PRELIMINARY DESIGN OF A SOCIAL ASYMMETRIC VIRTUAL REALITY UPPER-LIMB EXERGAME FOR INDIVIDUALS WITH DEMENTIA UTILIZING INSIGHTS FROM CAREGIVERS

by

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An oral defense of this thesis took place on September 11, 2023 in front of the following examining committee:

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Chair of Examining Committee	Patrick Hung
Research Supervisor	Alvaro Joffre Uribe Quevedo
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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

This thesis investigates the usability, task load, cooperative performance, and social presence effects of an asymmetric VR game for upper limb activity in the context of elderly care from the perspective of caregivers. The study presented participants with three different play modes: Cooperative within immersive VR, cooperative external to VR, and single-player within VR. The results indicate that the three conditions had above-average usability and social presence and a task load score lower than that of average daily activities. Additionally, a Sign test between the cooperative versions revealed a statistically significant difference in mean Behavioural Engagement scores favouring the version external to VR, $p = 0.031$. Although future studies with larger sample sizes are needed for an effective evaluation, these results indicate the exergame shows much promise in providing a highly usable, low cognitive load, socially involved exergame for people with dementia and their caregivers.

KEYWORDS: DEMENTIA, EXERCISE, VIRTUAL REALITY, EXERGAMING, GAMIFICATION

AUTHOR'S DECLARATION

I hereby declare that this thesis consists of original work of which I have authored. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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The research work in this thesis that was performed in compliance with the regulations of Ontario Tech's Research Ethics Board/Animal Care Committee under REB 17409 certificate file number.

Stephen Saunders

STATEMENT OF CONTRIBUTION

Sheri Horsburgh from the Ontario Shores Center for Mental Health Sciences was consulted on the exercise design described in Chapter 3 and provided feedback and ideation which influenced the final designs.

The overall design of the virtual room outlined in Chapter 3 was informed by Dr. Winnie Sun.

Several external assets were purchased from the Unity Asset Store and used to accelerate game development [19]. These include: 'Auto Hand' by Earnest Robot, 'Polygon Town' by Synty Studios, 'Low Poly Simple Furniture FREE' by Gobormu, 'Cleaner Pack' by Icosphere, 'Scratch Card' by Kostiantyn Saietskyi, and 'Technie Collider Creator' by Triangular Pixels [2, 13, 7, 3, 15, 17]. For more information on the individual uses of these assets see Chapter 3.3.

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ACRONYMS

Virtual Reality (**VR**)

People with Dementia (**PWD**)

Head-Mounted Display (**HMD**)

System Usability Scale (**SUS**)

NASA Task Load Index (**NASA TLX**)

Social Presence Gaming Questionnaire (**SPGQ**)

Cooperative Performance Metric (**CPM**)

Coronavirus Disease 2019 (**COVID-19**)

Digital Object Identifier (**DOI**)

User Interface (**UI**)

1 INTRODUCTION

Dementia is a blanket term for the many specific medical conditions that cause the degeneration of cognitive abilities that interferes with daily life [36]. People with dementia (PWD) often experience complications with short-term memory, attention, communication, reasoning, problem-solving, and visual perception [53]. As the elderly population increases, so does the prevalence of dementia, and with more than 55 million PWD worldwide and growing, it is likely that we or our loved ones could be impacted by dementia [52, 26]. Treatment of dementia-related symptoms includes pharmacological and non-pharmacological methods, the latter gaining momentum due to the unwanted potential side effects of the former, thus inspiring the development of novel solutions and aids [24, 25, 74, 39].

Among the novel approaches that are gaining momentum, immersive technologies provide moderately affordable access to controlled immersive environments that would otherwise be difficult to experience. For example, VR systems have been used to develop social connectedness and virtual tourism experiences for elderly people living in assisted living communities [30]. Immersive technology refers to technological systems that aim to alter our perception of reality while in use, thus creating a sense of immersion [27]. Such systems are often categorized into terms such as "Virtual Reality", "Augmented Reality", "Mixed Reality", and "Extended Reality", which refer to their methods of creating or modifying reality with computer graphics [94]. At present, one of the most sought-after types of new immersive technology is Virtual Reality (VR). VR is an "advanced form of human-computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion," often accomplished through systems involving real-time graphics, head-mounted displays (HMDs), and controllers [104]. Although the rise of contemporary VR only began around early 2013, often attributed to the release of the first consumer-level VR HMD from

Oculus (now Meta), it has since been adopted for uses in a variety of domains, including health care, education, and fitness [102, 22, 59]. When it comes to the implementation of VR with respect to dementia, the literature indicates the benefits of its application in reminiscence therapy, improving cognition, dementia detection, and exercise [98, 78, 111, 114].

The benefits of physical activity are well understood as well as its positive effects on older adults, helping maintain mobility and combat cognitive and physical decline [34, 65, 43]. Furthermore, when physical and cognitive interventions are combined, there is evidence of enhanced global cognitive functioning, improved mood, and increased ability to perform daily activities. [67]. Exercising requires intrinsic motivation, which can be adversely affected by its monotonous nature and pain, prompting the exploration of ways to inspire and increase participation in physical therapy. One such approach to increase engagement is the use of gamification techniques and game design elements. Gamification is the process of applying game design principles and elements to non-game contexts, such as exercise therapy [38]. For example, point systems, leader boards, and badges are commonly used strategies for using gamification [107]. Gamification has seen numerous uses over the years to motivate, actively engage, and improve the cognition of older adults [71]. Furthermore, the use of games in non-entertainment conxtes has led to its adoption into other forms of engaging activities. For example, exergames are video games focused on eliciting physical activity through game mechanics that require body movements [86]. Studies investigating the effects of exergaming on dementia found improved cognition and positive participation, which are maintained when used congruently [77, 65, 43].

Most traditional games for physical activity present single player experiences, with recent commercial games such as Beat Saber and OnShape bringing social components through multiplayer interactions and virtual coaching (this one is typical of fitness exergames). Multiplayer VR games typically require both players to own a headset, a limitation that introduces entry barriers as VR adoption continues to grow. This thesis investigates the usability, task load, cooperative performance, and social presence effects of an asymmetric VR game for upper limb activity in the context of elderly care from the perspective of caregivers. Asymmetry in VR refers to players playing the game on different media, meaning that one player is in VR and the other is not. Asymmetric games can be designed with players who possess different hardware, perspectives, or abilities [81]. For example, 'Keep Talking and Nobody Explodes' is an asymmetric game where one player uses a bomb diffuse manual printed or in PDF format, while the other player visualizes the bomb on a computer, tablet, or VR headset, requiring both players to communicate in order to reactive the bomb within the time frame. It is worth indicating, that to the best of our knowledge, nor the literature or commercial games report the use of asymmetric games for physical activity and social presences in the context of elderly care factoring caregivers.

1.1 MOTIVATION

Current interventions for PWD often involve prescribing medications, which in some cases may be inappropriate or not necessary [49]. This puts the recipient of such practices at increased risk of adverse health outcomes, as overwhelming evidence suggests that overprescribing antipsychotics and related psychotropic drugs only serves to aggravate symptoms of dementia or cause premature death [93]. Currently, there is a disproportionate number of PWDs in care facilities that are treated with neuroleptic drugs [76], often leading to a reduced quality of life and even an acceleration of cognitive decline [79]. Such a scenario has created opportunities for non-pharmacological interventions to be considered before resorting to pharmacological interventions.

Unlike pharmacological treatments for dementia, many non-pharmacological therapies can be used together without risking adverse effects or decreasing their individual efficacy [50]. Exercise therapy is a form of non-pharmacological treatment, also known as therapeutic exercise, which involves performing prescribed physical movements to maintain good physical health [91]. Unfortunately, exercise therapy can have many barriers to motivation among the elderly and PWDs as the activity is monotonous and may require a high cognitive load [106]. Furthermore, a decrease in visuomotor skills, which are often necessary with specific or repetitive exercises [82], in addition to age-related loss of physical function, can make exercise more difficult and potentially painful [92, 99].

Recently, the increasing adoption of virtual reality as a consumer-level technology is promising in overcoming some of the barriers involved in physical activity for the elderly and PWD, with current applications involving the creation of 360° VR videos with personal relevance for the individual that display relevant audiovisuals [45, 70]. Safe and controlled immersive environments are additional features of VR when limited space is available, as immersive experiences for scene navigation [30] or for exercises [109] can be achieved while in one location. Most recently, due to the COVID-19 pandemic, VR development for PWD has focused on social connectivity, and in particular involves caregivers, who are not included in several studies and can help design experiences that eliminate entry barriers associated with usability [33].

1.2 THESIS STATEMENT

The purpose of this thesis is to investigate the usability, cognitive load, cooperative performance, and social presence effects of an asymmetric social VR upper-limb experience for PWD from a caregiver's point of view under three conditions: Cooperative within immersive VR (Cooperative VR), cooperative external to VR (cooperative external), and single-player within VR (single player VR).

1.2.1 *Hypotheses*

When asymmetric multiplayer is introduced to an otherwise single-player VR upper-limb exergame, players may experience decreased cognitive load. The potential impact to usability in the asymmetric version is unclear as it relies on the performance of the second player.

The external role of the asymmetric multiplayer version may have similar social presence, engagement, and cooperative performance to the VR role of the same game. The external role may have decreased cognitive load when compared to the VR role. The single-player version of the same game should have comparable usability to the VR role and increased cognitive load when compared to either roles of the asymmetric multiplayer version.

1.3 DOCUMENT SUMMARY

In Chapter Two, a thorough review of existing literature involving VR, exercise, and gamification, where they pertain to PWD, will be presented in order to inform the design choices of the exergame and further define the gap.

In Chapter Three, the methodology and breakdown of the steps taken to create the exergame will be discussed. The justification for each design choice will be further expanded upon and the technical development will be revealed. The design of the study performed and analysis methods will also be made known.

In Chapter Four, a thorough breakdown of the results of the study will be presented and discussed including open-ended comments left by participants of the study.

In Chapter Five, a summary and final thoughts regarding any limitations and considerations for future works will concisely conclude the thesis.

2 RELATED WORK

2.1 OVERVIEW

This chapter presents a systematic review of the literature on keywords such as PWD, physical therapy, immersive technology, exergames, and the combination thereof. The purpose of the literature review is to identify what has been done, what is currently being done, and trends with regard to VR games for physical activity targeting the elderly and PWD.The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 guideline was chosen for this review of the literature [89]. The PRISMA guidelines are designed to help openly and clearly report the justification, methodology, and results of systematic reviews or meta-analyses. The PRISMA statement comprises a checklist and a flow diagram, in addition to the general practice sections, such as the abstract, introduction, and rationale. The checklist more thoroughly breaks down the methodology and results into the subsequent sections; The methodology is comprised of eligibility criteria, information sources, search strategy, selection process, data collection process, data items, study risk of bias assessment, effect measures, synthesis methods, reporting bias assessment, and a certainty assessment. The results section is divided into study selection, study characteristics, risk of bias in studies, results of individual studies, results of syntheses, reporting biases, and evidence certainty.

2.1.1 *Eligibility Criteria*

A preliminary investigation into papers on VR exergames for PWD performed through OntarioTech's implementation of the Omni academic search tool, which spans a total of 275 databases [9, 11, 10] revealed few relevant results. To discover more papers relevant to this thesis, a broader approach was taken. The key aspects related to the thesis were classified and defined by their associated keywords, resulting in four main categories: 'Elderly with Dementia', 'Exercise Therapy', 'Immersive Technology', and 'Games for Exercise' (see Table 1). Papers that involved at least three of the four categories were deemed relevant to be included. This strategy for including papers allows for the inclusion of papers that make statements about interactions between a majority of the most relevant categories to this thesis. For example, papers making statements only about exercise therapy using immersive technology for PWD can still provide useful information, despite their lack of gamification.

The vast range of technologies related to VR for exergaming and therapy has changed a lot since its inception [58]. For example, the first consumer-level VR HMD released by Oculus (later rebranded as Meta), the Oculus Rift DK1, was revolutionary for the VR market when it was released in early 2013, yet it now pales in comparison to the increased graphical quality, tracking capabilities, and performance of Meta's most recent consumer-level VR HMD [59]. As such, papers published within the last ten years have been reviewed, with the exception of those discussing fundamental concepts that are still relevant today.

Another factor that deemed a paper eligible for inclusion was its relevance to the search terms described in Table 1 as decided by each database's own relevancy algorithms, limited to the top 100 most relevant results from each database. The search algorithms of most databases used, which are outlined in the next section, are proprietary and as such little information is given about how they determine relevancy. Of the databases used, two offer open transparency in relevancy ranking (IEEE Xplore [6] and Oxford Academic [12]), three provide information on how their search engines work, but are vague about relevancy determinants (ACM Digital Library [1], PubMed Central [41] and Sage Journals [14]), and two offer almost no information (SpringerLink [16], Wiley Online [23]). The one-hundred-result limit was chosen specifically to account for potential differences in each database's algorithms whilst still aiming to keep the results relevant.

Table 1: Search categories and related search terms/keywords.

