CS in immersive VR (OR = 3.68, 95% CI [1.14, 12.9], p = 0.032). Sex was also significant, with males less likely than females to report symptoms (OR = 0.22, 95% CI [0.07, 0.58], p = 0.004). These results should be viewed cautiously due to the modest sample size and uneven group distribution. Age per 10 years increase, sleep problems, and negative emotions were not significantly associated with CS reporting. Though the latter two were spontaneously reported rather than systematically assessed; hence should be interpreted with caution.

Table 5.4. Descriptive statistics for user-related factors impacting CS susceptibility in Verbal immersive and non-immersive data (means ± SD)

	Verbal-immersive user-related factors subset	**Verbal-immersive full dataset**	**Verbal-nonimmersive subset**
N	117	179	450
CS (present/ absent)	39/78	43/136	31/419
Age	65.4 ± 12.13	55.84 ± 19.65	56.56 ± 17.85
Age range	23- 87	17- 87	4- 91
Sex (Male/Female)	41/76	70/109	159/291
CS present (Male/Female)	6/33	6/37	9/22
Sleep problems	4	n/a	32
Previous motion sickness experience	15	n/a	24
Negative emotions	14	n/a	49

Table 5.5. Multiple logistic regression results for predicting susceptibility to CS.

Contrast	**Verbal-immersive user-related factors subset**			**Verbal-immersive full dataset**			**Verbal-nonimmersive subset**		
	OR[1]	**95% CI[1]**	**p-value**	**OR[1]**	**95% CI[1]**	**p-value**	**OR[1]**	**95% CI[1]**	**p-value**
Sleep problems (Yes vs No)	2.18	0.19, 24.1	0.5				0.87	0.14, 3.19	0.9
Previous motion sickness (Yes vs No)	3.68	1.14, 12.9	0.032*				2.04	0.46, 6.55	0.3
Negative emotions (Yes vs No)	0.39	0.08, 1.50	0.2				0.84	0.19, 2.58	0.8
Sex (Male vs Female)									
Female	—	—		—	—		—	—	
Male	0.22	0.07, 0.58	0.004*	0.17	0.06, 0.41	<0.001*	0.73	0.31, 1.60	0.5
Age (per 10 years increase)	0.91	0.65, 1.29	0.6	1.28	1.04, 1.61	0.024*	0.96	0.79, 1.20	0.7

[1] OR = Odds Ratio, CI = Confidence Interval, * significant *p*-value<0.05

5.4.1.2 Verbal-immersive full dataset

Given the larger sample size available for age and sex alone, an additional model was run on the full Verbal-immersive dataset (n = 179). In this model, both age (per 10-year increase) and sex were significantly associated with CS occurrence (age: OR = 1.28, 95% CI [1.04, 1.61], p = 0.024; sex: OR = 0.17, 95% CI [0.06, 0.41], p < 0.001). While the age effect was relatively modest, it reached statistical significance in this larger sample.

5.4.1.3 Verbal-nonimmersive full dataset

In the Verbal-nonimmersive dataset (n = 450), logistic regression analyses revealed no statistically significant associations between user-related factors and the presence of CS symptoms (Table 4). This pattern may reflect both a lower overall incidence of symptoms in non-immersive VR and the limitations of verbal reporting, which likely under-captured mild symptoms.

5.4.2 Differences in Symptom Reporting Between Immersive and Non-Immersive Environments

To examine the effect of VR environment type on symptom reporting, the percentage of sessions with CS symptoms was graphed separately by assessment method (Figure 1). In verbal reports, symptoms were noted in 17.9% of immersive and 6.6% of non-immersive sessions. In contrast, questionnaire assessments reported symptoms in 80.8% and 76.0% of sessions, respectively. These higher rates likely reflect differences in symptom elicitation rather than true differences in participant experiences — a key methodological consideration when interpreting multi-source data.

While questionnaire data revealed high symptom prevalence in both VR formats, certain symptoms—notably nausea and dizziness—were reported more frequently in immersive sessions. Verbal data showed clearer differences in overall symptom reporting between the two VR technologies, with immersive sessions associated with higher symptom frequencies.

5.4.2.1 Questionnaire subset

Statistical comparisons of these patterns confirmed these descriptive trends. A Mann-Whitney U test on SSQ scores from the questionnaire subset indicated significantly higher scores in immersive sessions (W = 978, p = 0.043, Cliff's δ = 0.26, 95% CI [0.02, 0.5]; Figure 2). The effect size suggested a small to moderate difference, though the imbalance in sample sizes between immersive and non-immersive conditions (n = 36 vs. n = 43) should be noted when interpreting this result.

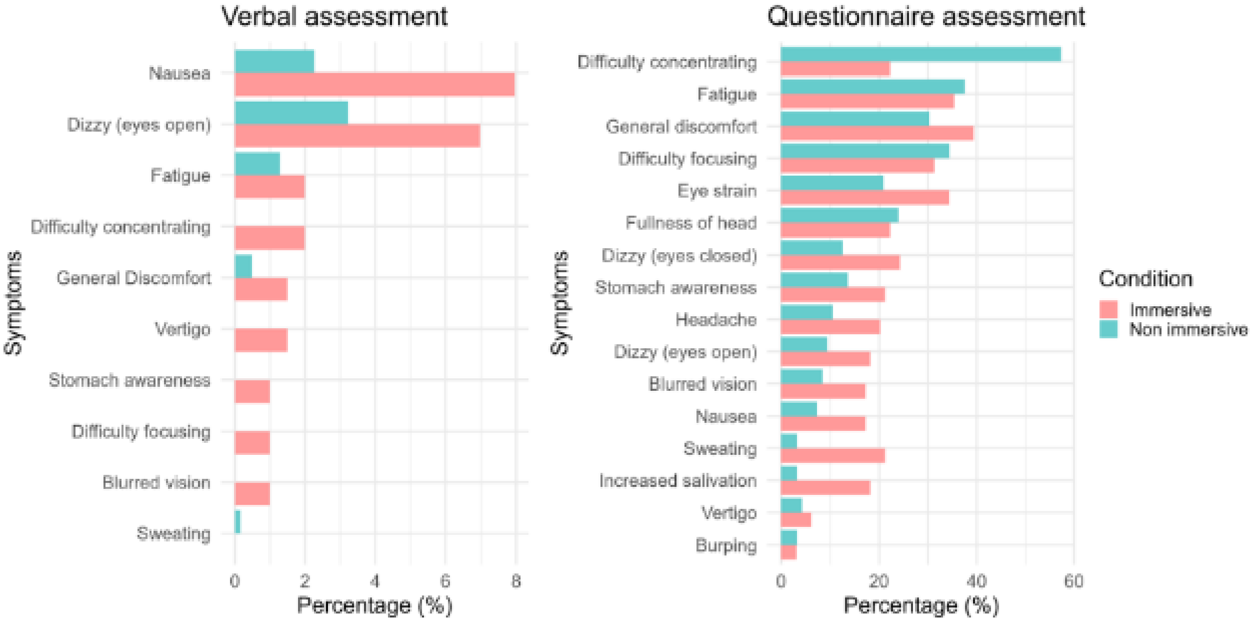

Figure 5.1. Percentage of the total sessions each of the cybersickness symptoms were experienced in; separately for verbal (Immersive (n)= 201, Non-immersive (n)= 621) and questionnaire (Immersive (n)= 99, Non-immersive (n)= 96) assessments.

5.4.2.2 Verbal independent subset

In the verbal data, a Chi-square test conducted on independent data points revealed a significant association between VR environment and CS symptom occurrence ($X^2 = 8.48$, $p = 0.0036$, OR = 2.49, 95% CI [1.38, 4.52], Cramér's V = 0.13). The modest effect size suggests a small but meaningful difference in symptom occurrence. However, as with the questionnaire data, differences in assessment method and session documentation may have influenced these frequencies.

5.4.2.3 Verbal dependent subset

A McNemar's exact test performed on the 46 participants who experienced both immersive and non-immersive sessions revealed a stronger association (OR = 4.18, 95% CI [2.13, 8.95], $p < 0.05$), indicating a large effect. It is worth noting, however, that the time between sessions for these participants varied considerably (from several months to years), introducing possible confounding factors such as changes in health status. Tables 5–7 summarize the descriptive and contingency table results for these comparisons.

Table 5.6. Descriptive statistics for influence of VR environment type on CS (means ± SD)

	Questionnaire subset	**Verbal independent subset**	**Verbal dependent subset**
N	79	534	46 pairs
VR type (Immersive/ Nonimmersive)	36/43	124/410	46/46
CS present (Immersive/ Nonimmersive)	31/28	21/31	11/0
SSQScore (Immersive/ Nonimmersive)	20.7 ± 19.4/ 13.9 ±18.8	n/a	n/a
SSQ Score median (Immersive/ Nonimmersive)	14.9/ 7.5	n/a	n/a

Table 5.7. Contingency table for the Verbal independent subset.

Verbal independent	VR Environment		
Cyber sickness	Non-immersive (n=410)	Immersive (n=124)	Total (n=534)
Absent	379 (92.4%)	103 (83.1%)	482
Present	31 (7.6%)	21 (16.9%)	52

Table 5.8. Contingency table for the Verbal dependent subset.