Category	Related Search Terms
Elderly with Dementia	Elderly, Aged, Older, Dementia, Cognitive Impairment, Cognition
Exercise Therapy	Exercise Therapy, Exercise, Physical Activity, Physical Rehabilitation, Physical Therapy
Immersive Technology	Immersive Technology, Immersion, Virtual Reality, VR, Augmented Reality, AR, Mixed Reality, MR
Games for Exercise	Gamification, Game Design, Game, Video Game, Exergame

The databases were chosen based on access, open or granted through Ontario Tech's libraries, and on their assessment and specific qualities, such as size and subject coverage, as outlined in the work of Gusenbauer M and Haddaway NR [57]. The databases of relevant papers discovered prior to conducting this review, Oxford Academic and Sage Journals, were also included, and the aforementioned papers were once again screened for eligibility.

A total of seven databases were used to identify relevant articles, and duplicates were removed prior to the screening process. The databases used, in alphabetical order, were: ACM Digital Library Complete, IEEE Xplore Electronic Library, Oxford Academic, Pubmed Central, Sage Journals, Springer Link, and Wiley Online Library. The databases were searched between the 6th of October 2022 and the 8th of November 2022.

2.1.2 *Search Strategy*

A diverse combination of search terms involving the keywords of each category and their synonyms, detailed in Table 1, were used within each database to identify the initial results. The search results were then constrained by the date published. Results that consisted of non-academic or informal literature, and non-text-based mediums, such as videos, were disregarded. Only full papers, no abstracts or posters, were collected.

2.1.3 *Selection Process*

The top 100 most relevant results from each database, as deemed by each database's "relevancy" methods, had their titles and abstracts manually screened and assessed to be relevant to at least 2 of the categories mentioned earlier as an initial step toward a more thorough review. This was performed to avoid spending too much time assessing each of the 700 most relevant results, since the titles and abstracts summarize the contents of the papers without having to read the entire article. This resulted in a total of 61 papers which were then more thoroughly investigated. A total of 36 articles were then excluded because they did not have relevance to 3 of the 4 categories previously outlined. A breakdown of the identification and selection process is described in Figure 1.

2.1.4 *Data Collection Process*

The articles were then compiled and organized into a spreadsheet using Google Sheets. Extracted data from each paper included the following: the title, author(s), type of publication, keywords, DOI, date published, assessment methods used, the technology used, number of participants, type of paper, main research problem, sub-research problems, and the results.

2.1.5 *Synthesis Methods*

Each manuscript was read and analyzed to determine its relevance and potential contributions to each category. Trend analysis was then performed in the final selection of articles to identify patterns over time and facilitate identification of current gaps [72]. Each aspect of the data extracted, except for the DOIs, from each paper was compared against the others to detect patterns. An initial comparison revealed two distinct categories of articles among those included in this review.

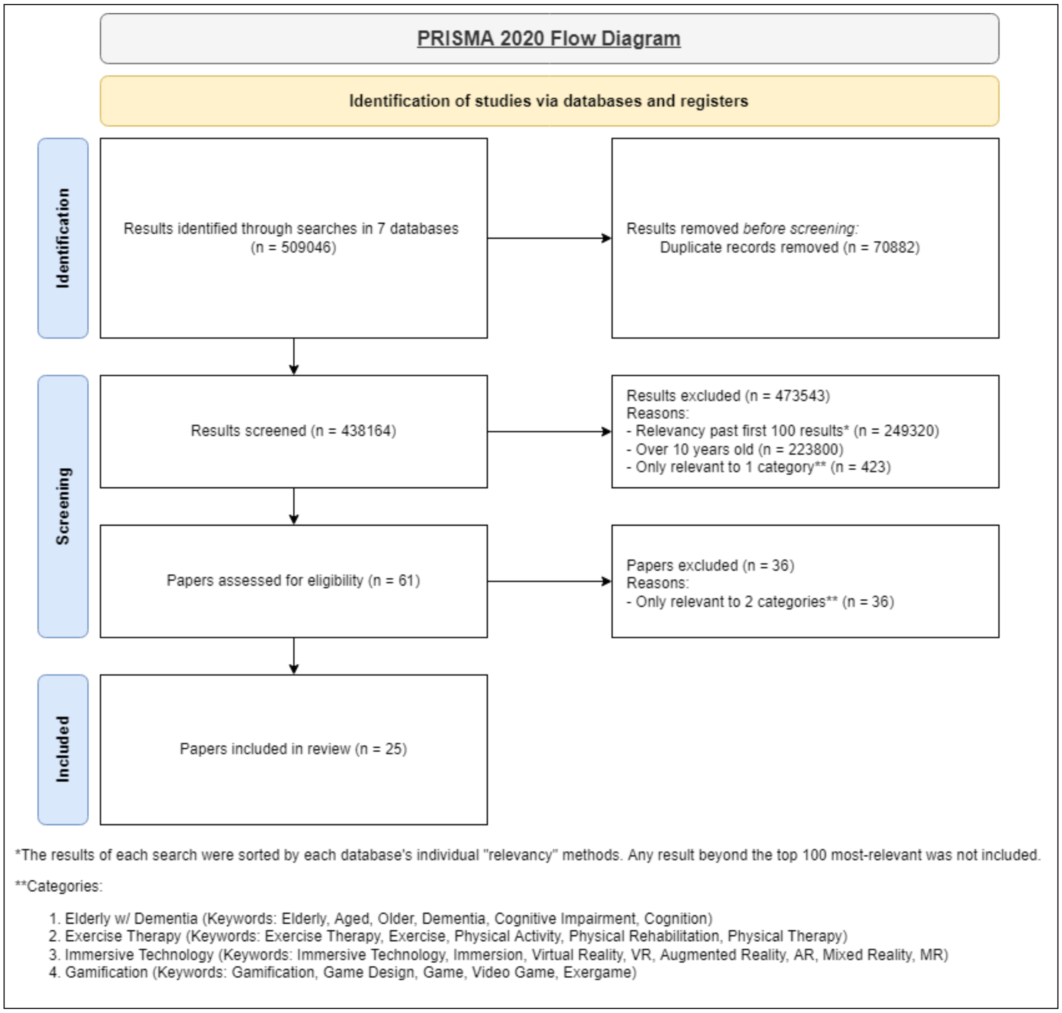


Figure 1: PRISMA 2020 Flow Diagram detailing the study identification, screening, and inclusion process.

These categories, of which each paper can only be sorted into one, are: "Framework Creation" or "Assessment."

The category of each paper is determined by its structure and content. A "Framework Creation" paper proposes a system, framework, program, or device as the paper's focal point. "Assessment" papers include all forms of assessment surrounding relevant materials, such as systematic and other literature reviews, meta-analyses, framework efficacy explorations, and other studies.

2.2 REVIEW RESULTS

2.2.1 *Study Selection*

An overview of the identification and selection process is presented in Figure 1, which presents the PRISMA flowchart for this literature review [89]. The initial search yielded 509,046 total results. These consisted of 214,830 results from the ACM Digital Library, 69,950 from IEEE Xplore, 24 from Oxford Academic, 277 from PubMed Central, 28 from SAGE Journals, 104 from SpringerLink, and 33 from the Wiley Online Library.

A total of 70,882 duplicates were removed, and the resulting 438,164 articles were screened according to the date published, the relevance of the database, and the relationship to at least one of the categories outlined in the eligibility criteria. A total of 61 articles were recovered and subjected to a second round of selection using the previously stated eligibility criteria. This resulted in an additional 36 papers being excluded as they were only relevant to 2 of the 4 categories. The final selection of manuscripts comprises the remaining 25 articles.

The basic information for each paper, including the title, authors and date published, is displayed in Table 2 and Table 3. Additionally, each work includes the main research problem of each paper.

2.2.2 *Results of Individual Studies*

2.2.2.1 *Framework Creation*

A "Framework Creation" paper proposes a system, framework, program, or device as the paper's focal point. A total of 9 papers were found to fit this description.

One such paper, the work of Munoz et al., investigated the use of human-centred design methods used in the creation of VR exergames aiming to promote physical activity for PWD [84]. To do this, they performed conceptualization, collaborative design, and playtesting activities with 7 PWD, 5 exercise professionals, 5 older adults, a VR company, and their research team of varying backgrounds. Their investigations yielded a VR exergame by the name of 'Seas the Day' and they presented a model of the interaction between the health care institution, industry partner, and academia. Their experience sheds light on the significant challenges and most important design aspects of creating such a framework. They acknowledged physical limitations such as the weight of VR headsets, risk of injury, cybersickness, and constraints such as specialized experience and headset cost. This article also acts as a call to action for future work in this field, highlighting its importance. Although no usable data has been collected, their model is currently the most up-to-date framework published.

Another paper focusing on the creation of a program is the work of Karaosmanoglu et al. [66]. This paper explored the design and development of a VR exergame for PWD through a four-step human-centred design approach. First, they collected the wants and needs of their stakeholders through semi-structured interviews. Then they conceptually designed and implemented an exergame named 'Memory Journalist VR.' Finally, they evaluated their creation through 5 focus group sessions with a total of 11 PWD and 6 people without dementia, none of whom had prior experience with VR. During the first four focus group sessions, participants played their game with the help of a health professional, and in the final focus group session, they observed caregivers leading a game session with PWD. They believe that their results show that it is possible to create and integrate a VR experience into the daily lives and routines of PWD. Finally, they indicated the importance of creating and maintaining a safe experience, having social gaming environments and shared aspects for PWD and their caregivers, and addressing the variance in declining cognitive-physical abilities through an inverse game flow.

Rather than a program, the framework developed by Abeele et al. took the form of empirically grounded design guidelines for immersive VR targeting older adults [32]. They developed 67 design guidelines as a result of an informed review of the literature. They then conducted a study with 38 participants between the ages of 55-95 years, none of whom had previous experience with VR. The study introduced them to the VR application 'Perfect' by nDreams, interviewed the participants about their experience, and performed 'UX Laddering' data analysis. Finally, they used their findings to reflect on their guidelines on what VR can offer older adults with regard to accessibility, usability, and user experience. As a result of their exploration, they concluded that older adults can express clear feelings of presence in a VR environment and that such VR experiences do not necessarily have to be simplified to be accessible to older adults.

The next framework paper presents an exergame developed by Li et al. by the name of 'MEMORIDE' [73]. They based their exergame on working memory training as an intervention for cognitive rehabilitation and used a participatory design approach to design their game for seniors with mild cognitive impairment. They evaluated their game through a study with 10 individuals with mild cognitive impairment over the age of 65. After the participants played the game for 30 minutes, a questionnaire was presented that collected feedback on perceived ease of use, challenge, enjoyment, and perceived usefulness of their game. Following this, they conducted a semi-structured interview for further insight. They concluded that their rehabilitation training in gamification was accepted, improved compliance, and is an effective motivator for participation in rehabilitation training, especially for older people who were affected by the COVID-19 pandemic at the time, or who otherwise have a difficult time getting out.

The paper by B.Y. Zhang and M. Chignell presents a person-centred design framework for serious games specifically targeting PWD [112]. Based on the results of a scoping literature review, which yielded 135 publications, they investigated popular applications of serious games, which they organized into four categories: testing, training, stimulation, and rehabilitation. Their resulting framework employs a Montessori method applied to older adults. Although the validity of their framework was not evaluated within the paper, they concluded that future serious games for PWD would benefit from a person-centered design approach and intend their framework to aid in the strategic design and development of future serious games.

The paper by Rings et al. introduces a VR exergame for PWD that aims to provide personalized moto-cognitive therapy [95]. They employed a human-centred design approach where all of their design choices were based on the results of focus groups and consultation with experts. They conducted two prototyping sessions at a hospital for older adults where participants played an early version of their exergame, which had them conducting an orchestra. The first session had 7 participants with an average age of 81.43, 2 of them PWD. The second session had 4 participants with an average age of 81.5, none of whom were PWD. During these sessions, they took observational notes and collected qualitative feedback, the results of which determined that the motions performed aligned with the opinions of a physiotherapist. They conclude that their exergame motivates older adults and PWD to perform physical activities daily through their virtual reality experience.

The work of M. Chignell, H. Matulis, and B. Nejati outlined a system they developed intended to motivate older adults to exercise [44]. They investigated the need to motivate exercise by analyzing data from the American Time Use Survey and determining that sedentary activities increase as people age. After reviewing early research on pedaling exergames, they developed various exergaming scenarios that combine engaging video content that can only be viewed while pedaling an exercise bike, social interaction, and competition as forms of extrinsic motivators. Although they hosted events that showcased their technology with an average of 15 attendees each session, no empirical information is given on the efficacy of their development.

A paper by Eisapour et al. presented two virtual reality environments with the goal of increasing the accessibility of exercise to PWD [51]. They compared the programs with therapist-guided exercises over 3 weeks of trials conducted with 6 PWD. During each week, the participants took part in 20-minute sessions, 5 days a week, where they compared 5 selected motions between a real-world guided method and their implementation of the motions as interactions within the virtual environments. After each daily session, participants received a questionnaire to assess their enjoyment and feeling of having exercised adequately. At the end of each week, another questionnaire was presented to evaluate feelings of comfort, perceived difficulty, engagement, and interest in the scenarios. They acknowledged limitations with the qualitative evaluations and small sample size, and concluded that their work appears to generate performance on par with human guidance and motivates its users to continue the exercise activities until they felt they had exercised adequately for the day.