Verbal dependent	VR Environment		
Cyber sickness	Non-immersive (n=46)	Immersive (n=46)	Total (n=92)
Absent	46 (100%)	35 (76.1%)	81 (88%)
Present	0 (0%)	11 (23.9%)	11 (12%)

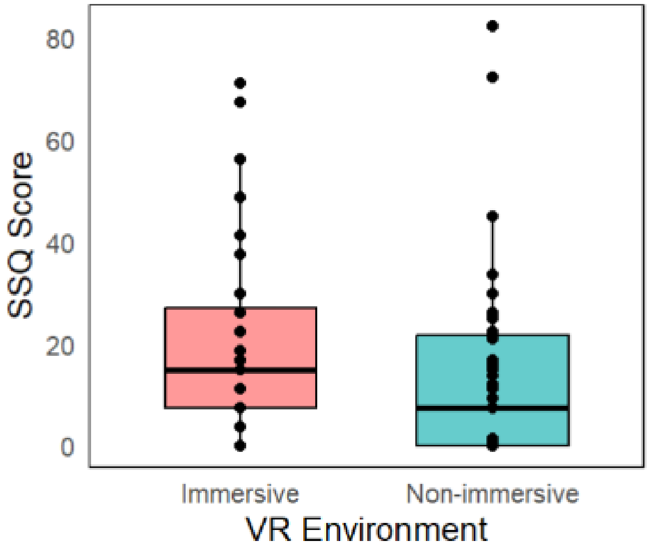

Figure 5.2. Boxplot comparing cybersickness scores (SSQ Score) of sessions in immersive and non-immersive environments in the questionnaire subset.

5.4.3 Differences in Symptom Reporting by Assessment Method

Exploratory comparisons also examined differences in symptom reporting by assessment method. As shown in Figure 1, verbal assessments consistently yielded lower symptom counts than questionnaire-based assessments. In immersive VR sessions, participants reported 9 of the 16 possible symptoms verbally, compared to all 16 symptoms on the SSQ. Similar patterns were observed in non-immersive sessions, with 5 verbal symptoms compared to 16 questionnaire-reported symptoms.

Table 5.9. Descriptive statistics for investigating effect of reporting method on number of CS symptoms reported

	Immersive subset	**Non-immersive subset**
N	201	509
Reporting method (Questionnaire/ Verbal)	36/165	43/466
Symptom count Mean ± SD (Questionnaire/Verbal)	0.8 ± 1.8 (3.6 ± 2.9/ 0.3 ± 0.6)	0.2 ± 0.8 (1.8 ± 2.3/ 0.09 ± 0.3)
Symptom count median (Questionnaire/ Verbal)	3/0	1/0

Descriptive statistics for the number of symptoms reported in each condition are presented in Table 8. In the immersive subset, the median number of symptoms reported was 3 for the questionnaire group and 0 for the verbal group, with a similar but less pronounced pattern in the non-immersive subset. These data suggest that participants tend to report a greater number of symptoms when prompted with a structured checklist than when asked open-ended verbal questions.

Mann-Whitney U tests confirmed these descriptive trends (Table 9, Figure 3). In the immersive subset, a significant difference in symptom count was observed between reporting methods ($W = 5337$, $p < 0.001$), with a large effect size (Cliff's $\delta = 0.79$, 95% CI [0.64, 0.92]). A similar though slightly smaller difference was observed in the non-immersive subset ($W = 16011$, $p < 0.001$), with a moderate to large effect size (Cliff's $\delta = 0.59$, 95% CI [0.44, 0.75]). These findings reinforce the substantial influence of assessment method on symptom reporting frequency and highlight the importance of consistent, transparent symptom elicitation protocols in future VR research with older adults.

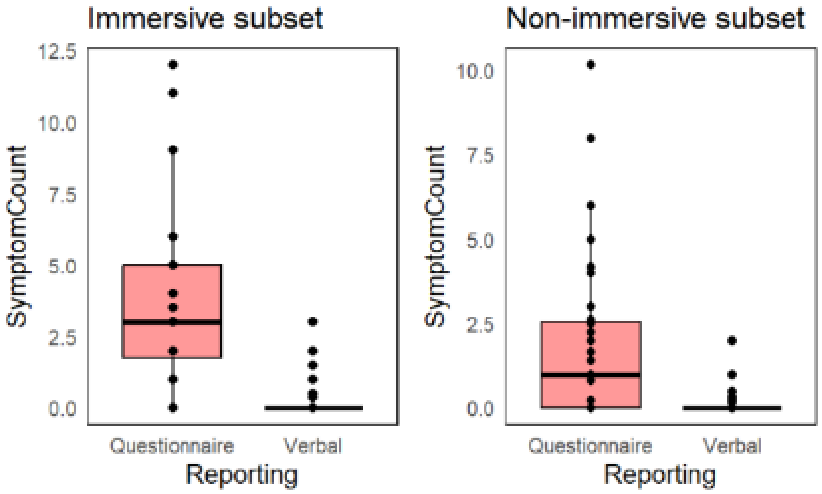

Figure 5.3. Boxplots of number of symptoms reported in questionnaire and verbal methods of reporting in immersive and non-immersive subsets separately.

Table 5.10. Mann Whitney U results of reporting method difference in number of symptoms reported for the immersive and non-immersive subset.

	W	**p-value**	**Cliff's delta**	**95% CI[1]**
Immersive subset	5337	<0.001*	0.79	0.64, 0.92
Non-immersive subset	16011	<0.001*	0.59	0.44, 0.75
[1] CI = Confidence Interval, * significant *p*-value<0.05				

5.5 Discussion

This retrospective analysis highlights the cybersickness challenges faced in VR rehabilitation studies with older adults, even when applications were designed to minimize risk. Despite mitigation strategies like self-controlled locomotion, slower speeds, and narrower fields of view, cybersickness remained a concern. These findings show the persistent risks and methodological challenges in managing CS in aging populations and the need for continued caution in VR-based cognitive interventions.

5.5.1 Age and Cybersickness

Within immersive VR sessions, we observed that age was associated with increased odds of reporting CS symptoms, with the risk rising by 1.28 times (95% CI [1.04, 1.61]) for every 10-year age increment. This result aligns with earlier work by [46, 138]. Importantly, these findings emerged despite our attempts to reduce CS risk in the VR games, indicating that susceptibility in older adults remains a concern even in carefully adjusted environments. No such age effect was detected in non-immersive conditions, highlighting the CS risk posed by immersive systems for older adults. While using VR applications, extra precaution is particularly warranted for participants 60+ years, who made up over half our sample and among whom CS reporting rates were notably higher in immersive conditions.

5.5.2 Sex and Cybersickness

In dataset used in this study, females were significantly more likely than males to report cybersickness symptoms in immersive VR environments, with a female-to-male incidence ratio of approximately 4.5:1. This aligns with prior research showing higher cybersickness reporting in females in both self-report surveys [143, 153, 154] and lab-based studies [154, 155]. Lawson and Bolkhovsky (2023) in their expansive review, similarly, noted that most positive evidence for sex differences came from studies using self-reported symptoms, while broader evidence on sex effects in motion sickness remains mixed. This difference is unlikely to be solely due to reporting bias, as a large sea passengers survey found a 5:3 female-to-male risk ratio for vomiting [157], a concrete, physiological outcome.

No sex differences were observed in non-immersive environments, unlike some earlier desktop VR studies with small, imbalanced samples (21 participants, 6 females) [134]. Prior work [154] showed sex differences appear only with forced-choice sickness classifications, highlighting the impact of assessment methods. Since our data was self-reported symptoms, the observed sex difference is consistent with patterns seen in other self-report-based cybersickness research.

5.5.3 Motion Sickness History and Cybersickness

Participants with a history of motion sickness were significantly more likely to verbally report CS symptoms in immersive VR. This result is consistent with previous research on positive correlation between motion sickness history and risk of experiencing CS [46, 66]. However, in this study, motion sickness history was collected informally without standardized phrasing, which may have led to underreporting. These findings reaffirm the importance of screening for motion sickness history in VR research, particularly when working with older adults, where self-control over virtual locomotion may not fully mitigate risk for all individuals.

5.5.4 Sleep, negative emotions and Cybersickness

Neither sleep disturbances nor negative emotions emerged as significant predictors of CS in this study. This contrasts with previous reports suggesting a link between poor sleep and increased CS susceptibility [147] and between anxiety-related symptoms and CS [148, 150, 158]. However, a key limitation is that these variables were informally assessed via assessor notes rather than structured or validated instruments. A potential explanation is the difference in study focus and population. One study that specifically investigated sleep disorders in association with CS, 50% of its participants were diagnosed with insomnia [147], while the studies whose data were used in this study relied on verbally reported sleep issues, which occurred in only 3.4% of the immersive population and 7.1% of the non-immersive population. As such, while these factors were not statistically associated with CS in this analysis, future prospective studies employing standardized measures would be needed to clarify their roles.

5.5.5 Immersive vs Non-Immersive VR Challenges

Consistent with previous studies [159, 160], participants experienced significantly more CS in immersive VR than in non-immersive environments. Immersive sessions carried 2.49 (95% CI [1.38, 4.52]) times higher odds of experiencing CS symptoms, and for participants exposed to both formats, odds were 4.18 (95% CI [2.13, 8.95], $p<0.05$) times higher in immersive sessions. Questionnaire data further showed higher CS severity in immersive conditions. These results reinforce that even with self-controlled movement, immersive VR presents a heightened CS risk, emphasizing the importance of display modality selection when working with older or sensitive populations.

Interestingly, when examining symptom frequencies (Fig. 1), certain symptoms such as difficulty concentrating, difficulty focusing, fullness of head, and fatigue appeared more frequently in non-immersive sessions. This may reflect the greater opportunity for disengagement in desktop-based VR, where participants can easily avert their gaze or self-modify exposure when discomfort arises. In contrast, immersive VR environments with the use of a headset may help maintain participants' focus on the task or can induce a sense of awe and sustained attentional engagement due to their enveloping visuals, which could lead to reporting lesser distraction. These findings highlight the potential trade-offs between immersion, engagement, and symptom awareness when designing VR studies for older adults.

5.5.6 Differences in Symptom Reporting by Assessment Method

In both immersive and non-immersive conditions, participants reported more symptoms with SSQ than verbal reports, likely because the SSQ's predefined symptom list prompts more detailed reporting. This may also reflect a "nocebo" effect, where structured questionnaires lead participants to notice symptoms they might not have otherwise identified [161]. Importantly, these methods differed, warranting cautious comparison. While widely used, SSQ was originally developed for simulators and has limitations in immersive VR [162]. Future studies should consider adopting VR-specific tools like Cybersickness Questionnaire [163] or Virtual Reality Sickness Questionnaire [164] that are better suited to cybersickness assessment [162].

It is also important to note that reporting individual symptoms does not necessarily equate to experiencing cybersickness. Symptoms like headache or eyestrain may occur in VR for reasons unrelated to motion sickness, and participants may report such symptoms while explicitly denying that they feel "sick." In this study, cybersickness was operationally coded based on symptom presence, which may overestimate sickness prevalence in the absence of direct self-assessments of overall sickness experience. Future VR studies should consider incorporating direct self-assessments of sickness presence alongside symptom inventories to clarify this nuance.

5.5.7 Practical Implications

These findings highlight important considerations for VR studies amongst older adults. Screening for prior motion sickness and choosing low-immersion VR, when possible, may reduce cybersickness risk. Balancing structured questionnaires with unprompted verbal reports can minimize reporting bias and better capture user experience. Overall, the results emphasize the need for age-sensitive, human-centered VR designs that account for system features and individual tolerability in interventions for aging populations.

5.6 Study Limitations and Future Directions

This study has several limitations. First, there was an imbalance between questionnaire and verbal data, as well as between immersive and non-immersive conditions, reducing statistical power and requiring non-parametric tests. However, the groups with less data often showed higher symptom means, suggesting no bias favoring larger groups.

Verbal cybersickness assessments were informal— without standardized phrasing—limiting severity rating and comparisons with questionnaire data to symptom counts only. Prior motion sickness was also assessed informally, possibly causing underreporting.

Variations in VR task design (hallway widths, turning angles) may have influenced cybersickness but could not be fully analyzed due to small per-application sample sizes. Device specifications might also have differed across studies, but incomplete documentation prevented further analysis of these effects. Although VR game design features aimed to reduce cybersickness, their effectiveness remains unconfirmed due to lack of control conditions. All the VR tasks had self-controlled locomotion and should not be generalized to passive VR experiences or ones where no locomotion is involved, where cybersickness responses may differ [153].

User-related factors like sleep problems and negative emotions were recorded when spontaneously reported or observed, introducing potential reporting bias and limiting interpretability; thus, these findings are exploratory. While the dataset was large, the modest number of cybersickness cases limited inferential power- reinforcing the exploratory, descriptive nature of this analysis.

Despite these limitations, this study provides valuable descriptive insights from a long-term, diverse VR dataset with over half older adult users. By synthesizing data from multiple studies with varied assessment approaches, it highlights the practical challenges of tracking and comparing cybersickness symptoms in applied VR research. Future work with more balanced sample sizes, consistent data collection procedures, standardized self-report instruments, and controlled task designs will be essential to build on these findings and more reliably identify factors influencing cybersickness in aging populations.

Chapter 6. Ways to Improve Motivation and Satisfaction when Playing Serious Games for Older Adults with Dementia

Improving Motivation and Satisfaction when Playing Serious Games for People Living with Dementia

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Abstract

Game-based therapy for people living with dementia has become popular. These games fall under serious games. Making serious games for people living with dementia engaging can be challenging. If people living with dementia are not engaged and satisfied with playing the games, they would not want to play it regularly. This would defeat one of the primary purposes of cognitive rehabilitation, as regularity in playing serious games is crucial for sustaining and improving cognitive abilities. Utilizing existing theories of technology adoption and acceptance, as well as motivation for gameplay, we identified key elements influencing long-term engagement in gaming for people living with dementia. This discussion also draws upon our experience conducting dementia studies. Motivation and satisfaction to play serious games was found to be influenced by game design components and interaction with people living with dementia. We offer recommendations for the development and implementation of serious games for cognitive programs, emphasizing strategies to enhance long-term engagement.

Key Points for Practice

- Tailored Game Design: Customize serious games by incorporating larger font sizes, intuitive controls, and simplified tasks to accommodate cognitive and motor impairments.
- Positive Interaction: Foster positive engagement by using encouraging language, avoiding elderspeak, and building rapport with people living with dementia to create a supportive and enjoyable gaming environment.
- Autonomy and Choice: Respect the autonomy of people living with dementia by offering choices within the game and allowing them to play at their own pace, ensuring a sense of control and empowerment.
- Continuous Feedback: Provide constructive feedback tailored to the individual's level of competence, focusing on specific achievements and areas for improvement to maintain motivation and engagement.
- Awareness Building: Educate caregivers, researchers, and long-term care staff about the capabilities of people living with dementia and the benefits of serious gaming interventions.

6.1 Introduction

In 2020 over 55 million people were living with dementia worldwide and there is no cure for the disease. Although medications are often used, their effectiveness is quite low [165]. In comparison, game-based therapy has been shown more success in improving and maintaining cognitive abilities of people living with dementia [5]. These special video games, known as serious games, are aimed towards educating and learning rather than just entertain.

Serious games began as traditional board games like puzzles. With the rise of video games, popular ones like Angry Birds were used for game therapy [130]. However, these games are designed by and for able-bodied, cognitively healthy individuals, making them challenging for people living with dementia. To offer effective game-based therapy, we need to customize games to accommodate the physical and cognitive limitations of the target audience.

Another significant challenge serious games face is *long-term engagement*. This means how willingly and regularly people living with dementia use the game over time. Regular play is required to improve and maintain cognitive abilities. Hence, long-term engagement is especially important for serious games. If people living with dementia are not satisfied with playing the game, they would not want to play it regularly, defeating the purpose. Our team considers this a worthwhile challenge.

Our paper explores ways to improve long-term engagement in serious games for dementia. We review current research and literature using two theoretical frameworks- the *Unified Theory of Acceptance and Use of Technology* (*UTAUT*) [67] and *Cognitive Evaluation theory* (CET) [68].

UTAUT helps us understand how users perceive and accept technology. The UTAUT says a user’s intention to use a technology is influenced by- performance expectancy, social influence and facilitating conditions. CET focuses on intrinsic motivation, which is the inherent satisfaction and excitement from doing an activity. It highlights four key principles- autonomy, competence, presence, and intuitive controls [68]. These principles either boost or hinder a person's natural motivation to play games.

By combining insights from these frameworks, our paper aims to provide recommendations to make serious games more engaging for people with dementia, ensuring they play regularly and benefit cognitively.

Figure 6.1. Older adults playing a navigation-based serious game.

6.2 Factors influencing long-term engagement and satisfaction for people living with dementia

6.2.1 Behavioural and social factors

The UTAUT theory outlines three main factors influencing the intention and continued use of technology: performance expectancy, social influence, and facilitating conditions.

1. *Performance expectancy* is the belief that using the technology will improve performance. For people living with dementia, believing that playing the game will enhance their cognitive abilities is crucial for motivation [6].
2. *Social influence* helps increase motivation for all kinds of activity. Playing serious games can be more enjoyable and motivating if done in social settings such as part of senior centre activities or with family members.
3. *Facilitating conditions* can help a user believe that the technology can support them effectively. Asking for preferences like volume and screen brightness and allowing

the user to explore the game environment before playing the game could help them get comfortable with the technology.

6.2.2 Environment and game design factors

According to Cognitive Evaluation Theory (CET), four key principles—autonomy, competence, presence, and intuitive controls—affect intrinsic motivation and engagement.

Autonomy

Feeling free to make your own choices increases motivation [69]. Games should provide non-controlling instructions and choices [68]. It is also important to respect a person living with dementia's decision if they do not want to play regularly. It is better for long-term engagement if they play it only once or twice a week when they want to rather than forcing them to stick to a regular schedule.

Competence

This is the feeling of effectively interacting with the environment [166]. Games should have intuitive controls, gradually increasing difficulty, and provide positive feedback. Early feedback should be encouraging, while later feedback should be constructive and specific. Positively pointing out errors while praising their specific achievements is an effective way for them to feel motivated. However, always keep in mind the attitude of the person living with dementia and interact accordingly. For this reason, interaction is a key aspect that we will discuss later in the paper.

Presence

Presence in the context of gaming, is the sense of feeling part of the game world [167]. A game in which a player feels more present is a game that they will enjoy coming back to and hence presence improves long-term engagement and satisfaction. Presence can be increased by providing user friendly and intuitive controls, having an engaging storyline and appealing visuals within the game.

Intuitive controls

Easy-to-use controls improve satisfaction [68]. It is difficult for people living with dementia to multi-task, so keyboard arrows and mouse are not intuitive for them. Using a single thumb stick on a gaming controller instead of the traditionally used two, can make navigation easier for people with dementia. When unable to use a technology, attributing it to their dementia and giving up on them is not fair to them. In most cases there will be some other solution that will work.

6.3 Improving motivation and satisfaction

6.3.1 Customizing the game and gadgets

Serious games should accommodate the cognitive and motor impairments of people living with dementia. Ben-Sadoun et al.'s recommendations (2018) offer valuable insights in this regard. To avoid multi-tasking, actions should be less in number, simple and easy to learn. To ensure that the game remains engaging and appropriately challenging for users at different stages of dementia, varying difficulty levels should be offered. Finally, due to impairments in memory, older adults living with dementia- depending on the severity of dementia- might not be able to retain all the information they require to achieve the goals within the game. Hence, beyond in-game instruction guidance, they need tutors to guide them regularly on what needs to be done in the game and to provide positive feedback on where they went wrong and how performance can be improved.