The last framework paper that was investigated was by Boger et al. and describes the iterative, participatory design, and development of a VR exergame aiming to promote physical exercise in PWD [42]. Throughout the design process, they involved kinesiologists, recreational therapists, and PWD. After the results of two design iterations, they selected five motions for their game scenario consisting of head rotation, reaching straight ahead, cross-body reaching, lifting both arms, and rowing with both hands. Once they had created a prototype program, they presented it to 6 kinesiologists/recreational therapists and four residents in a long-term care facility. This garnered a lot of positive feedback regarding enjoyment, level of engagement, and degree of motion used by the game. Using the feedback, they iterated upon their design and conducted a pilot test with 3 PWD playing the game seated. They acknowledge that further experimentation is needed to effectively evaluate their exergame, and conclude that based on the feedback garnered from their tests, their exergame shows promising results in motivating exercise in PWD.

A common link, found between six of the articles, was the expressed importance of involving PWD in the design process through a participatory or human-centered design process [84, 66, 73, 112, 95, 42]. Another common trend among the articles was the perceived ability of their solutions to motivate participation in rehabilitation interventions, and four of the articles expressed this trend that has developed in terms of physical activity [95, 44, 51, 42], and one regarding the trend of working memory training [73].

Although most of these articles had little empirical data to validate the efficacy of their individual solutions, many of them investigated the literature available at the time and identified similar gaps they aimed to fill, namely the need for a VR experience that promotes physical activity in PWD. Additionally, these papers identify a number of guidelines and suggestions for future work, including the need for further research within this domain, involving PWD in the design process, addressing variance in cognitive-physical abilities, including social gaming environments and shared aspects, and creating/maintaining a safe experience.

2.2.2.2 *Assessment*

An "Assessment" paper is one that assesses or evaluates papers, studies, and frameworks relevant to 3 of the 4 categories described in the eligibility criteria (See Table 1). These include systematic and other literature reviews, meta-analyses, framework efficacy explorations, and other studies. A total of 16 papers were found to fit this description, 11 of which are literature reviews [103, 113, 96, 101, 115, 97, 46, 83, 110, 71, 77]. As the literature reviews contain less variation in their methods, discussion of their methods in this paper will naturally take up less space than those discussed in framework papers or assessment of framework papers. This fact does not devalue their contributions.

In their review of the effects exergames have on the brains and cognition of older adults, M. M. Torre and J.-J. Temprado employed the PRISMA guidelines which resulted in 23 studies being included [103]. Papers that were not qualitative reviews did not test conventional combined training interventions, did not concern healthy older adults, or did not report measures of cognitive outcomes were excluded from their review. They evaluated the included papers through a structured framework similar to the classic PICO procedure. They concluded that regardless of the type of training, exergaming may improve the cognitive processes of healthy older adults, which they found to be consistent with most previous reviews. However, they also pointed out that 8 of 11 studies they reviewed that compared exergames with conventional means did not reveal superiority to exergaming.

Two of the papers included in this review were similarly systematic reviews of the effects of exergaming on PWD. One of them, the work of Zhao et al., aimed to summarize the results of such articles on physical and cognitive functions, and the other, the work of Santen et al., aimed to summarize the results on quality of life and physical, cognitive, emotional, and social functioning of PWD [113, 96]. Both followed the PRISMA guidelines. The first of the two included 10 articles after filtering for randomized controlled and controlled clinical trials, exergaming interventions, participants with dementia, and results related to cognitive and physical functions. They found that 7 of the studies, which had a low risk of bias, showed statistically significant effects of exergaming on the cognitive functioning of PWD, and 3 of 5 full-scale studies indicated positive results on physical functioning. Meanwhile, the review by Santen et al. only included studies on exergames for PWD which were randomized controlled studies, and compared their results with other interventions, of which they found 3. They found that 2 of the 3, which had small sample sizes, found that exergaming had statistically significant effects on the physical, cognitive and emotional functioning of PWD.

Similarly, a systematic review, by Robert Stojan and Claudia Voelcker-Rehage, investigated the effects of exergaming on cognitive functions and potential neurophysiological correlates, specifically with regard to healthy older adults [101]. They also followed the PRISMA guidelines and used an extensive list of selection criteria to ensure relevancy and high methodological quality. They examined 15 eligible studies and concluded that exergames appear to be equally or slightly more effective when compared to other physical interventions for improving cognitive functions. They also noted that tailored exergames, developed with much consideration, have the potential to garner more significant effects on cognitive functions.

Some articles focused on VR for PWD or older adults and included games or physical therapy in their results. Two articles investigated VR solutions for PWD and two articles investigated VR solutions related to the physical functioning of older adults. The first of these reviews was conducted by Zhu et al. [115]. The Web of Science database was the only database used, and papers were excluded from their review if they were not officially published, unrelated, duplicates, or conference abstracts and proceedings, which yielded 230 included papers. This review did not analyze the efficacy of the papers included, but instead the trends involved. Having been published in January 2022, their trend results are incredibly up-to-date and reveal that the hot topics in VR solutions for PWD often include extreme games, serious games, activities of daily living, and exercise.

Sayma et al. specifically investigated VR solutions to improve cognitive function following the PRISMA guidelines [97]. They included studies of any type, but excluded conference abstracts / proceedings and articles that did not focus on VR for PWD. A total of five heterogeneous studies with small sample sizes were included in their review and they found mixed results, leaving them unable to draw definitive conclusions on the efficacy of VR in improving cognitive function.

The systematic review conducted by Corregidor-SÃ¡nchez et al. also used the PRISMA guidelines and focused on the effect VR has on the functional mobility of older adults [46]. They only included randomized controlled trials and excluded articles if they were irrelevant or had targeted older adults with neurological diseases such as dementia, resulting in the inclusion of 18 studies. They found that results suggested virtual reality is effective at improving the functional mobility of older adults when compared to conventional treatments, especially non-specific VR technology, though they recognize that more studies are required due to the low methodological quality of the papers they reviewed.

Similarly, Molina et al. conducted a systematic review of VR games as a means of improving physical functioning in older adults [83]. Only randomized controlled clinical trials were included and studies were excluded based on relevance, if they targeted participants with specific conditions such as dementia, or if their games were performed sitting down. They included 13 studies in their review and found that most had methodological problems according to the PEDro scale. They reported that the benefits of physical functioning remain inconclusive; however, they discovered a clear consensus among studies indicating that exergames are effective motivators.

A systematic review by Yang et al. explored how effective combined interventions are in improving PWD functioning [110]. They used the PRISMA guidelines and selected articles based on whether they targeted PWD over the age of 50, used interventions that combined cognitive and physical elements, and included a control condition. Ten independent articles were included. They found preliminary evidence suggesting positive effects of combined interventions that can improve the cognitive-motor abilities of PWD, although they recognize that the methodological strength of the evidence is limited.

Two systematic reviews focused specifically on gamification for elderly individuals whose results included physical therapy interventions. Both reviews were carried out according to the PRISMA guidelines. The first of the two, by Jonna Koivisto and Aqdas Malik, only included studies that met predefined PICOS criteria relating to adults aged 55 and over, the intervention method used, and if they were peer-reviewed with empirical data analysis in English [71]. A total of 12 studies were considered eligible and their analysis indicated that older adults may benefit from gamification and game-based interventions, particularly in the health domain. However, they acknowledged methodological shortcomings and stressed the need for further research.

The second paper, from Martinho et al., explored the use of gamification techniques in elderly care [77]. Articles included 42 manuscripts, finding that most recent works aimed to tailor interactive systems to each user's capabilities and needs, and that there is a lack of healthcare services that can provide such systems. They highlight a number of game design elements for providing feedback, improving proficiency with the game, and enhancing social interaction. They also identified the need for the presence of a healthcare professional and unfamiliarity with new technology as the main challenges facing these systems.

The remaining five papers assessed systems and frameworks related to the categories mentioned in the eligibility criteria (See Table 1).

A study by Kuo-Ting Huang aimed to investigate whether playing VR games would have an impact on the executive functions of older adults and whether the feeling of presence played a role [62]. A total of 33 participants over the age of 50 were randomly assigned to either an immersive virtual environment or a non-immersive virtual environment to play the game 'Fruit Ninja' spanning eight sessions within 4 weeks. The Stroop Test, Trail Making Test, and Digit Span task were used for cognitive assessments before and after the 20-minute exergaming sessions. After four weeks of training, the tests revealed that the immersive virtual environment had a significant impact, improving cognitive performance in inhibition and task switching.

Another study involving immersive technology for dementia was a mixed-methods pilot study by D'Cunha et al. that investigated the use of a virtual, immersive cycling experience [47]. They had a total of 10 participants who were all PWD living in a long-term care facility. Using a randomized crossover design, participants participated in a virtual cycling experience and a physical activity session, both of which lasted 25 minutes, were self-paced, sat, and were facilitated in groups of 5 participants. Video analysis was performed in the sessions using the Person-Environment Apathy Rating Scale and the Engagement of a Person with Dementia Scale. After the experiences, they conducted semi-structured interviews and performed thematic analysis. They discovered that no differences were observed between the sessions, with the exception of environmental stimulation, which generated a lower response in the intervention compared to the control. They also received feedback that the intervention was pleasant and immersive. They concluded that their intervention was an engaging alternative that may motivate further exercise.

A 3-arm randomized controlled trial by Karssemeijer et al. compared exergame training, aerobic training, and an active intervention used as a control [68]. They randomized 115 PWDs and had them individually train three times a week for

12 weeks. Before the 12-week intervention and after, they used the Evaluative Frailty Index for Physical Activity as a measure of frailty. Covariance analysis was used to control differences between groups. This paper demonstrates promising results, positing that its exergame intervention positively reduced the level of frailty in dementia users. They argue the significance of their findings through their assertion that frailty is a powerful predictor of numerous disadvantageous health outcomes. Additionally, they found that exergaming effectively engaged users in activities, boasting high adherence rates to physical exercise.

Another study, by Anderson-Hanley et al., conducted a multisite cluster randomized clinical trial to assess the impacts on the cognitive function of older adults when comparing a cyber-cycling game with traditional exercise over a period of 3 months [35]. They had a total of 102 older adults. They measured and evaluated executive functions through Color Trails 2-1 difference scores, the Stroop C test, and the Digit Span Backwards task, each measured at the beginning of the study, 1 month in, and at the end of the 3 months. They also used numerous other tests for neuropsychologic measures such as a Letter Digit Symbol Test to measure attention, a Controlled Oral Word Association Test to measure verbal fluency, and a Rey Auditory Verbal Learning Test to measure verbal memory. Although exercise effort and fitness were found to be comparable between their cyber-cycling intervention and traditional exercise, they found statistically significant evidence that older adults who participated in the cyber-cycling exergame achieved better cognitive function. The authors of this study conclude that these results suggest that combined cognitive and physical interventions have a higher potential to prevent cognitive decline.

An exploratory field study conducted by Unbehaun et al. aimed to investigate the social impact of an educational suite of exergames for PWD and their caregivers [105]. To do this, they collected observational data on the daily lives of 14 PWD and their caregivers and conducted semi-structured interviews during training sessions of 4-5 participants twice a week for 8 months. The researchers suggest that their ICT-based exergame suite, which was developed as part of a much larger research project, helped PWD enjoy parts of social and daily activities that they had previously lost contact with as the exergame was played and spectated in a group. They also indicated that their games provide caregivers with more leisure time. In addition, they believe that their system improved social interaction and empowered individuals with dementia and their caregivers to overcome their daily challenges. Their study implies that a social experience can be beneficial to emotional well-being and overall quality of life.

2.2.3 *Takeaways from the Systematic Literature Review*

The results reveal that exercise therapy, immersive technology, and gamification, individually and combined, are comparable to, if not slightly better than, traditional physical interventions in terms of benefits to the cognitive, emotional, and physical functioning of older adults and PWD.

A resounding pattern between the papers was the need for more research into this domain, to which this thesis aims to contribute. Further investigation into patterns in the techniques and methods used by these papers revealed a benefit in incorporating features that allow social interaction. When socialization aspects were implemented, they showed promising cognitive function and mood benefits. Despite being beneficial, features that allow for socialization are rarely incorporated into research projects within this field of study. The included paper by Karaosmanoglu et al. examined the social interactions generated by their VR exergame, 'Memory Journalist VR,' without any explicit social features added. They found that social environments can "improve psychological well-being." However, without any features to stimulate social interaction, they "did not observe any increase in social interaction among older adults with dementia" [66]. Examining the future work sections of the included papers makes it clear that a further step in developing a VR exergame for PWD would be to include more customization and socialization features.

Another large pattern noticed was the call for a human-centred/participatory design approach that involves all stakeholders, in this case, PWD, their caregivers, health experts, and the research team, as 6 of the 9 'Framework Creation' papers both employed and stressed the importance of such a design strategy.

Despite the benefits of socialization features and participatory design highlighted in the reviewed articles, none of them sought to involve caregivers in the inclusion of such socialization features. As caregivers are the ones with whom PWD are more likely to spend the majority of their time, tailoring the design of any social aspects to include them makes the most sense.

The patterns identified through this literature review form a clear gap for further research which this thesis aims to participate in.

Title	Authors	Venue/Journal	Pub. Year	Main Research Problem
Immersive Virtual Reality Exergames for Persons Living With Dementia: User-Centered Design Study as a Multistakeholder Team During the COVID-19 Pandemic	John Munoz; Samira Mehrabi; Yirou Li; Aysha Basharat; Laura E Middleton; Shi Cao; Michael Barnett-Cowan; Jennifer Boger	JMIR Serious Games 2022;10(1):e29987	2022	Collaboratively create VR exergames that promote physical activity for persons living with dementia/mild cognitive impairment.
Lessons Learned from a Human-Centered Design of an Immersive Exergame for People with Dementia	Sukran Karaosmanoglu; Sebastian Rings; Lucie Kruse; Christian Stein; Frank Steinicke	Proceedings of the ACM on Human-Computer Interaction Volume 5 Issue CHI PLAY September 2021 Article No.252 pp 1-27	2021	Develop and test a human-centered design approach to address the specifics of developing VR exergames for people with dementia
Immersive Virtual Reality for Older Adults: Empirically Grounded Design Guidelines	Vero Vanden Abeele; Brenda Schraepen; Hanne Huygelier; Celine Gillebert; Kathrin Gerling; Raymond Van Ee	ACM Transactions on Accessible Computing Volume 14 Issue 3 September 2021 Article No.: 14 Pages 1-30	2021	Comprehensive guidelines on designing immersive and engaging VR for older adults remain sparse
MEMORIDE: An Exergame Combined with Working Memory Training to Motivate Elderly with Mild Cognitive Impairment to Actively Participate in Rehabilitation	Xin Li; Ting Han; Enjia Zhang; Wen Shao; Liang Li; Chenye Wu	HCII 2021: Human Aspects of IT for the Aged Population. Supporting Everyday Life Activities Pages 90-105	2021	Factors such as declining memory and physical function as well as psychological resistance to training decrease the effectiveness of such training
A Person-Centered Design Framework for Serious Games for Dementia	Bella Yigong Zhang; Mark Chignell	Proceedings of the 2020 Human Factors and Ergonomics Society Annual Meeting, Volume 64, Issue 1, Pages 18-22	2021	A lot of the work behind serious games for dementia is built upon a lacking theoretical base
Using Exergames to Train Patients with Dementia to Accomplish Daily Routines	Sebastian Rings; Sukran Karaosmanoglu; Lucie Kruse; Daniel Apken; Tobias Picker; Frank Steinicke	CHI PLAY '20: Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play	2020	Motivate physical activity in order to reduce the progress of neuronal degeneration
Motivating Physical Exercise in the Elderly with Mixed Reality Experiences	Mark Chignell; Henrique Matulis; Brian Nejati	HCII 2020: Distributed, Ambient and Pervasive Interactions Pages 505-519	2020	Motivate elderly individuals to exercise
Virtual Reality Exergames for People Living with Dementia Based on Exercise Therapy Best Practices	Mahzar Eisapour; Shi Cao; Laura Domenicucci; Jennifer Boger	Proceedings of the Human Factors and Ergonomics Society Annual Meeting Vol 62, Issue 1, 2018	2018	Increase exercise accessibility
Participatory Design of a Virtual Reality Exercise for People with Mild Cognitive Impairment	Mahzar Eisapour; Shi Cao; Laura Domenicucci; Jennifer Boger	CHI EA '18: Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems	2018	Create an exergame through participatory design with and for individuals with mild cognitive impairment

Table 2: Papers selected for the Framework category and their characteristics, organized

Title	Authors	Venue/Journal	Pub. Year	Main Research Problem
Effects of Exergames on Brain and Cognition in Older Adults: A Review Based on a New Categorization of Combined Training Intervention	Marta Maria Torre; Jean-Jacques Temprado	Frontiers in Aging Neuroscience, March 2022, Volume 14, Article 859715	2022	Report an up-to-date review of the literature to discover how exergames compare to typical forms of physical exercise.
Study of Virtual Reality for Mild Cognitive Impairment: A Bibliometric Analysis using CiteSpace	Kaiyan Zhu; Rong Lin; Hong Lia	International Journal of Nursing Sciences, January 2022, Volume 9, Pages 129-136	2021	Perform a bibliometric analysis of the literature to discern trends.
Effects of a Virtual Group Cycling Experience on People Living with Dementia: A Mixed Method Pilot Study	Nathan M D'Cunha; Stephen T Isbel; Jane Frost; Angie Fearon; Andrew J McKune; Nenad Naumovski; Jane Kellett	Dementia 2021, Volume 20, Issue 5, Pages 1518-1535	2021	Test the efficacy of virtual reality on motivating physical activity in individuals with dementia.
Effectiveness of Virtual Reality Technology on Functional Mobility of Older Adults: Systematic Review and Meta-Analysis	Ana Isabel Corregidor-Sanchez; Antonio Segura-Fragoso; Marta Rodriguez-Hernandez; Concepcion Jimenez-Rojas; Begona Polonio-Lopez; Juan Jose Criado-Alvarez	Age and Ageing, Volume 50, Issue 2, March 2021, Pages 370-379	2020	Test the efficacy of virtual reality on improving functional mobility in older adults when compared to conventional treatment methods.
Gamification for Older Adults: A Systematic Literature Review	Koivisto, Jonna; Malik, Aqdas; Heyn, Patricia C	The Gerontologist, 2021-09-13, Vol.61 (7), p.e360-e372	2020	Find the current state-of-the-art of gamification techniques applied to elderly care.
Exergaming Executive Functions: An Immersive Virtual Reality-Based Cognitive Training for Adults Aged 50 and Older	Kuo-Ting Huang	Cyberpsychology, Behavior, and Social Networking. Mar 2020.143-149	2020	Investigate the efficacy of combining exergaming and VR and examine the role of presence as a potential mediator between immersive exergaming and cognitive improvement.
A Systematic Review of Gamification Techniques Applied to Elderly Care	Martinho, Diogo; Carneiro, Joao; Corchado, Juan M; Marreiros, Goreti	The Artificial intelligence review, 2020-02-04, Vol.53 (7), p.4863-4901	2020	Find the current state-of-the-art of gamification techniques applied to elderly care.
Effectiveness of Combined Cognitive and Physical Interventions to Enhance Functioning in Older Adults With Mild Cognitive Impairment: A Systematic Review of Randomized Controlled Trials	Chenchen Yang; Ami Moore; Elias Mpofu; Diana Dorstyn; Qiwei Li; Cheng Yin	The Gerontologist, Volume 60, Issue 8, December 2020, Pages e633-e642	2019	Review the literature surrounding combined interventions for individuals with mild cognitive impairment.
Are We There Yet? Immersive Virtual Reality to Improve Cognitive Function in Dementia and Mild Cognitive Impairment	Meelad Sayma; Remco Tuijt; Claudia Cooper; Kate Walters	The Gerontologist, Volume 60, Issue 7, October 2020, Pages e502-e512	2019	Review and analyze the current literature.
Effectiveness of Exergaming in Improving Cognitive and Physical Function in People With Mild Cognitive Impairment or Dementia: Systematic Review	Zhao Y; Feng H; Wu X; Du Y; Yang X; Hu M; Ning H; Liao L; Chen H; Zhao Y	JMIR Serious Games 2020; 8(2):e16841	2019	Review and analyze the current literature.

Table 3: Part One. Papers selected for the Assessment category and their characteristics, organized by date.

Title	Authors	Venue/Journal	Pub. Year	Main Research Problem
Exergaming as a Physical Exercise Strategy Reduces Frailty in People With Dementia: A Randomized Controlled Trial	Esther G.A. Karssemeijer; Willem J.R. Bossers; Justine A.Aaronson; Lianne M.J. Sanders; Roy P.C. Kessels; Marcel G.M. Olde Rikkert	Journal of the American Medical Directors Association Volume 20, Issue 12, December 2019, Pages 1502-1508.el	2019	Test the efficacy of exergame training on frailty in individuals with dementia.
A Systematic Review on the Cognitive Benefits and Neurophysiological Correlates of Exergaming in Healthy Older Adults	Robert Stojan; Claudia Voelcker-Rehage	Journal of Clinical Medicine, Volume 8(5), 734, May 2019	2019	Investigate the effects of exergaming and the affected neurophysiological mechanisms through reviewing the literature.
Effects of Exergaming in People with Dementia: Results of a Systematic Literature Review	van Santen, Joeke; Droes, Rose-Marie; Holstege, Marije; Henkemans, Olivier Blanson; van Rijn, Annelies; de Vries, Ralph; van Straten, Annemieke; Meiland, Franka	Journal of Alzheimer's Disease, vol. 63, no. 2, pp. 741-760, 2018	2018	Review the effects of exergaming on individuals with dementia.
Exploring the Potential of Exergames to affect the Social and Daily Life of People with Dementia and their Caregivers	David Unbehaun; Daryoush Daniel Vaziri; Konstantin Aal; Rainer Wieching; Peter Tolmie; Volker Wulf	CHI '18: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems April 2018 Paper No.: 62 Pages 1-15	2018	Assess the social impact of various exergames.
Virtual Reality using Games for Improving Physical Functioning in Older Adults: A Systematic Review	Karina Iglesia Molina; Natalia Aquaroni Ricci; Suzana Albuquerque de Moraes; Monica Rodrigues Perracini	Journal of NeuroEngineering and Rehabilitation volume 11, Article number: 156	2014	Review the literature and effects of exergaming on physical functioning in the elderly
Exergaming and Older Adult Cognition: A Cluster Randomized Clinical Trial	Cay Anderson-Hanley; Paul J. Arciero; Adam M. Brickman; Joseph P. Nimon; Naoko Okuma; Sarah C. Westen; Molly E. Merz; Brandt D. Pence; Jeffrey A. Woods; Arthur F. Kramer; Earl A. Zimmerman;	American Journal of Preventive Medicine Volume 42, Issue 2, February 2012, Pages 109-119	2012	Test the efficacy of stationary cycling with virtual reality tours on executive function and clinical status when compared to traditional exercise, test if the effort put into exercising will explain improvement, and test if the brain-derived neurotrophic growth factor will increase

Table 3: Part Two. Papers selected for the Assessment category and their characteristics, organized by date.

3 METHODOLOGY

3.1 OVERVIEW

This chapter presents the methods driving the design, development, and assessment of the proposed asymmetric exergame for the purposes of investigating its usability, cognitive load, cooperative performance, and social presence, thus addressing the hypotheses. First, the design of the exergame is covered, followed by its development and implementation. Once implemented, the study design is presented.

3.2 EXERGAME DESIGN

The design of the exergame is broken down into the following interconnected design aspects: upper limb movements, virtual room design, exergame activities, VR iterative design, game elements, and the core game loop. Designing with consideration to both the overall design and its most important sub-aspects is aligned with common best practices for developing video games [54]. As indicated in Chapter 1, the purpose of an exergame is to induce physical activity in an engaging manner through the use of gamification practices and game design principles [87]. Because of this, best practices for gamification, such as having clear goals and rewards, were also considered [64, 28, 29].

This exergame was designed with the intention of understanding the effects of asymmetry in an upper limb VR game with insights from caregivers in terms of social presence, cognitive load, usability, and performance. To this end, cooperative virtual reality and single-player versions of the game are developed. The context of the game proposed in this thesis is part of a larger initiative to develop immersive technologies for the care of PWD, such as reminiscence therapy [33], and as such some parts of the exergame design were predetermined based on previous assertions, such as a focus on hygiene. In this case, the focus is on good hygiene practices associated with daily activities such as cleaning a window, wiping a surface, or organizing items on a shelf.

Since every design aspect had an effect on the usability of the game, the specific design choices made to benefit usability will be mentioned during the discussions of the other design aspects to avoid unnecessary repetition.

3.2.1 *Upper Limb Movement*

Game mechanics play an important role in game design. The rules, systems, and interactions that drive the gameplay of a game determine how players interact, progress, and receive feedback from the game. The most important design aspect to consider for defining the game mechanics are the movements associated with the core physical activity that the players will primarily perform with their upper limbs to complete the game.

The upper limb, occasionally called the upper extremity, refers to the arm, forearm and hands [88]. The upper limb is comprised of several bones, joints, muscles, blood vessels, nerves, and other supporting structures that enable a wide range of movements and functions. Because of its structure, the upper extremity has seven degrees of freedom (DOF), three at the shoulder, two at the elbow, and three at the wrist, in addition to 17 DOF when combining all fingers [69]. The combination of DOF allows the upper limb movements on the sagittal, coronal, and transverse planes resulting in flexion, extension, abduction and adduction, pronation and supination, and radial and ulnar deviation.

Maintaining upper limb mobility, circulation, and strength requires performing exercises routinely. There are a number of upper limb exercises depending on the desired exercising outcome. Since the context of this exercise is to induce physical activity while performing chores in a virtual room, the upper limb movements focus on occupational health care exercises which involve flexion and extension, most often of the elbow joint, and the circumduction of the shoulder and the wrist joints [21, 20].

3.2.2 *Virtual Room Design*

The virtual room design was informed by Dr. Winnie Sun, a context expert in the care of PWD within the context of a larger reminiscence therapy tool [33]. Because of this, the aesthetic design was heavily influenced by having an environment reminiscent of a typical room found in long-term care.

The virtual room does not present a photorealistic environment. It is generally assumed that more realistic graphics increase immersion, however, discrepancies between the level of visual detail of a simulated environment and the level of control a user has within a simulation have been shown to encumber cognitive resources and negatively impact learning outcomes [61]. This means that if a simulated environment has a high level of visual detail, it should also allow for a high level of control, and if it has a low level of detail, it should have a low level of control. In this case, the negative effects on cognitive resources and learning outcomes are found when there exists a high level of detail and a low level of control, and vice-versa. The current design of our exergame's locomotion controls, which is expanded upon later in this chapter, leverages the user's level of control in exchange for minimizing the risk of motion sickness. Implementing realistic graphics in conjunction with the current level of control could create a discrepancy, which has the potential to have a negative impact on the user's cognitive load.