6.3.2 Promoting positive interaction

The quality of interaction between tutors and the people living with dementia is vital for game enjoyment. A tutor can be anyone guiding them to play the game like a caregiver at home, a student in a research environment, a care practitioner in a long-term care environment, senior centre staff members in the community. Interaction needs to be positive while playing the game, otherwise they will not want to play the game regularly [168], which would defeat the purpose of the game.

Use positive language

Positive language makes people living with dementia feel more comfortable and engaged [169]. As a tutor, being encouraging and positive creates a safe space where people will want to work on improving their performance. However, it is important to reiterate here, that positive feedback does not mean superlatives. People usually want to know mistakes they made. Feedback should be framed constructively.

Reduce elderspeak

Elderspeak is a speech style like baby talk used oftentimes to different extents by younger adults to talk down to older adults living with dementia. Elderspeak can imply incompetence that could decrease self-esteem and engagement. Older adults living with dementia react negatively to elderspeak [170]. As a tutor it is important to make a conscious effort not to use elderspeak.

Get to know the person living with dementia

For a tutor it is key to build rapport with the older adult living with dementia they are guiding to play the game. This increases the level of comfort, well-being and long-term engagement in the game. In cases where a tutor has continuous one-on-one interaction like a caregiver or a student researcher, it is easier to form a relation. In situations where the tutor is a long-term care or a senior centre staff, it is a little more difficult to do so, but important to have a basic relation with everyone they are guiding.

Build awareness about strengths of people living with dementia

Staff perceptions about capabilities of people living with dementia is one of the biggest barriers to gaming technology adoption [171]. A lot of the time, staff do not attempt to use the technology with people with advanced cognitive impairments because they think it might be disorienting [172].

People who will be tutors for the serious games need to be made aware of the strengths and capabilities of people living with dementia. Awareness sessions and demonstration videos showing people living with dementia playing serious games can help change perceptions.

6.4 Conclusion

Serious games can be a valuable recreational activity for older adults living with dementia, providing both enjoyment and cognitive benefits. When played regularly, these games can help maintain and even improve cognitive abilities. However, finding enjoyment in these games and maintaining the motivation to play regularly can be challenging. It's essential for game designers to create games that are enjoyable and accessible for people living with dementia. Tutors also play a crucial role in making game sessions interactive and engaging, helping to foster regular participation. Our paper has outlined practical solutions for improving game design and interactions. Quality of interaction with the person assisting is an overarching influence on the other elements discussed and hence it is important to focus attention on this for future research.

A key takeaway is the importance of respecting the autonomy of individuals with dementia. They should have the freedom to choose activities that enhance their quality of life and should not be forced to play games if they do not enjoy them. While playing serious games can provide cognitive benefits, any improvement is an added bonus rather than a necessity. As the population ages and technology continues to advance, future generations of older adults will likely be more familiar with gaming. This familiarity will likely lead to a greater acceptance and enjoyment of game-based therapies, making them an even more effective tool for supporting people living with dementia.

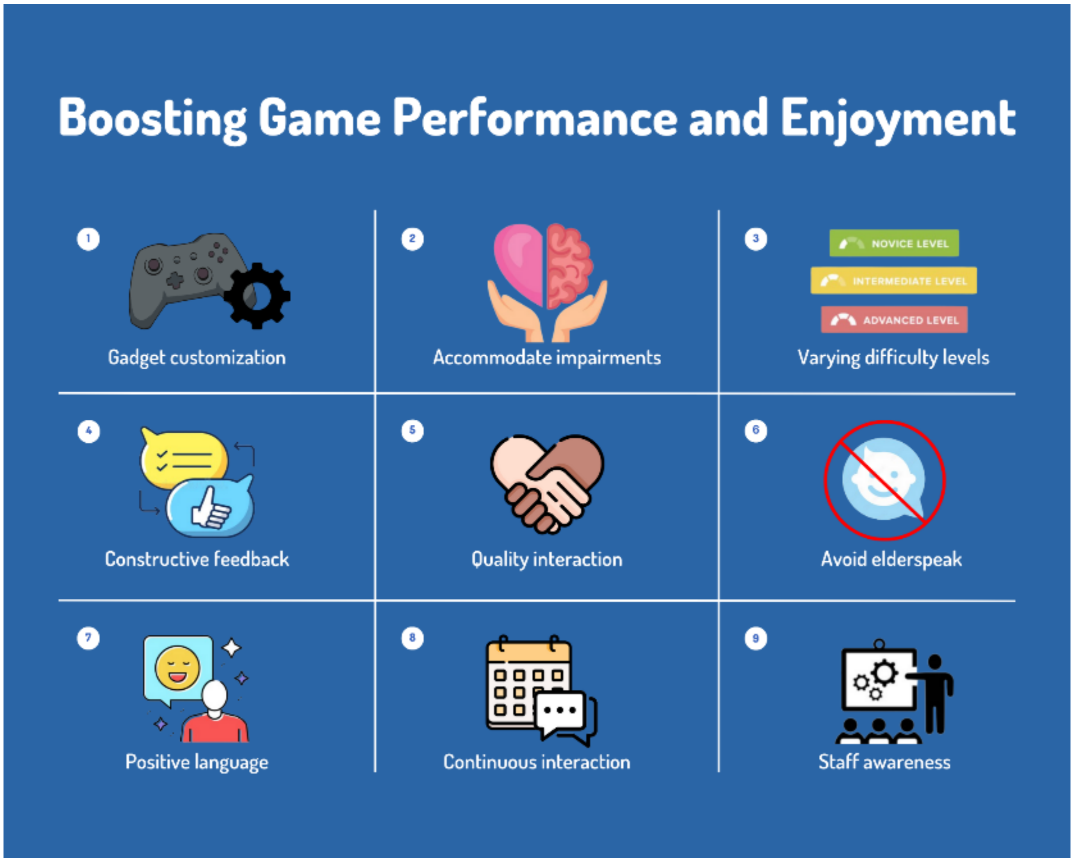

Figure 6.2. Summary infographic for boosting game performance and enjoyment

Chapter 7. Conclusion

7.1 Summary of Findings

In this series of studies, we investigated feasibility of using the Barn Ruins as a rehabilitation tool while also studying the navigation patterns of older adults with MCI and AD and the effect of different user and external factors on susceptibility to cybersickness and on motivation and satisfaction. In Chapter 2 the development of Barn Ruins and its scoring system was presented. The distance traversed parameter was shown to be influenced by experience with a gaming controller and hence this parameter was not used in the scoring system. The formulated game score was evaluated to determine whether it was influenced by prior experience with a controller. Statistical analysis indicated that controller experience did not have a significant effect on the game score. This was needed as most of our target audience would not have used gaming controllers before and we did not want experience to affect performance. The game score was found to be age sensitive with a moderately negative relationship between the two.

An observation from the exploratory study in Chapter 2 was that any route where the target could be seen from the starting point, or the turnings were far apart and curved were easier than routes where the target was hidden from sight and ones with sharp turns in quick succession. On looking at the success rates in each difficulty category (eg: Ent1-Easy, Ent1-Medium) from the data in Chapter 2, we switched around a couple of the difficulty levels and the new difficulty categories were used for the study in Chapter 3 as provided in Table 3.1.

In Chapter 3 Barn Ruins Spatial Learning Score was also found to be cognition sensitive as MoCA had a strong positive relationship with the Spatial Learning Score and regression analysis also showed that the Spatial Learning Score could explain 59.7% of the variance in the

MoCA scores of our dataset. Logistic regression and Area Under the Curve analysis showed that Barn Ruins and its scoring system had specificity of 0.95 and sensitivity of 0.7. Higher-than-average specificity demonstrates strong accuracy in correctly identifying participants without cognitive impairment. However, the R^2 of 0.597 was more important than the sensitivity and specificity as the Barn Ruins was not developed as a diagnostic tool. The moderately high R^2 shows how well the game's performance correlates with an established measure of cognitive ability like MoCA. It also demonstrates Barn Ruins' meaningful connection to the cognitive abilities that are aimed to be trained with the game.

Mental rotation of spatial representations was also studied in Chapter 3 with the Barn Ruins. For younger adults and people with Alzheimer's disease, there were no significant differences in Spatial Learning Scores grouped by entrance. Entrance in the Barn Ruins was used as a measure of mental rotation as participants had to rotate the mental map by 90 degrees for Ent2, by 180 degrees for Ent1 and did not have rotate at all for Ent3, to figure out their way to the treasure box (Fig. 2.1a). In cognitively healthy older adults, the difference in game scores grouped by entrances was statistically significant. It was significantly lower for Ent2 compared to Ent1 and Ent3. This shows that it was more difficult to rotate a mental representation by 90 degrees than it is to imagine the original representation or rotate by 180 degrees.

The Barn Ruins was assessed as a rehabilitation tool in Chapter 4 and game performance through the Spatial Learning score was seen to improve significantly from Week 1 to Week 7 and 8. Game performance had a ceiling effect for the Easy routes Week 4 onwards. On the other hand, for the Hard routes, performance fluctuated till Week 5 and then there was a steady improvement in performance. Performance in the primary outcome measure (VRNHouse) and the secondary outcome measure (Clock Orientation Test) showed no significant differences when comparing results from Week 0 to Week 9, indicating no measurable far effects. This may be attributed to the small sample size or the possibility that the assessments did not target the specific spatial components emphasized during training with the Barn Ruins. However, both assessments demonstrated moderate to high efficacy when evaluated on an individual basis. The VRNHouse showed an efficacy rate of 71.4%, while the Clock Orientation Test achieved an efficacy rate of 66.7%.