In addition to seeking harmony between the user's level of control and the realism of the graphics, the game elements are visually clear and simple. With our setting being focused on personal hygiene, representations of dirt and grime became important game-related elements, which are discussed in more detail later in this chapter. The choice of graphics provides an opportunity to depict dirt in a manner that is much more apparent and visually distinct than in real life. The virtual room is shown in Figure 2.

Figure 2: Visual design of the virtual room environment.

3.2.3 *Exergame Activities*

The combination of upper limb movements and the designed virtual room led to the articulation of these within VR. The choice of using VR was informed by the literature review and the opportunities it presents for highly immersive experiences. Unfortunately, the use of VR can put users at risk of motion sickness and disorientation, especially when users move a lot [80]. Having users seated while using a VR HMD can help minimize this risk [80].

Taking into account the aesthetic theme of the game, upper limb activity, and the use of VR headsets, in consultation with Sheri Horsburgh from the Ontario Shores Center for Mental Health Sciences, a set of suitable physical actions related to household tasks were defined, such as cleaning or dusting surfaces, sorting clothes in a dresser, plucking weeds from a garden, pouring drinks, and replacing light bulbs in lamps. These exercises disguised as chores were later iterated upon to better fit the asymmetric social component of the exergame, resulting in the following:

- Wiping surfaces with cleaning tools (Sponge, brush, etc): Circumduction of the shoulder.
- Organizing objects: Flexion and extension of elbow and shoulder joints, and
- Picking up and throwing out empty cans: Flexion and extension of the elbow and shoulder joints.

The examples of the final implementations of these chores are showcased in Figure 3 and 4. Additionally, to maintain exercise consistency, we can detect when a player's movements are being performed too suddenly.

3.2.4 *VR Iterative Design*

The VR development requires the definition of core interactions pertaining to locomotion and manipulation of objects.

3.2.4.1 *Locomotion*

Initially, the movement of the players within the room was determined by the VR controller joysticks. Players could use the left joystick to move around the room and the right joystick to rotate their virtual body. This would allow players more control and freedom of movement while playing the game seated. However, after implementation and discussion with content experts, it was decided that this form of movement can be a bit jarring and is likely to evoke visually induced motion sickness, even while seated, a decision supported by the work of Nooij et al. [85]. An alternative to player movement using the joysticks is teleportation in conjunction with some pre-determined anchor points, which has been shown to cause fewer symptoms of motion sickness [75].

Teleportation is another locomotion technique that requires the player to hold down the 'A' button, and after doing so, they can aim a beam of light that emits from their virtual hands in an arc, displaying a circle where the beam makes

Figure 3: Examples of chore implementations as described in section 3.2.3.

contact with the anchor point on the ground. The circle will light up red if they cannot teleport to that location, and green if they can. When a player teleports to their desired location, the screen will fade to black before fading back into the game once they have arrived. This was done in order to create a smoother and less jarring transition. Players are still able to rotate their virtual bodies with the right joystick should they need a better orientation, but instead of a smooth movement, as was done previously, they now can rotate in increments of 15 degrees with the same fade-to-black transition as the teleporting. s making picking and placing objects the most frequent interaction in the game.

3.2.4.2 *Interactions*

During the earlier stages of the VR design process, hand tracking was considered a potential solution to provide ease of use. However, early prototypes integrating object manipulation and locomotion showed the challenges and limitations of the hand-tracking technology in terms of accuracy and reliability, the need for a gesture library of actions that account for hand occlusion and poor lighting conditions, in addition to the field-of-view limitations of the trackers. Therefore, hand tracking would result in incorrect hand movements, such as dropping items, which could make the exergame frustrating to play. Taking all of this into account, the use of VR controllers presented the best solution in order to keep interactions in the game simple and satisfying. Since hand tracking would fail to increase immersion, Auto Hand [2], a Unity asset that allows the creation of realistic hand poses to grab objects was chosen. The poses created by AutoHand accurately represent hand positions made when grabbing real-world objects, which has the potential to make grabbing objects in VR feel more natural and increase player immersion.

How players would interact with the user interface (UI) was also an area of consideration. The UI for the menus and their options was made to be 3D, as opposed to the traditional 2D, to simulate interacting with physical buttons and other real-world analogs. When the menus are open, they will always re-orient themselves to be positioned in front of the player in order to avoid losing track of them. Additionally, in the event that a player cannot reach a menu item with their VR hands, they can use a laser to target and interact with UI elements instead. In addition to the other design choices made for the UI menus, the pause menu, which will appear during the active play session when the player presses the 'Menu' button, will always be rendered in front of all other objects in the scene to avoid losing it behind walls and other objects in the virtual environment. Additionally, when the player pauses the game all colour in the scene apart from that of the pause menu is muted. This is done to make it very clear that the game is paused in case the ’Menu’ button is pressed accidentally. Apart from the UI of the menus, the UI of a few other elements was also taken into account. To keep track of how many days the player has played, a calendar was placed on a wall of the virtual room. Although the calendar is not interactable, it displays a green checkmark on days in which the player completed all of the tasks and a yellow highlight, along with the number of extra points the player would gain for completing days consecutively, on the current date. Finally, other information, such as tutorial prompts and feedback for incorrect actions are relayed to the player through floating 2D pop-ups that contain relevant text and are also voiced by a text-to-speech reader when they appear. These pop-ups appear in the room near items and areas associated with the information presented in each specific pop-up, such as tutorial elements and areas where incorrect actions were performed. These pop-ups simply present information and do not halt operations within the game. They can be easily dismissed by pressing them with a virtual finger or interacting with them using the previously mentioned UI laser.

3.2.5 *Game Elements*

Objectives, rules, and feedback are formal game elements that constitute the foundation of the game. These elements help shape the gaming experience, and their goal is to allow the creation of meaningful interactions and challenges [55]. When designing a game, flow, often described as an optimal state of engagement and immersion, aims to leverage difficulty and skill. Flow plays an important role in balancing the difficulty of game mechanics, a factor that can discourage players [37]. Since usability and low cognitive load are the top priorities of the exergame, rules, goals, and feedback had to be clear and consistent to further encourage our players [60, 31, 63, 4]. These game mechanics were chosen to be articulated through an asymmetric design, where one player uses an HMD and the other player contributes from outside of VR. This approach was chosen to reduce the need for additional VR HMDs and the dependency on a reliable Internet connection. The approach was later realized by having one player provide a set of instructions to another player in VR.

Incorporating the setting and theme, described in subsection 3.2.2 subsection 3.2.2, into the game elements was also taken into account during the game design process. Additionally, careful consideration was made about the behaviors our rulesets, goals, and feedback can encourage. For example, to avoid incentivizing players to rush their exercises, time-based elements were used sparingly, and other elements described later in this chapter were included to dissuade rushing. Ultimately, the design of the game should encourage players to perform exercises routinely, correctly, accurately, and consistently.

3.2.6 *Core Game Loop*

The game loop refers to the continuous cycle of actions and processes that occur within a game from the start to the end. The game loop allows defining the inputs, outputs, processes, and feedback given to players articulated with the mechanics of the game [108].

Since the game is designed to be both social and asymmetric, PWD and their caregivers will assume different roles while playing the game. As previously stated, the asymmetric approach eliminates the need for both players to use a VR HMD. Since the main beneficiary of the immersive experience the VR HMD provides is meant to be PWD, they will be the ones utilizing an HMD while the caregivers take on the other role. These roles will henceforth be referred to as 'VR players,' fulfilled by PWD utilizing the VR HMD, and 'external players,' fulfilled by their respective caregivers external to the VR environment.

The game loop for the exergame requires the VR player to select the 'Play' option from the main menu, which will bring the player to the virtual bedroom. During this time, the VR player is tasked with communicating visual information about 3 visual elements within the room: a red can, trinkets on a bookshelf, and the contents of an abstract painting (See Figure 3 and Appendix A). Since external players will be unable to see what the VR players see, they will need to interpret the information being communicated to them by the VR player in order to determine the specific details of the elements being described. External players are provided with a look-up sheet containing the necessary information needed to do this (See Appendix A). Each of the 3 visual elements has a variety of hidden tasks for the VR player associated with specific details about the said elements, which are also provided in the look-up sheet for the external players. It is then the goal of the external player to communicate which tasks the VR player must complete in order to beat that specific play session, and it is subsequently the goal of the VR player to complete them. The details of these elements, such as their location within the room, order, or visual layout, and thus their associated hidden tasks, are randomized at the beginning of every play session to add a level of variability in hopes of keeping the gameplay fresh.

The elements and their tasks are as follows:

- Red Can: There is a red soda can somewhere in the room. Depending on its location, players are tasked with moving it to a predetermined location and either cleaning another location or relocating a blue can.

- Organizing Trinkets: On the bookshelf are a number of trinkets, toys, and collectibles. Based on the starting position of the trinkets, players will have to reorganize them.

- Abstract Paintings: In the room there is an abstract painting of a red triangle, blue rectangle, and green circle hung above the bed. The players will have to communicate the size and position of the shapes in order to discover the associated task. The associated task involves cleaning various surfaces, such as windows, door knobs, drawer handles, and light switches. Once a player begins cleaning the correct surface, the dirt, which was previously invisible, will appear. After the dirt has appeared, the VR players can press and hold the B button to highlight any remaining dirt to ensure that they cleaned all of it.

Once both players have successfully worked together to complete all hidden tasks or ended the session of their own accord, the VR player will be shown their final score. A player's total score is determined by a number of factors.

First, points are awarded every time a task is completed. If the VR player completes a task correctly on their first attempt, bonus points are awarded. If a task is completed incorrectly, such as when incorrect information is provided and acted upon or when the VR player attempts to find the tasks without the help of the external player, the VR player will be notified of the mistake and will no longer be able to receive the bonus points associated with completing that task on the first try.

Points are also awarded for how many consecutive days the exergame has been played. This was implemented to incentivize players to play the exergame daily, which is intended to aid in the creation of healthy exercise habits. At the same time that players are shown their final score, they will also be shown their current high score as a reference for estimating personal performance. The points players are awarded after each play session are accumulated and can be used as a form of currency in order to unlock cosmetic items for their virtual space. For example, they can unlock a variety of trinkets, different colours they can apply to their cleaning supplies, and different appearances of the furniture in their room.

Players can also choose to play in single-player mode, where they will be provided hints about the hidden tasks whenever they press the "hint" button on the wall. In this mode they will receive bonus points based on how few hints they had to use before discovering and completing each hidden task.

3.3 SYSTEM DEVELOPMENT AND IMPLEMENTATION

The main tool used in the development and implementation of the exergame was the Unity Real-Time Development Platform due to the prior experience of the research team members [18]. The HMD used as the primary platform of the exergame is the Oculus Quest 2, chosen due to its ease of use and compatibility with various game engines and plugins as a consumer-level standalone VR headset that can be used without the need for external trackers or a PC [8]. External packages acquired from the Unity Asset Store were used to speed up the development process [19]. For example, 'Auto Hand' by Earnest Robot was used for its ability to create realistic hand grasps [2]. 'Polygon Town' by Synty Studios was used for the stylized low-poly environment [13]. 'Low Poly Simple Furniture FREE' by Gobormu was used for the stylized low-poly furniture [7]. 'Cleaner Pack' by Icosphere was used for its stylized low-poly cleaning tools [3]. 'Scratch Card' by Kostiantyn Saietskyi was adapted for the dirt cleaning system [15]. And finally, the 'Technie Collider Creator' by Triangular Pixels was used for optimizing the mesh colliders of interactive objects [17].

Figure 4: A demonstration of the typical use-case, with one player using a VR HMD and the other participating through the look-up sheet.

3.4 CAREGIVER FEEDBACK STUDY DESIGN

3.4.1 *Description*

The study described in this section was reviewed and approved by the Research Ethics Board of Ontario Tech University [#17409] on 7 July 2023. The 'VR player' and 'external player' roles, in addition to the non-social singleplayer mode, each described in Section 3.2.6, were categorized into three distinct 'versions' for the study. This was to increase the clarity in the investigation of the differences not only between the asymmetric social roles but between the main social and non-social methods of playing the exergame. These versions are henceforth referred to as 'VR Co-op,' which showcases the role of the VR player, 'External Co-op,' which showcases the role of the external player, and 'Singleplayer' which demonstrates the single-player mode. A within-subjects design was employed that allowed all participants to play each of the 3 versions of the game. After completing each version, participants were asked to complete a questionnaire on their experience with the said version.

3.4.2 *Recruitment*

Participants were recruited through word-of-mouth and the use of a recruitment poster (See Appendix B). Potential participants could scan the QR code on the poster to open an intake form (see the Appendix C) or email the research team directly. Once interest was expressed, a member of the research team would reach out to confirm they met the criteria in the in-take form (low risk of motion sickness and no vision or physio-motor impairments), provide a link to the consent form (See Appendix D), and schedule a time to meet in person at the OntarioTech graduate GAMER lab.

3.4.3 *Procedures*

The study was carried out in person in individual meetings for each participant, with a total of one session per participant, each lasting approximately 65 minutes. Participants were given time to complete the consent form if they had not prior to the study and reminded that they were free to withdraw without consequence at any point before the end of their study session, at which point their data would be anonymized, thus making it virtually impossible to know which data to withdraw. The participants were then introduced to a demographics questionnaire which aimed to gain further insight into their gender, age range, professional/educational background, VR use habits, history of elderly care, and intentions to provide care in the future (See Appendix E). They were then introduced to one of the 3 versions and were provided instructions on how to play. After each version, they were asked to complete a questionnaire regarding the version they played which aimed to evaluate its usability, task load, and in the case of cooperative versions, social presence, through established qualitative scales detailed in the following section, and a short break was provided (Appendix F).

In the 'VR Co-op' version, participants used the VR HMD (Meta Quest 2) and were tasked with communicating with a research team member in order to discover and complete hidden tasks. The research team member was tasked with using the provided instructions/look-up sheet to relay the necessary information. During this time, a research team member recorded Cooperative Performance Metrics described in the following section and took observational notes on participant actions. Their perspective within the HMD was video-recorded in order to further examine the in-game interactions. This process captured only what was displayed by the headset and did not capture audio or the likeness of any participants. This was done by mirroring the VR HMD's display to the computer and capturing it with a video-recording application (OBS).

In the 'External Co-op' version, participants and the research team member took on inverse roles to that of the 'VR Co-op' version, with participants utilizing the look-up sheet to guide the research team member through the hidden tasks.

In the 'Singleplayer' version, participants were instead provided with vague hints relating to the hidden tasks they needed to complete. Through the same processes as the 'VR Co-op' version, a research team member took notes and once again video-recorded their perspective within the game.

3.4.4 *Analysis Methods*

The questionnaire consisted of 3 parts detailed here (Appendix F). Due to the nature of the social presence measure, participants did not have to complete that part for the single-player version.

The System Usability Scale was used to measure how usable the different versions of the exergame were. Generally, the average SUS score is 68, with the highest possible score being 100 [90].

The NASA Task Load Index (TLX) was used to measure perceived workload. The overall workload score ranges from 0-100, where a lower score would indicate a lower workload. For further reference, the majority of workload scores for daily activities are below 36.77 [56].

The Social Presence Gaming Questionnaire was used to measure the social presence between the two cooperative versions of the exergame. The questionnaire consists of three subscales that measure empathy, negative feelings, and behavioural engagement. The first two subscales, 'Empathy' and 'Negative Feelings', describe positively and negatively toned emotions towards co-players respectively, whilst the 'Behavioural Engagement' subscale measures the participant's perception of how dependent their actions were on the actions of their co-player [48].

The resulting scores for each SPGQ subscale are on a scale of 0-4. A higher score on either or both of the empathy and negative feelings subscales is more indicative of psychological involvement, while a higher score on the final scale is more indicative of behavioral involvement as the name would suggest [48].

The Cooperative Performance Metrics (CPM) developed by Sief El-Nasr et al. were used as a basis for structured observation of cooperative play sessions [100]. See Appendix G for a breakdown of the CPMs and how to apply them.

The questionnaire, demographic, and CPM results were compiled in Google Sheets and then analyzed using IBM's Statistical Package for Social Sciences (SPSS) software by IBM [5]. The normality of the results, discussed in the next chapter, was assessed through Kolomogorov-Smirnov and Shapiro-Wilk tests before performing Repeated-Measures ANOVA, Friedman's ANOVA, Pairwise, and/or Sign tests depending on if the data was parametric, as evidenced by the normality.

3.5 chapter summary

This chapter detailed the overall methodology behind the design and implementation of the exergame and its subsequent study. The rationale behind the inclusion of every element of the final exergame's design, including the upper-limb movement, virtual room design, exergame activities, VR iterative design, game elements, and the core game loop, was presented. The tools used in the development of the exergame were addressed, and a thorough breakdown of the design and methods of the caregiver feedback study was described.

4

RESULTS

4.1 OVERVIEW

This chapter presents the results of the study and provides a discussion of the findings. The results include self-reported measures of usability, workload, and social presence using standardized questionnaires on the cooperative external VR, cooperative VR, and single-player VR versions of the exergame, in addition to observational analysis and feedback provided by participants.

4.2 PARTICIPANT DEMOGRAPHICS

A total of 10 participants, 8 male, 1 female, and 1 non-binary volunteered to participate in the study. Of these participants, eight were within the age range of 18-24 years and the remaining 2 were in the age range of 35-54 years. The frequency of use of VR HMD varied among participants, with the majority of participants using a VR HMD more than once a month (see Figure 5). The professional and / or educational background also varied (see Figure 5). Furthermore, 5 participants indicated that they had not previously provided care to an elderly individual, 3 responded with "maybe / uncertain," and 2 had previously provided care. When asked if they planned to provide care to an elderly individual in the future, 4 planned to provide care, 4 responded with "maybe/unsure," and 2 did not plan to provide care. It is important to consider the impact the participant's demographics have on the results of the study. Although all participants have the potential to be caregivers, their results are not indicative of PWD simply due to the difference in age. Since most of the participants have backgrounds in computer-related fields and only one of the participants had never tried a VR HMD prior to the study, the resulting qualitative usability and task load metrics are likely higher than they would have been had PWD participated in the study.

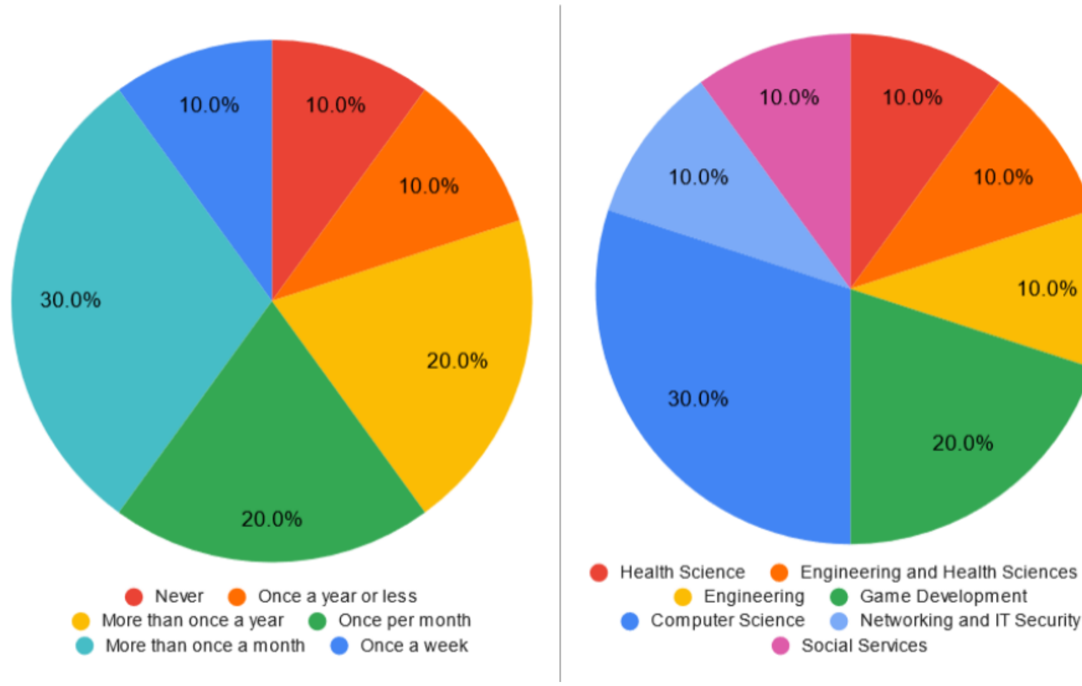


Figure 5: Demographic survey responses to the question, "How often do you use a VR head-mounted display?" (left) and "What is your professional background or field of study?" (right).

4.3 SYSTEM USABILITY SCALE

Individual SUS scores varied between participants and between versions (see Appendix H). The highest average SUS score between the versions belonged to the 'VR Co-op' version with an average score of 89.5, and the lowest belonged to the 'Singleplayer' version with an average score of 81 (See Table 4). Repeated measures ANOVA followed by a pairwise comparison utilizing the Bonferroni correction revealed that the lowest adjusted significance between the versions was $p = 0.066$. As the significance must be below 0.05 in order to reject the null hypothesis, which assumes that the true mean difference between each version is zero, there is no statistical significance between the mean SUS scores of each version. The previous

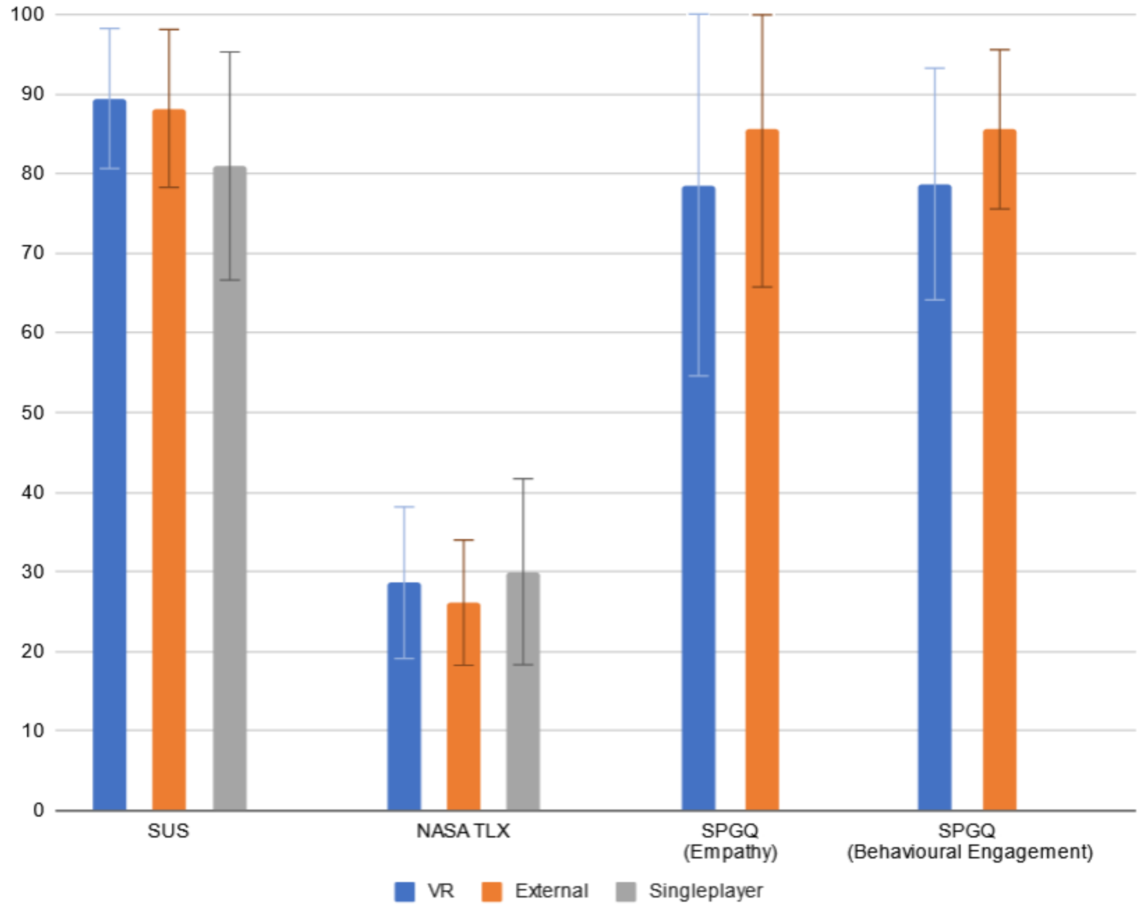


Figure 6: Average scores of each questionnaire from each version. SPGQ scores (0-4) were scaled to match a 0-100 scale. Error bars represent the standard deviation of each.

hypothesis, in regard to usability scores of the Singleplayer and VR versions being comparable, was fairly accurate, however the Singleplayer version scoring a bit lower may be due to the vagueness of the provided hints, which tended to cause some confusion. This has since been remedied.

Table 4: The average SUS score, standard deviation, and number of responses for each of the versions.

Descriptive Statistics

	Mean	Std. Deviation	N
SUS (VR)	89.5000	8.80341	10
SUS (External)	88.2500	9.93381	10
SUS (Singleplayer)	81.0000	14.34689	10

4.4 RAW NASA TASK LOAD INDEX

The individual results of the NASA TLX varied among participants and between versions (See Appendix I). The version with the highest mean TLX score was the 'Singleplayer' version, with a mean score of 30, and the lowest mean score belonged to the 'External Co-op' version, with a mean score of 26.11 (See Table 5). A Friedman's ANOVA was performed due to the normality distribution, revealing the data to be nonparametric and it showed no statistical significance between the mean TLX scores of each version. These results are in line with the cognitive load hypnotheses expressed in Chapter 1.

Table 5: The mean TLX scores, standard deviation, and minimum and maximum TLX scores for each version.

Report

	NASA TLX (VR)	NASA TLX (External)	NASA TLX (Singleplayer)
Mean	28.6110	26.1111	30.0000
Std. Deviation	9.53747	7.87848	11.69746
Minimum	16.67	16.67	19.44
Maximum	47.22	36.11	55.56

4.5 SOCIAL PRESENCE GAMING QUESTIONNAIRE

Individual SPGQ scores varied among participants, subscales, and between versions (see Appendix J). The mean scores for each subscale per version are outlined in Table 6. Most notably, not a single participant reported any trace of negative feelings for either version, resulting in both 'Negative Feelings' subscales reading 0. As for the 'Empathy' subscale, the 'VR Co-op' version had a mean score of about 3.14 and the 'External Co-op' version had a mean score of about 3.43. The mean 'Behavioural Engagement' score for the 'VR Co-op' version was about 3.15, whilst the 'External Co-op' version has a mean score of about 3.43.