While this thesis focused on the development and evaluation of Barn Ruins as a spatial navigation game, it does not directly assess whether improvements in virtual performance transfer to real-world navigation abilities. This remains a critical gap in the current research. Future work should address this by incorporating ecologically valid wayfinding tasks in real-world settings, supported by wearable tracking technologies. Establishing such transfer effects would be essential for validating the broader applicability and clinical utility of the Barn Ruins intervention.

Cybersickness was studied in Chapter 5 using a large dataset from longitudinal studies over 14 years. This adds value to the literature on cybersickness as most studies in this field have small sample sizes while investigating factors that influence susceptibility to cybersickness. The study revealed that increased age, female sex, and a prior history of motion sickness were significant factors associated with heightened susceptibility to cybersickness in immersive environments. The study also found that immersive VR environments elicited greater cybersickness compared to non-immersive ones. Additionally, the reporting methodology influenced the frequency of reported symptoms, with the SSQ method potentially introducing a nocebo effect due to its predefined and detailed symptom list.

Lastly, factors that affected motivation and satisfaction of older adults in playing serious games was investigated through the theories of Unified Theory of Acceptance and Use of Technology (UTAUT) and Cognitive Evaluation theory (CET) along with practical experience of conducting studies for older adults. Tailored game design, positive interaction, autonomy and choice, continuous feedback and community awareness were found to be factors that could boost motivation and satisfaction of older adults playing rehabilitation games.

7.2 Recommendations for Future Work

7.2.1 Expanded intervention study with Barn Ruins: standardized spatial assessments and larger sample size in individuals with Alzheimer's disease

One of the primary limitations of the Barn Ruins intervention study in Chapter 4 was the small sample size, which restricted the statistical power and generalizability of the findings. Additionally, the lack of a cognitively healthy control group matched in age and sex hindered the ability to make robust comparisons and draw definitive conclusions about the effectiveness of the Barn Ruins game as a neurorehabilitation intervention. Future studies should aim to recruit a larger, more diverse sample, including individuals at different stages of cognitive impairment, to evaluate the intervention's efficacy more comprehensively. An important future investigation for the Barn Ruins is a sensitivity analysis for the scoring system to find the optimal deductions for each error category. Following this, the study in Chapter 3 should be repeated with a bigger sample size to have more statistical confidence in the results. Furthermore, an interesting area for exploration would be the influence of impairment severity, as measured by Montreal Cognitive Assessment (MoCA) scores, on the rate of learning within the game. This could provide valuable insights into how cognitive decline impacts spatial navigation and learning outcomes.

To further strengthen the validity of findings, future studies should integrate standardized spatial assessments alongside previously used tools like VRNHouse. Established tests such as the WAIS Block Design Test (WAIS-BDT) and the Virtual Reality (VR) Morris Water Maze could provide a more comprehensive and objective measure of spatial cognition. Longitudinal studies tracking participants over extended periods (e.g., 6–12 months) would also be beneficial to assess the long-term effects of game-based spatial training [173].

In addition to behavioral measures, neuroimaging techniques such as fMRI could be used to investigate structural and functional changes in the brain regions associated with spatial navigation. This would provide valuable evidence on the neural mechanisms underlying the effectiveness of the Barn Ruins intervention. Combining behavioral, cognitive, and neural data would allow for a more holistic understanding of the potential of serious games in dementia care.

7.2.2 Incorporating postural stability and physiological signals into cybersickness predictor analysis

Postural stability has been studied as a predictor of cybersickness measured using SSQ [174] and Fast Motion Sickness (FMS) [175]. The study in [174] did not find a significant relationship between postural sway and cybersickness. Similarly, the study in [175] found no significant correlations between occurrence of cybersickness and traditional postural sway measures. However, they found some recurrence quantification analysis-based measures were good predictors of cybersickness. Another possible reason for not finding significant relations could be that in both studies cybersickness was measured only with subjective questionnaires like SSQ and FMS.

Future cybersickness predictor analysis, similar to the one in Chapter 5, could benefit from incorporating postural stability as a predictor and more objective measures of cybersickness using physiological signals like ECG and EEG. In [176] the authors demonstrate that the time between heartbeat peaks on an ECG is less when using HMD compared to a monitor and there was a near significant main effect of display ($p= 0.056$; 20 participants, 6 women). In the case of EEG, the research in [177] revealed that the absolute theta wave activity in the occipital lobe exhibited a positive correlation with the Nausea category of SSQ while the relative theta wave activity in the temporal lobe showed a negative correlation with the Disorientation category of the SSQ. These biomarkers could be potential objective measures of cybersickness.

By integrating these objective physiological measures with standardized questionnaires, future studies can provide a more comprehensive understanding of the underlying mechanisms of cybersickness, potentially leading to more effective prediction and mitigation strategies.

7.2.3 Adaptive Game Mechanics for Personalized Spatial Rehabilitation

While Barn Ruins was designed as a serious game for spatial cognition training, future iterations should explore adaptive game mechanics that dynamically adjust difficulty based on a player’s performance and cognitive profile. Implementing AI-driven difficulty scaling, where game challenges are tailored in real time based on player performance, could enhance engagement and optimize training outcomes. For example, reinforcement learning algorithms could be used in serious games [178] to adjust navigation complexity, timing constraints, and environmental cues based on a player's learning curve. This approach would ensure that players remain challenged without becoming overwhelmed, an important factor in maintaining motivation for individuals with cognitive impairments. Additionally, integrating biometric feedback (e.g., heart rate variability, eye-tracking) could enable the game to respond to physiological signs of frustration or cognitive overload, further personalizing the experience.

7.2.4 Investigating Transfer Effects to Real-World Navigation

One of the critical questions in serious game-based interventions is whether improvements observed in virtual environments translate to real-world navigation abilities. Future research should incorporate real-world navigation assessments, such as wayfinding tasks in unfamiliar environments, to determine whether Barn Ruins training enhances everyday spatial abilities. Wearable tracking devices (e.g., GPS-based motion sensors) could be used to measure participants' real-world navigation behaviors before and after intervention. Furthermore, exploring whether improvements in spatial cognition generalize to other cognitive domains, such as working memory or executive function, would provide deeper insights into the broader cognitive benefits of serious game interventions. This could be examined through comprehensive neuropsychological assessments administered pre- and post-training.

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Appendix A. Questionnaires

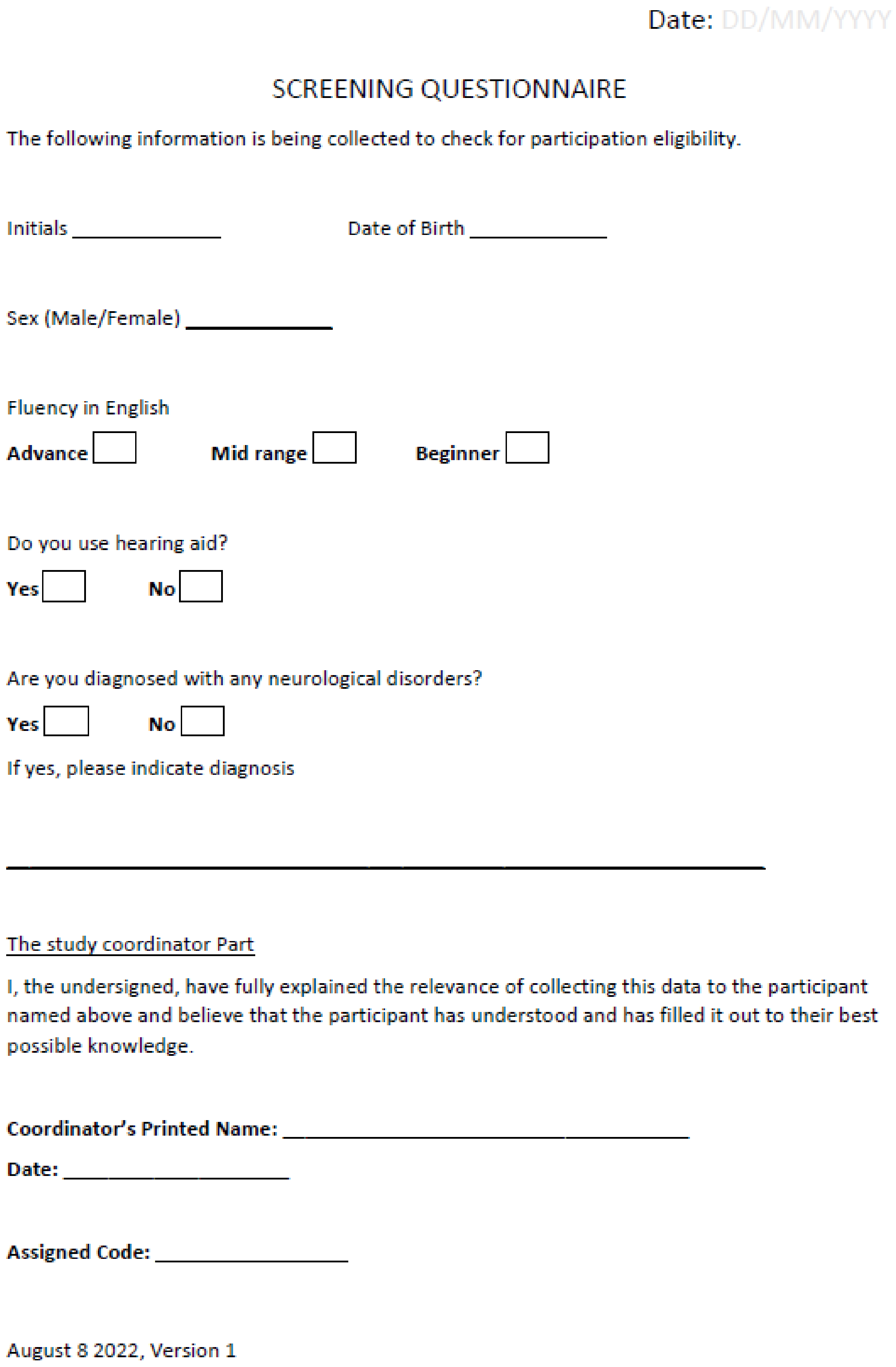
A.1 MoCA

MoCA is designed as a rapid screening instrument for mild cognitive dysfunction. It assesses different cognitive domains such as the followings:

- Attention
- Concentration
- Executive functions
- Memory
- Language
- Visuoconstructional skills
- Conceptual thinking
- Calculations
- Orientation

Administering the MoCA for cognitively healthy people takes about 10 minutes. The total possible score is 30 points; it is calculated by the sum all sub-scores with adding one point for an individual who has 12 years or fewer of formal education.

A.2 Screening Questionnaire



Date: DD/MM/YYYY

SCREENING QUESTIONNAIRE

The following information is being collected to check for participation eligibility.

Initials ______________ Date of Birth _____________

Sex (Male/Female) ______________

Fluency in English

Advance ☐ **Mid range** ☐ **Beginner** ☐

Do you use hearing aid?

Yes ☐ **No** ☐

Are you diagnosed with any neurological disorders?

Yes ☐ **No** ☐

If yes, please indicate diagnosis

____

<u>The study coordinator Part</u>

I, the undersigned, have fully explained the relevance of collecting this data to the participant named above and believe that the participant has understood and has filled it out to their best possible knowledge.

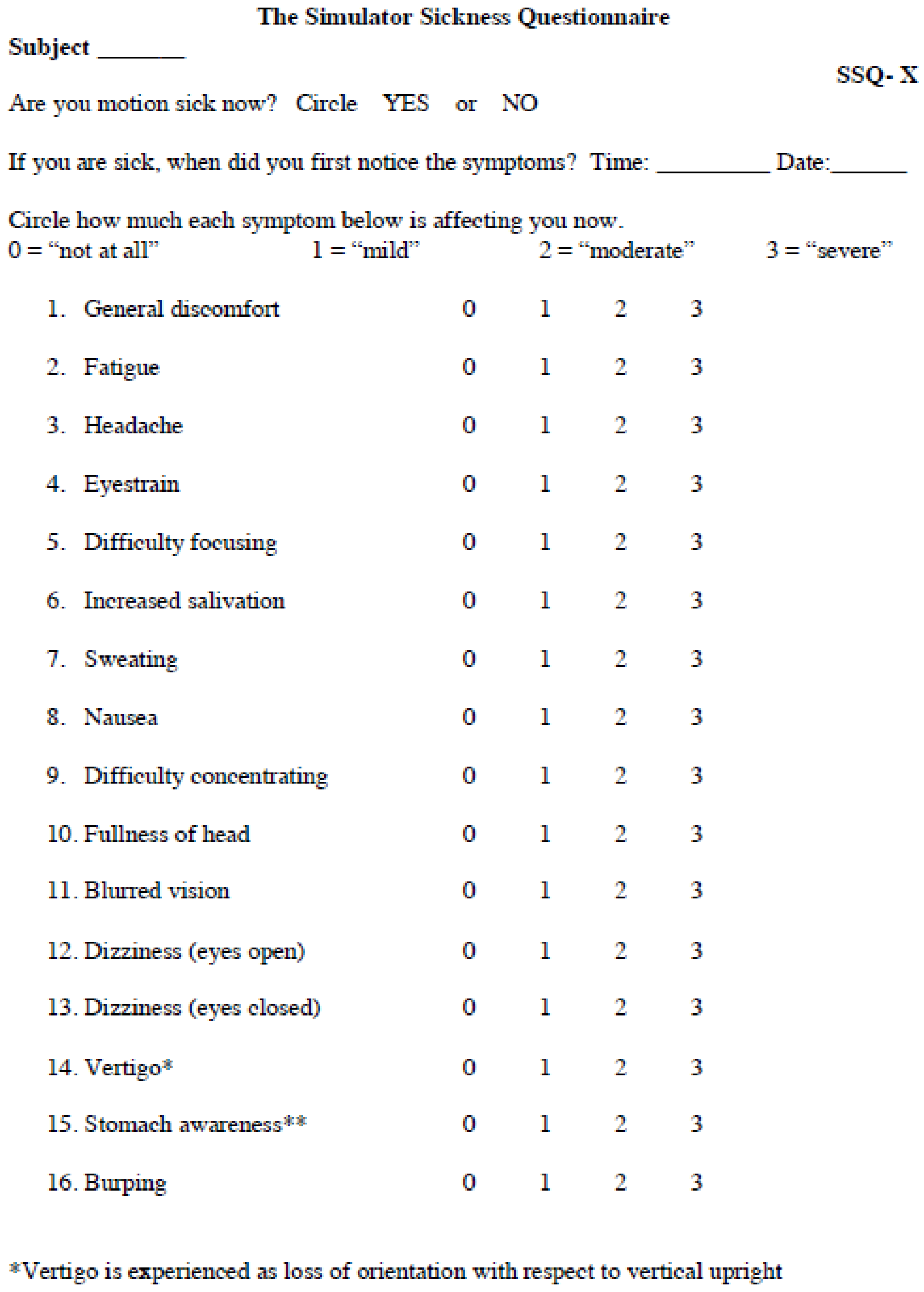
Coordinator's Printed Name: ______________________________________

Date: _____________________

Assigned Code: __________________

August 8 2022, Version 1

A.3 Simulator Sickness Questionnaire



The Simulator Sickness Questionnaire

Subject _______

SSQ- X

Are you motion sick now? Circle YES or NO

If you are sick, when did you first notice the symptoms? Time: __________ Date:______

Circle how much each symptom below is affecting you now.

0 = "not at all" 1 = "mild" 2 = "moderate" 3 = "severe"

1. General discomfort	0	1	2	3
2. Fatigue	0	1	2	3
3. Headache	0	1	2	3
4. Eyestrain	0	1	2	3
5. Difficulty focusing	0	1	2	3
6. Increased salivation	0	1	2	3
7. Sweating	0	1	2	3
8. Nausea	0	1	2	3
9. Difficulty concentrating	0	1	2	3
10. Fullness of head	0	1	2	3
11. Blurred vision	0	1	2	3
12. Dizziness (eyes open)	0	1	2	3
13. Dizziness (eyes closed)	0	1	2	3
14. Vertigo*	0	1	2	3
15. Stomach awareness**	0	1	2	3
16. Burping	0	1	2	3

*Vertigo is experienced as loss of orientation with respect to vertical upright

Appendix B. Consent Forms

B.1 Participant Information and Consent Form (Single session study)

Title of Study: “Evaluating two virtual reality serious games designed to assess spatial orientation and spatial memory, across different age groups of healthy individuals and those with memory impairments.”

Protocol version: “Ver 4, November 2022”

Principal Investigator: Rashmita Chatterjee, Biomedical Engineering, University of Manitoba, Winnipeg, Email: chatter2@myumanitoba.ca

Supervisor: Dr. Zahra Moussavi, Email: Zahra.Moussavi@umanitoba.ca

Sponsor: MITACS

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

You are being asked to participate in a research study on investigating how well our designed game score can represent aging effect. You may discuss your decision about participating in this clinical trial with your regular doctor, friends and family before you make your decision. This consent form may contain words that you do not understand. Please ask the study doctor or study staff to explain any words or information that you do not clearly understand.

The study investigator and institution are receiving funds from the funder, **MITACS, Canada** for the cost of the project to conduct this study.

Purpose of Study

This research is being conducted to evaluate two virtual reality games designed to assess memory and ability to find your way around a new environment and to investigate how well our game’s score can estimate age and memory and navigation capability.

Navigation and memory games have been shown to be useful as a rehabilitation tool. However, most of the studies in the field have used parameters such as distance traversed, and time taken to assess game performance and such parameters are affected more by experience of video games rather than age and memory and navigation capability. A previous study of our lab came up with an error scoring system with better correlation with these parameters. This research will use the concept of a formula based on counting errors and number of times one uses the help buttons for scoring game and investigate its validity by adapting it for two new game environments that require different navigational techniques that people normally use. The first game (Game 1) requires you to learn the map and remember the room in which a treasure box is hidden in a barn ruins environment. Game 2 requires you to learn the route in a castle environment to find a stolen crystal.

Screening Session

To participate in the study, you need to be of an age between 18 to 40 years or between 55- 90 years. We will check your eligibility by asking you to fill out a screening questionnaire to confirm your continuation in the study. Individuals diagnosed with Parkinson's, Parkinsonian dementia, Huntington disease, speech disorder and intellectual disability, major depression/anxiety, bipolar disorder, schizophrenia, or any other major mood disorder will be excluded. Your cognitive functioning will be screened by a questionnaire called "Montreal Cognitive Assessment (MoCA)"; those with a score between 9 to 30 out of 30 are eligible to be enrolled in this study. The screening visit is in-person in our lab at Riverview Health Centre. A screening session may take up to thirty minutes.

Time commitment

If you are playing one game, you will require a time commitment of up to 2 hours on a single day to complete the whole experiment. If you choose to play both games, you will have to come for two assessment sessions on 2 days in the same week or consecutive weeks. First session will require a time commitment of up 2 hours to conduct baseline assessments and play one of the games, and the second session will require up to one hour to play the other game and provide experiment feedback.