Table 6: The number of results, mean scores, standard deviation, and minimum & maximum scores of each subscale for each version.

Statistics

		Empathy (VR)	Empathy (External)	Negative Feelings (VR)	Negative Feelings (External)	Behavioural Engagement (VR)	Behavioural Engagement (External)
N	Valid	10	10	10	10	10	10
	Missing	0	0	0	0	0	0
Mean		3.1429	3.4286	.0000	.0000	3.1500	3.4250
Std. Deviation		.95476	.79682	.00000	.00000	.58274	.62417
Minimum		.86	1.71	.00	.00	2.25	2.38
Maximum		4.00	4.00	.00	.00	4.00	4.00

When testing for normality, the Kolomogorov-Smirnov and Shapiro-Wilk tests revealed the 'Empathy' results did not follow a normal distribution, whilst the 'Behavioural Engagement' results did (See Table 7).

Table 7: The results of the normality tests for each version's mean 'Empathy' and 'Behavioural Engagement' scores.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Empathy (VR)	.318	10	.005	.779	10	.008
Empathy (External)	.271	10	.036	.749	10	.003
Behavioural Engagement (VR)	.150	10	.200*	.947	10	.630
Behavioural Engagement (External)	.222	10	.179	.849	10	.057

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

A Sign test was performed on each subscale. The null hypothesis, which is that the median of differences between the 'VR Co-op' and 'External Co-op' versions is equal to 0, is retained for the results of the 'Empathy' subscale. The results of the Sign test on the 'Behavioural Engagement' subscale demonstrated a statistically significant median difference of 0.3125 (See Table 8) where the 'External Co-op' version garners more behavioural engagement, $p = 0.031$ (See Table 9). These results are a departure from the social presence and engagement hypotheses which predicted both cooperative versions would have comparable scores. This may be caused by the external player having to actively engage in order to determine the correct information to communicate to the player in VR.

Table 8: The percentile statistics of the 'Behavioural Engagement' scores between cooperative versions.

Descriptive Statistics

	N	Percentiles 25th	50th (Median)	75th
Behavioural Engagement (VR)	10	2.5625	3.2500	3.6250
Behavioural Engagement (External)	10	2.9688	3.5625	4.0000

Table 9: The null hypothesis and statistical significance of the 'Behavioral Engagement' results.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The median of differences between Behavioural Engagement (VR) and Behavioural Engagement (External) equals 0.	Related-Samples Sign Test	.031[c]	Reject the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

c. Exact significance is displayed for this test.

4.6 cooperative performance metrics

Observed CPM results varied among the participants and in cooperative versions (see Appendix L). It is important to note that the participants played the cooperative versions with a member of the research team rather than another participant. Because of this, CPMs were only recorded based on the participants' actions and were never initiated or goaded by a research team member. It is also important to re-iterate that the in-game scenario was the same between play sessions, but different between versions. This means that the research team member always gave the same instructions for the 'VR Co-op' version and always received the same instructions, which were unique from the instructions given in the 'VR Co-op' version and from the participant in the 'External Co-op' version. For a higher precision of the CPM results, future studies should maintain consistency between play sessions, but use additional participants.

Not a single participant refused to communicate during the cooperative play sessions, and as such, by virtue of the exergame's fundamental design, every participant took part in the 'Global Strategies' and 'Worked out Strategies' CPMs in each version of the exergame. For brevity and clarity, these CPMs were not included in the final list of CPMs and resulting figures. The remaining CPMs were recorded only once per cause per session, as should be [100]. See Figure 7 for the totals of each CPM for each version of the exergame.

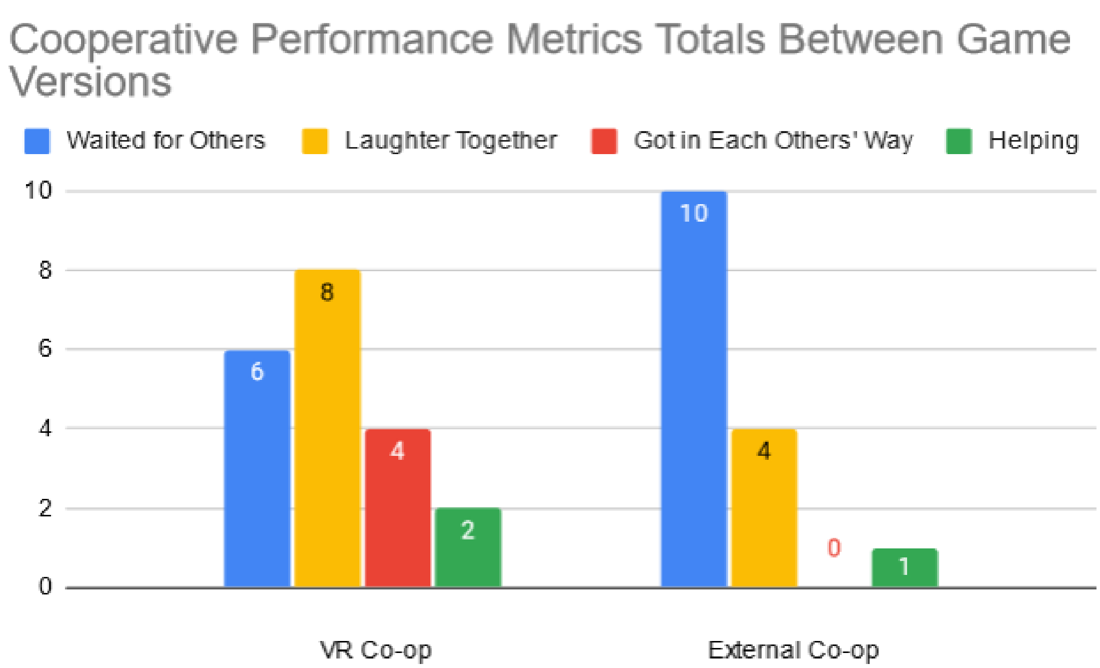


Figure 7: Total cooperative performance metrics between game versions

4.6.1 *Laughter or Excitement Together*

The 'Laughter or Excitement Together' (LT) CPM was only recorded when a participant laughed at or communicated wonder/excitement with an element of the exergame.

During the 'VR Co-op' version a total of 8 instances of LT were recorded. Each instance was associated with the 'Miscellaneous' cooperative design pattern identified by Sief El-Nasr et al., specifically the visual design and interactive objects [100]. Most often these events were caused by the dirt-cleaning aspect of the exergame, with participants making comments such as, "This is good stress relief" and "This is more fun than [cleaning] in real life." Additionally, one instance was caused by a participant expressing excitement at throwing interactable objects around the room, and one instance was caused by excitement with the visual effects that occur when a task is completed, most notably the confetti effect that occurs when all tasks have been completed.

The 'External Co-op' version had 4 instances of LT, all associated with the 'Shared Puzzles' cooperative design pattern. All instances were caused by participants who expressed their enjoyment watching the member of the research team perform the in-game tasks in VR as a result of their instruction.

4.6.2 *Helping*

The 'Helping' (H) CPM was only recorded when a participant struggled with an element of the exergame and requested assistance from the research team member.

There were only three instances of the 'Helping' CPM in total, all associated with the 'Miscellaneous' cooperative design pattern. During the 'VR Co-op' version 2 of these instances occurred. One was caused by confusion about how to use the VR controllers and the subsequent control scheme, and one was caused by confusion about how to use the sponge in-game to clean dirt. The remaining instance occurred during the 'External Co-op' version and was caused by the visual design of the look-up sheet being too confusing to accurately decipher, resulting in communicating the incorrect tasks.

4.6.3 *Waited For Each Other*

The 'Waited for Each Other' (WO) CPM was only recorded when a participant waited patiently for the research team member to finish communicating information regarding the in-game tasks.

The 'VR Co-op' version had 6 instances of WO, whilst the 'External Co-op' version had 10 instances, one for each participant. Each instance was associated with the 'Shared Puzzles' cooperative design pattern and was caused by waiting patiently for the research team member to finish communicating the tasks they had to complete or explaining in-game elements needed to determine the tasks, respectively. As demonstrated by the distribution of instances between the two versions, participants were more likely to interrupt communication when they were the ones who needed to complete the tasks rather than when they only had to determine and communicate which tasks had to be done.

4.6.4 *Got in Each Others' Way*

The 'Got in Each Others' Way (GW) CPM was only recorded when a participant actively interrupted the research team member while communicating information regarding the in-game tasks or refused to communicate.

The only instances of GW occurred during the 'VR Co-op' version, with a total of 4 instances. Each instance was associated with the 'Shared Puzzles' cooperative design pattern and was caused by interrupting or speaking over the research team member to more quickly answer questions regarding the tasks or explain elements of the exergame necessary to determine which tasks to complete.

4.7 RESULTS SUMMARY

The results of the study provide a promising glimpse into the asymmetric exergame and the potential benefit of adding its social component. Although more data must be collected to further identify areas with statistical significance with respect to usability and cognitive load, some lessons can still be taken from the statistically significant difference between the median values of the SPGQ behavior engagement scores. The work of Biocca et al. on which the SPGQ is partially based defines behavioral engagement as "the degree to which the [participant] believes that his/her actions are interdependent, connected to, or responsive to the other and the perceived responsiveness of the other to the [participant's] actions" [40]. The fact that the exergame scored quite high in this regard is expected as the actions of each player, regardless of cooperative version, are heavily dependent on the perception of and information provided by the other player simply by virtue of the exergame's asymmetric design. The fact that the 'External Co-op' version garners more behavioural engagement is less expected. This difference could potentially be due to the methods of obtaining the information that needs to be communicated to the other player. In the 'VR Co-op' version the participant simply needed to communicate visual information about elements in the virtual room (red can location, trinket order, and abstract painting appearance), whereas in the 'External Co-op' version the participant had to interpret the visual information being provided and determine the associated task to communicate to the other player. We hypothesize that the additional level of complexity in the 'External Co-op' version is responsible for the increased perception of behavioural engagement, though more data is needed to validate that hypothesis.

Additionally, though there is no statistical significance for the differences in SUS, NASA TLX, SPGQ 'Empathy', and SPGQ 'Negative Feelings' scores between the versions, they still provide insight into the usability and workload of each version individually. It is again important to note the demographics of the participants, as these results are more indicative of potential caregivers than PWD. As stated in Section 3.4.4, the average SUS score is 68 with a maximum score of 100 [90]. Each version of the exergame scored significantly higher than the average, with the highest score of 89.5 belonging to the 'VR Co-op' version, meaning that every version of the exergame has a high level of usability (see Table 4).

When it comes to NASA TLX scores, lower scores are indicative of a lower workload, with the majority of workload scores for daily activities below 36.77, as stated in Section 3.4.4 [56]. Every version of the exergame has lower mean workload scores than the daily activities comparison, with the highest score (30) belonging to the 'Singleplayer' version and the lowest score (26.1) belonging to the 'External Co-op' version, meaning that every version of the exergame has a low workload score (See Table 5).

Across a wide variety of games the SPGQ was tested on, the average 'Empathy', 'Negative Feelings', and 'Behavioural Engagement' scores are 1.47, 0.75, and 2.2 respectively [48]. The results of the SPGQ as outlined in Section 3.4.4 indicate that both cooperative versions boasted an 'Empathy' score of more than double the average, a 'Negative Feelings' score of 0, and a 'Behavioural Engagement' score also greatly above average (See Table 6). This means that both versions of the cooperative exergame provide a high level of social presence.

Finally, the CPM results provide valuable insight into the parts of the exergame that participants enjoyed the most through the 'Laughter or Excitement Together' metric, which parts may need more work through the 'Helping' metric, and the level of cooperation the exergame inspires through the remaining metrics. By virtue of the exergame's asymmetric design, participants are constantly cooperating through 'Global Strategies' and 'Worked out Strategies'. Meanwhile, though not necessary to complete the exergame, participants frequently displayed patience while communicating, as seen through the 'Waited for Each Other' and 'Got in Each Others' Way' metrics, especially in the 'External Co-op' version. Although much more data is needed to know for sure, these results bode well for what cooperation between PWD and their caregivers might look like.

4.8 open-ended comments

Participants were also given the opportunity to provide comments are completing the aforementioned questionnaires for each version. There was a total number of 8 comments split between 6 participants (See Appendix L). Only 3 comments were attributable to specific versions of the exergame, with 2 comments for the ’External Co-op’ version and 1 comment for the ’Singleplayer’ version. The remaining comments were made regarding aspects shared between versions. In regard to the ’External Co-op’ version, participants commented that it was "fun directing the [research assistant]" and that "being the one giving instructions was a cool experience and it was made pretty well," with one of the two commenters adding that the look-up sheet had "a lot of words." The comment made specifically about the ’Singleplayer’ version stated that, "the hints could be a bit confused." The majority of the remaining comments were positive, with 2 complementing the quality of the exergame, 1 expressing that the concept was "really neat" and that they "like being able to perform the [exergame] activities while seated," and 1 expressing that the "way the random selection of tasks was implemented is very interesting and well integrated." Finally, 2 comments expressed issues with the VR versions of the exergame (’VR Co-op’ and ’Singleplayer’). One participant found some difficulty using the sponge to clean in-game dirt, and one participant found that even while seated, the movement around the room made them "feel a bit of simulation sickness." It is important to note that, at the time of the study, the original method of locomotion was implemented, which has since been changed to the teleportation method described in Chapter 3 in order to further mitigate the risk of participants experiencing simulation sickness.