Experiment session(s)

A standard questionnaire will be used to assess presence of depression and if so, level of it. You will then be asked to fill out a Simulator Sickness Questionnaire (SSQ) so that you know what you are looking for if you feel sick while playing the game. Then you will be asked to play Game 2. While playing the game you will be asked verbally if you are feeling nauseous in 5-minute intervals with expected answers ranging from "no" to "moderately nauseous, want to stop". After playing the game, level of simulation sickness you might feel from playing the game will be noted in a written manner by having you fill out a blank SSQ form. If you are playing one game, this will be your only session for the experiment and after the SSQ, you will be requested to fill out a participant feedback questionnaire.

If you are playing two games, the SSQ will be run at both sessions.

The location for the session(s) will be room PE-449 (or one of the other assigned rooms for our labs on the same floor) in the administration building of Riverview Health Centre.

Assessments

We will run several assessments that include a test to assess the general level of your cognition for eligibility to participate in this study and a questionnaire for assessing presence and if so level of depression. In addition, we have a short feedback questionnaire for assessing your satisfaction after the experiment as well as another questionnaire about any simulator sickness that one may experience because of playing virtual reality games.

Benefits

There is no benefit for the participants from participating in this study other than you may enjoy playing the games. We hope the information learned from this study will benefit other people with memory and cognitive declines related to dementia and age-related cognitive disorders, such as Alzheimer's disease in the future.

Costs

All the procedures, which will be performed as part of this study, are provided at no cost to you.

You will receive no payment or reimbursement for any expenses related to taking part in this study.

Risks and Discomforts

The castle serious game (Game 2) can be used with or without head mounted display (HMD), a goggle to have full immersion in VR environment. Using the simulator with HMD will provide a higher level of immersion and sense of the reality; however, it may cause simulator sickness. For this reason, we offer playing the game using a laptop screen. If you wish to try the game with HMD; you may do so, but we will watch you carefully and with slightest motion sickness symptom, it will be removed. Game 1 will be played using a laptop screen. Although unlikely, it is also possible that some people feel motion sickness while using the laptop screen. In that case, the simulation session will be stopped immediately, and you will be withdrawn from the study. It is unlikely to happen because we have already limited the speed of character movement and camera rotation in the game to a low level so that it does not cause motion sickness. Nevertheless, in case if you present any simulator sickness symptom, the experiment will be stopped by the PI who will be there throughout the experiment observing for symptoms, and the PI will remain with you until you feel alright. The PI may withdraw you from the study if it is for your benefit.

If you will be coming for the experiment session with a caregiver, we will notify the caregiver if there is any moderate or severe symptom. The PI will let her supervisor know; they will follow up with you to check your well-being afterwards to check there is no lingering effect of simulator sickness. All these plausible issues will be documented and reported to Ethics Board.

While running a questionnaire to assess participants' depression level, if one expresses suicidal thoughts, we will encourage the participant to call his/her family doctor as well as calling the following help lines:

1. Mobile Crisis Services (204-940-1781),

2. Manitoba Suicide Prevention (1-877-435-7170),

3. Mental Health Crisis Line (204-786-8686).

Confidentiality

Information gathered in this research study may be published or presented in public forums; however, your name and other identifying information will not be used or revealed. Any document containing your identity will be treated as confidential in accordance with the Personal Health Information Act of Manitoba. The anonymized study data will be kept for 10 years after the end of the study. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

Increasingly, the scientific community, the granting agencies and medical scientific journals require that data be stored and made available for secondary review and analyses. Data sharing will of course be anonymized in terms of confidential information. Your demographic information (e.g., age, sex, etc.) along with your performance data anonymously (without your name, contact information or any identifying information) may be sent outside of the University of Manitoba or Riverview Health Centre to other researchers, academic institutions, health care facilities, or organizations for further analysis, testing or as part of the research study.

The University of Manitoba Biomedical Research Ethics Board may review research-related records for quality assurance purposes. All records will be kept in a locked secure area and only those persons identified will have access to these records. If any of your research records need to be copied to any of the above, your name and all identifying information will be removed. No information revealing any personal information such as your name, address or telephone number will leave the Riverview Health Centre. In case of any publication of results of this study, information will be provided in such a way that you cannot be identified.

With your permission, your Family Physician (GP) may be notified if we find any concern and need consult.

Voluntary Participation/Withdrawal from the Study

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time. Also, if the study staff feels that it is in your best interest to withdraw you from this study, they will remove you without your consent.

We will tell you about any new information that may affect your health, welfare, or willingness to stay in this study.

Results of the Project

All participants have the option of receiving a lay summary of their own assessments at the end of the experiment. If you wish to be informed of your results, please inform the student PI investigator at the time of your participation or you may contact the supervisor of this study, Dr. Zahra Moussavi by email (Zahra.Moussavi@umanitoba.ca).

Questions

If you require further information or if you have any problems concerning this project (for example, any side effects), you can contact the PI’s supervisor, Dr. Zahra Moussavi (204-474-7023 or 204-478-6163). For questions about your rights as a research participant, you may contact the University of Manitoba Biomedical Research Ethics Board at 204-789-3389.

Statement of Consent

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the University of Manitoba Biomedical Research Ethics Board. If you have any concerns or complaints about this project, you may contact any of the above-named persons or the University of Manitoba Bannatyne Campus at 204-789-3389**.** A copy of this consent form has been given to you to keep for your records and reference.

I agree to being contacted in relation to this study. **Yes** ☐ **No** ☐

I agree to my family physician being notified of my participation in this study. **Yes** ☐ **No** ☐

If you were told to choose if you want to play one or both games, we need the following information:

I consent to play **1 game only** ☐ **Both games** ☐

Participant signature_________________________ **Date** ___________________

Participant printed name: ________________________ **(day/month/year)**

Date of Birth: _______________

Contact Number: _______________ **Email:** _________________

****

The study coordinator Part

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent

Coordinator's Signature: ____________________________ **Date** ___________________

Coordinator's Printed Name: _________________________ **(day/month/year)**

Role in the study: ____________________________

Relationship to study team members_________________*[eg. supervisor, teacher/professor or family member.]*

Assigned Code: _________________

B.2 Participant Information and Consent Form (Intervention Study)

Title of Study: "Evaluating two virtual reality serious games designed to assess spatial orientation and spatial memory, across different age groups of healthy individuals and those with memory impairments."

Title of the sub-study: "Pilot study evaluating the Barn Ruins navigation game as a spatial skill improvement and preservation tool for older adults with memory impairments."

Protocol version: "Version 1, November 2023"

Principal Investigator: Rashmita Chatterjee, Biomedical Engineering, University of Manitoba, Winnipeg, Email: chatter2@myumanitoba.ca

Study Recruiter: Elaine Kroeker, the Director of Life Enrichment at Lindenwood Retirement Living, Email: ekroeker@lindenwood.ca

Supervisor: Dr. Zahra Moussavi, Email: Zahra.Moussavi@umanitoba.ca

Sponsor: MITACS

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you a basic idea of what the research is about and what your participation will involve. If you would like more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

You are being asked to participate in a research study investigating whether our designed game can help with improving navigation skills. You may discuss your decision about participating in this study with your regular doctor, friends and family before you make your decision. This consent form may contain words that you do not understand. Please ask the study staff to explain any words or information that you do not clearly understand.

The study investigator and institution are receiving funds from the funder, **MITACS, Canada** for the cost of the project to conduct this study.

Purpose of Study

This research is being conducted to evaluate a virtual reality game designed to assess memory and ability to find your way around a new environment and to investigate how well the game can improve memory and navigation capability by playing the game regularly.

Navigation and memory games have been shown to be useful as a rehabilitation tool. However, most of the studies in the field have used parameters such as distance traversed, and time taken to assess game performance and such parameters are affected more by experience of video games rather than age and memory and navigation capability. A previous study of our lab came up with an error scoring system with better correlation with these parameters. We came up with a game based on counting errors and number of times one uses the help buttons for scoring the game to account better for memory impairments rather than experience playing games. We now want to use this game as a training tool over 2 months and see if it improves memory and navigation abilities.

Screening Session

To participate in the study, you need to be of an age between 60 to 99 years. We will check your eligibility by asking you to fill out a screening questionnaire to confirm your continuation in the study. Individuals diagnosed with Parkinson's, Parkinsonian dementia, Huntington disease, speech disorder and intellectual disability, major depression/anxiety, bipolar disorder, schizophrenia, or any other major mood disorder will be excluded. Your cognitive functioning will be screened by a questionnaire called "Montreal Cognitive Assessment (MoCA)"; those with a score between 9 to 25 out of 30 are eligible to be enrolled in this study. The screening session is in-person at the Lindenwood Manor building of Lindenwood Retirement Living. A screening session may take up to thirty minutes.

Time commitment

You will be required to be available for 2 months from the start date at the Lindenwood Retirement Living facility. The time commitment for the training sessions would be 30 minutes on Mondays, Wednesdays and Fridays for 8 weeks. This could change with notice due to holidays, weather and/or health reasons. And one final thirty-minute session on the week after you finish training.

Experiment sessions

A standard questionnaire will be used to assess presence of depression and if so, level of it during the first session and other questionnaires to assess memory impairment level and navigation capability before training. The rest of the 24 sessions over 8 weeks will each be 30 minutes training sessions where you will be playing the navigation game we have developed. After playing the game, level of simulation sickness you might feel from playing the game will be noted in a written manner by having you fill out a blank Simulator Sickness Questionnaire (SSQ) form. Your motivation and satisfaction from playing the game will also be regularly noted by having you fill out a questionnaire. At the end of the 8 weeks, one last 30 minutes session will take place the next week where navigation assessments post training will be conducted and at the end of the study you will be asked to fill a participation feedback form.

The location for the sessions will be room the office space opposite the Enhanced Care facility in the Lindenwood Manor building of the Lindenwood Retirement Living.

Assessments

We will run several assessments that include a test to assess the general level of your cognition for eligibility to participate in this study and a questionnaire for assessing presence and if so level of depression. In addition, we have a short feedback questionnaire for assessing your satisfaction after the experiment as well as another questionnaire about any simulator sickness that one may experience because of playing virtual reality games.

Benefits

There is no benefit for the participants from participating in this study other than you may enjoy playing the games. We hope the information learned from this study will benefit other people with memory and cognitive declines related to dementia and age-related cognitive disorders, such as Alzheimer's disease in the future.

Costs

All the procedures which will be performed as part of this study are provided at no cost to you.

You will receive no payment or reimbursement for any expenses related to taking part in this study.

Risks and Discomforts

The game will be played using a laptop screen. Although unlikely, it is also possible that some people feel motion sickness while using the laptop screen. In that case, the simulation session will be stopped immediately, and you will be withdrawn from the study. It is unlikely to happen because we have already limited the speed of character movement and camera rotation in the game to a low level so that it does not cause motion sickness. Nevertheless, in case if you present any simulator sickness symptom, the experiment will be stopped by the PI who will be there throughout the experiment observing for symptoms, and the PI will remain with you until you feel alright. The PI may withdraw you from the study if it is for your benefit.

If you will be coming for the experiment session with a caregiver, we will notify the caregiver if there are any moderate or severe symptoms. The PI will let her supervisor know; they will follow up with you to check your well-being afterwards to check there is no lingering effect of simulator sickness. All these plausible issues will be documented and reported to Ethics Board.

While running a questionnaire to assess participants' depression level, if one expresses suicidal thoughts, we will encourage the participant to call his/her family doctor as well as calling the following help lines:

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2. Manitoba Suicide Prevention (1-877-435-7170),

3. Mental Health Crisis Line (204-786-8686).

Confidentiality

Information gathered in this research study may be published or presented in public forums; however, your name and other identifying information will not be used or revealed. Any document containing your identity will be treated as confidential in accordance with the Personal Health Information Act of Manitoba. The anonymized study data will be kept for 10 years after the end of the study. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

Increasingly, the scientific community, the granting agencies and medical scientific journals require that data be stored and made available for secondary review and analyses. Data sharing will of course be anonymized in terms of confidential information. Your demographic information (e.g., age, sex, etc.) along with your performance data anonymously (without your name, contact information or any identifying information) may be sent outside of the University of Manitoba to other researchers, academic institutions, health care facilities, or organizations for further analysis, testing or as part of the research study.

The University of Manitoba Biomedical Research Ethics Board may review research-related records for quality assurance purposes. All records will be kept in a locked secure area and only those people identified will have access to these records. If any of your research records need to be copied to any of the above, your name and all identifying information will be removed. No information revealing any personal information such as your name, address or telephone number will leave Lindenwood Retirement Living. In case of any publication of results of this study, information will be provided in such a way that you cannot be identified.
With your permission, your Family Physician (GP) may be notified if we find any concern and need consult.

Voluntary Participation/Withdrawal from the Study

Your decision to take part in this study is voluntary. You may refuse to participate, or you may withdraw from the study at any time. Also, if the study staff feels that it is in your best interest to withdraw you from this study, they will remove you without your consent.

We will tell you about any new information that may affect your health, welfare, or willingness to stay in this study.

Results of the Project

All participants have the option of receiving a lay summary of their own assessments at the end of the experiment. If you wish to be informed of your results, please inform the student PI investigator at the time of your participation or you may contact the supervisor of this study, Dr. Zahra Moussavi by email (Zahra.Moussavi@umanitoba.ca).

Questions

If you require further information or if you have any problems concerning this project (for example, any side effects), you can contact the PI's supervisor, Dr. Zahra Moussavi (204-474-7023 or 204-478-6163). For questions about your rights as a research participant, you may contact the University of Manitoba Biomedical Research Ethics Board at 204-789-3389.

Statement of Consent

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the University of Manitoba Biomedical Research Ethics Board. If you have any concerns or complaints about this project, you may contact any of the above-named persons or the University of Manitoba Bannatyne Campus at 204-789-3389**.** A copy of this consent form has been given to you to keep for your records and reference.

I agree to being contacted in relation to this study. **Yes** ☐ **No** ☐

I agree to my family physician being notified of my participation in this study if needed. **Yes** ☐ **No** ☐

Participant signature_________________________ **Date** ___________________

Participant printed name: ________________________ **(day/month/year)**

Date of Birth: _________________

Contact Number: ________________________ **Email:**______________________________

****

<u>The study coordinator Part</u>

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent

Coordinator's Signature: ____________________________ **Date** ___________________

Coordinator's Printed Name: _________________________ **(day/month/year)**

Role in the study: ____________________________

Relationship to study team members__________________*[eg. supervisor, teacher/professor or family member.]*

<u>Assigned Code: _________________</u>

B.3 Photography Consent and Waiver

Consent to Use My Image

I,________________________________, consent to, and authorize the University of Manitoba, including authorized representatives, successors, and assigns (collectively, the "University"), to photograph me or otherwise use my image ("my image").

I hereby grant the University the right to reproduce, use, exhibit, post, display, broadcast and/ or distribute my image on/ in an Open Educational Resource (OER), such as a journal paper, textbook, module, video, website, or other media. The collected photograph will be made freely available to the public under a Creative Commons license of the University's choosing. This license allows others to freely adapt, copy, edit, distribute, transmit, publish or exhibit the media, or use the media in other works, and is irrevocable.

I further understand that because these materials are made available under a Creative Commons license that the University of Manitoba is unable to control the use of these materials beyond its own use. Photographs are the property of the University of Manitoba.

Waiver/Release

I waive all copyright interest including moral rights, and any rights to claim royalties, or any other form of compensation or interest arising from the University's use of my image.

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☐I am more than 18 years of age.

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Appendix C. Cybersickness Data Coding Instructions

C.1 Stage 1: Cybersickness symptoms and health factors presence/absence

For each response, please code the data according to whether you feel a symptom is present or absent in the response. There is a separate column for each of the 16 common symptoms of motion sickness as mentioned in the Simulator Sickness Questionnaire (SSQ). Please mark as 1 in the column, e.g. Nausea column, if you feel the response mentions participant felt nauseous. If you do not think the response mentions nausea, mark the Nausea column 0 for that participant.

There are some symptoms mentioned across the data which I felt did not fall under the 16 common categories. For example, some mentioned "participant felt motion sickness". You can mention this keyword in the Other column and we will discuss it later. If you find words mentioned that are outside the vocabulary of the SSQ, you can use your judgement to place it in the symptom you think matches best or mention it in the Other column. Any of the ones we are confused about, we can discuss during our weekly meeting and come to an agreement.

For each response, also consider all the health factors listed. Please code the data according to whether you feel a factor is present or absent in the response. If you feel a factor was not present, rate that as 0 under that specific column, otherwise 1.

Description of the 3 health factors:

1. Sleep problems/ didn't sleep well previous night so tired – chronically has trouble getting enough sleep and wakes up tired. Cases of "I don't sleep well" but later says gets enough sleep or doesn't wake up tired in the morning, won't be counted. Cases where participant takes

sleep medication and wakes up well rested are not being counted. Basically, any chronic or the night before sleep problems that affect them during the day.

2. Previous motion sickness or any of the symptoms/ Inner ear problems- Has experienced motion sickness before or has felt any of the symptoms before, like vertigo, or feeling dizzy when getting up suddenly or balance problems. Or has had inner ear infection or chronic inner ear problems (this would lead to vestibular problems. The vestibular system plays an important role in motion sickness).

3. Negative emotions (Anxiety or anxious/ stressed/ frustrated from session) – Chronic anxiety or takes anti-anxiety pills. Also, if they felt any negative emotions during the session like anxious, stress, frustration, being hard on themselves and getting irritated that they can’t do it. However, if they mention they had anxiety many years ago and are feeling better now, don’t count that. Same for, if they used to take medication for anxiety years ago but not anymore. Do not count depression or taking anti-depression pills in this category.

Things to remember:

- Feeling disorientated in the game when it is used with phrases like “forgot”, “did not remember” usually means the orientation of the game was confusing. Whereas disorientation in the real world after playing the game is related to motion sickness. Disorientation is not one of the 16 symptoms, but Dr. Moussavi mentioned that cases where they felt disoriented in the real world after playing the game are important to flag and discuss.

C.2 Stage 2: Cybersickness symptom severity

For each response, consider all the symptoms listed. First, decide which all symptoms you feel is present in the response. If you feel a symptom was not present, rate that symptom as 0 under that specific column. If present, then you must rate the severity of the symptom you feel the response indicates. Enter the appropriate code into the column titled with that symptom. The following are the codes.

0- No symptom

1- Mild symptom

2- Moderate symptom

3- Severe symptom

There are two sheets in the excel "Stage 2 Motion Sickness Data Coding"- "Immersive" and "Non immersive". The same process needs to be done for both sheets. However, please note the list of symptoms in the 2 cases are different.

Things to remember:

- Look at the example below for some severity keywords.
- Make sure that the symptom noted in the response is associated with playing the virtual reality games. If there are reasons cited in the response that are outside of our motion sickness context, they do not count.
- Feeling disorientated in the game when it is used with phrases like "forgot", "did not remember" usually means the orientation of the game was confusing. Whereas disorientation in the real world after playing the game is related to motion sickness.

Response	**Nausea**	**Focusing**	**Real-world disorientation**	**Fatigue**	**Dizziness**
Participant felt very nauseous and this was causing some problems with focus but we were still able to complete the trials. Reported very slight dizziness afterwards which went away in 5 minutes.	3	2	0	0	1