4.9 chapter summary

This chapter has provided the study results described in Chapter 3 and a discussion of them. The normality of the SUS, NASA TLX, and SPGQ results were analyzed with the Kolomogorov-Smirnov and Shapiro-Wilk tests. Based on the results of the normality tests, the SUS scores of each version were compared with a repeated-measures ANOVA, the NASA TLX scores of each version were compared with Friedman's ANOVA, and the SPGQ scores of the cooperative versions were compared with a Sign test. Tables and figures are provided to summarize the data and visualize it for further clarity. The results were then summarized and discussed, followed by open-ended comments provided by the participants.

5 CONTRIBUTIONS & CONCLUSION

The rise of contemporary VR has inspired many explorations into their use as an alternative intervention for PWD, yet the research surrounding them is still lacking [30]. The conducted literature review revealed VR exergames to be a comparable intervention to traditional exercises with the added benefit of increased motivation. It also presented a few notable patterns in the existing literature: the importance of involving caregivers, PWD, health experts, and the development team in the design process, and the emotional and psychological benefit of adding shared social aspects.

This thesis presents the development of a social asymmetric virtual reality upper-limb exergame for PWD from a caregiver point of view. A within-subjects study focused on potential/existing caregivers was conducted to understand the usability, cognitive load, cooperative performance, and social presence when playing the game with both roles, VR and external, along with the cooperative and the single-player version. A total of 10 participants were recruited, who after completing the study, completed a series of self-reported questionnaires during each play session in addition to open feedback about the experience. The results of the study indicate that each version of the exergame has above-average usability, a cognitive load lower than that of average daily activities, and high levels of social presence. A statistically significant difference between the median values of behavioural engagement, favouring the 'External Co-Op' version, is hypothesized to be caused by the additional step of having to determine the correct information to communicate to the player in VR. Participants found the exergame to be novel and quite enjoyable, as evidenced by their feedback. These results indicate the exergame shows lots of promise in providing a highly usable, low cognitive load, socially involved exergame for both PWD and their caregivers. Based on insights gained during the development process the use of hand-tracking was avoided and a teleportation method of locomotion was adopted. This thesis contributes its social asymmetric upper-limb VR exergame to the currently-sparse collection of VR exergame interventions for PWD from a caregiver point of view. This exergame is also a planned part of a much larger suite of exergames for PWD that will see interventions and data collection with PWD in the future. Based on the lessons learned during the design, development, and study process, we recommend the use of shared social aspects and the inclusion of caregivers in them for future related works.

5.1 LIMITATIONS

Participant recruitment post-COVID-19 proved to be challenging, thus leading to a small sample size that impacted the statistical power of the data analysis. As such, further studies are required to effectively evaluate the exergame with larger sample sizes. Additionally, whilst it has been minimized, it's still important to acknowledge the risk of cybersickness present when playing the exergame. For example, one participant expressed concerns about the possible risk of experiencing vertigo prior to the study, and after the study, another one expressed feeling nauseated when navigating the room using the VR controller joysticks. To further validate the minimized possibility of cybersickness, an investigation of other locomotion techniques that enable access to the various locations within the room, such as teleportation, needs to be conducted. It is also important to acknowledge the risk of neck injury a VR HMD can pose to those with general frailty, osteoporosis, or other similar conditions. To minimize this risk, the HMD used in this paper is among one of the lightest currently available. However, despite these limitations, we believe the thesis, study, and exergame show lots of promise in motivating exercise in PWD.

5.2 FUTURE WORK

The design, developments, and results discussed in this thesis highlight the need for future research within the domain of VR exergames for PWD, especially those with social aspects, just as the literature review indicated. With the high degree of usability, there is also the potential for the exergame to be applied outside of just PWD. In favour of this, the exergame has already garnered much interest from a variety of age groups during multiple public showcases, such as those organized through the Shad Canada summer program and hosted on campus at OntarioTech, of prototype versions of the exergame. Future related works would benefit from incorporating social aspects that involve caregivers. Another consideration for future work would be to implement post-processing accessibility features, such as a colour-blindness mode or allowing players to adjust brightness. Additionally, in order to avoid the current limitation of a heavy HMD's risk of neck injury, future work should include a non-immersive alternative such as a desktop application. Future work will further investigate the efficacy of the exergame through the use of social experiences tailored to each user, designed through a human-centred/participatory design approach, and empirically tested in a long-term randomized controlled trial involving PWD and caregivers alike.

APPENDIX A: EXTERNAL PLAYER INSTRUCTIONS A

External Player Instructions

Please communicate with you partner and use the following reference sheet/look-up tables in order to discover the hidden tasks that the VR Player must complete.

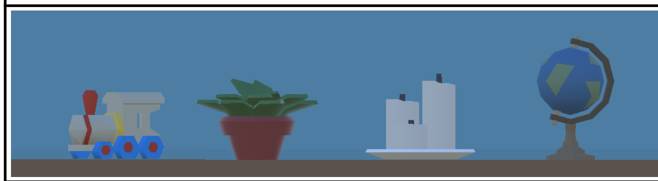
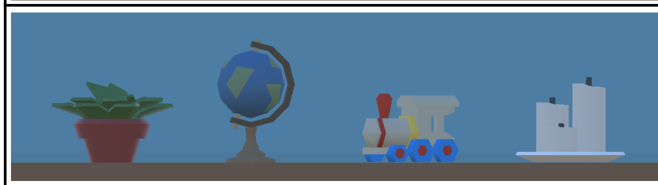
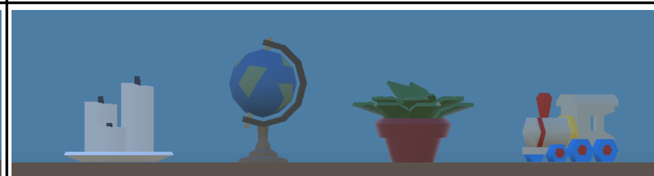
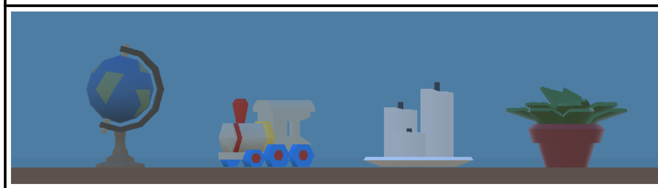
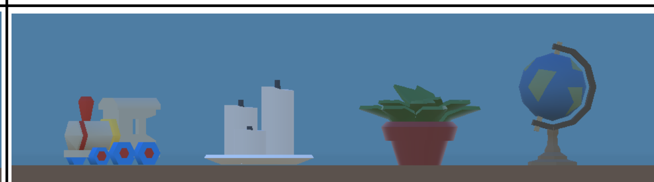
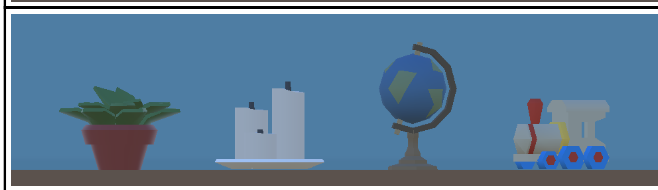
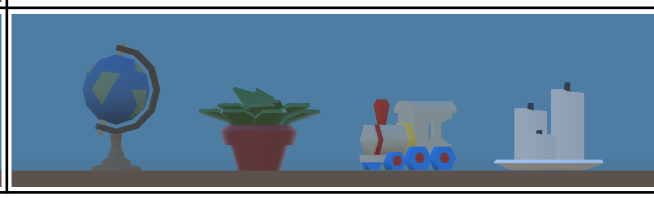
Red Can

Somewhere in the room will be a red soda can. Depending on its location within the room you will be given different hidden tasks. Use the table below as a reference.

Red Can Position	Hidden Task
Bedside Table	The can is empty and has been there for a while. Put the can in the garbage. Dust the bedside table.
On Top of Bookshelf	The can had been forgotten but isn't empty. Place the can on the left side of the dresser. Dust the top of the bookshelf.
Second Shelf of Bookshelf	The can is there to hold up the books. Replace the can with the book left on the chair. Put the can in the garbage.
Dresser (Right Side)	The can is new and ready to be enjoyed while reading a good book. Dust the window ledge beside the chair and then place the can there.
Dresser (Left Side)	The can had been forgotten but is now ready to be enjoyed. Place the can on the window ledge beside the chair and dust the dresser.
Window Ledge Beside Chair	The can has just recently been emptied. Place the can in the garbage. Place the book on the chair back on the second shelf of the bookshelf.
Beside Chair on Floor	This can has spilled on the floor. Wipe the floor clean and place the can in the garbage. Grab the blue can on the right side of the dresser and place it on the window ledge beside the chair.
Beside Garbage Can on Floor	This can is a vintage collectible and was almost thrown out by accident. Replace the blue can on the second shelf of the bookshelf with this red can. Put the blue can in the garbage.

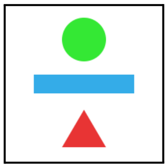
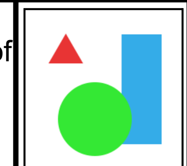
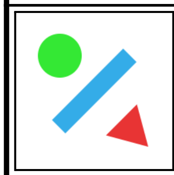
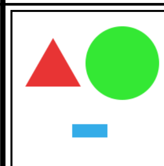
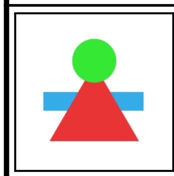
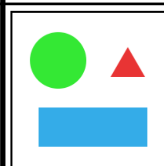
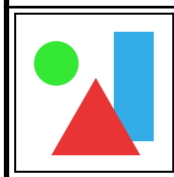
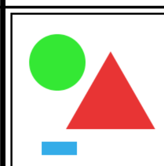
Organizing Trinkets

On the nearby shelf will be a number of trinkets, toys, and collectibles that must be organized in a particular way. Using their starting positions as a reference, use the following table to determine their true placement.

Starting Position	**True Placement**
	
	
	
	

Abstract Paintings

In the room there will be an abstract painting hung above the bed. Please communicate with your partner to discover which of the following paintings is in the room. The VR Player is then tasked with completing the associated hidden task.

Painting	Hidden Task	Painting	Hidden Task
	Clean the window beside the foot of the bed and the door knob of the door nearest to the window.		Clean both door knobs.
	Clean the drawer handles on the dresser and the door knob of the door beside the light switch.		Clean the drawer handles on the bedside table and the door knob of the door nearest to the window.
	Clean the window beside the chair and the door knob of the door beside the light switch.		Clean both windows.
	Clean the window beside the chair and the drawer handles on the bedside table.		Clean the window beside the foot of the bed and the drawer handles on the dresser.

B

APPENDIX B: RECRUITMENT POSTER

Do you want to experience virtual reality?

Researchers from OntarioTech are looking for adult volunteers to participate in a research study centred around an asymmetric multiplayer virtual reality game.

In order to participate you must not have vision, depth-perception, or physio-motor impairments. Additionally, you must also not be susceptible to vertigo.

This study will take approximately 60 minutes in a single session to complete. This study has been reviewed by the Ontario Tech University Research Ethics Board #17409 on July 7, 2023.

Scan this QR Code to participate:

FOR MORE INFORMATION

Please contact Dr. Uribe Quevedo at alvaro.quevedo@ontariotechu.ca or (905)721-8668 ext: 2615

OntarioTech UNIVERSITY

APPENDIX C: IN-TAKE FORM

C

VR Multiplayer Game Study

Researchers from Ontario Tech are looking for adult volunteers to participate in a research study centred around an asymmetric multiplayer virtual reality game.

* Indicates required question

If you are interested in participating in this study, please click 'Next'!

Please answer the following questions to the best of your ability

1. Are you particularly vulnerable to motion sickness? *
   During the study you'll be using the VR headset for about 10 minutes at a time.

   Mark only one oval.

   - Yes
     Skip to section 4 (Thank you for your interest, but unfortunately you do not fit our inclusion criteria.)
   - No
   - Maybe/Unsure
     Skip to section 4 (Thank you for your interest, but unfortunately you do not fit our inclusion criteria.)

2. Do you have any vision, depth perception, or physio-motor impairments? *

   Mark only one oval.

   - Yes
     Skip to section 4 (Thank you for your interest, but unfortunately you do not fit our inclusion criteria.)
   - No
   - Maybe/Unsure
     Skip to section 4 (Thank you for your interest, but unfortunately you do not fit our inclusion criteria.)

Thank you for your interest, you fit all of our criteria to participate!

3. Please enter your email address here so we can contact you: *

   ____

Thank you for your interest, but unfortunately you do not fit our inclusion criteria.

If you know of anyone else who may wish to participate in our study, please send them our way!
We wish you the best of luck in your future endeavours.

D

APPENDIX D: CONSENT FORM

Appendix 2: Consent Form

In order to consent to participation in the research study, please complete this form.

* Indicates required question

Title of Research Study:
An Experimental Study on the Effects of Adding Multiplayer to a Virtual Reality Exercise Game

Name of Principal Investigator (PI):
Alvaro Joffre Uribe Quevedo PhD

Name(s) of Co-Investigator(s), Faculty Supervisor, Student Lead(s), etc., and contact number(s)/email(s):

- Stephen Saunders, Student Lead
- Tom Tsiliopoulos, Student Lead

Departmental and Institutional Affiliation(s):
Ontario Tech University
Faculty of Business and Information Technology

External Funder/Sponsor:
Natural Sciences and Engineering Research Council of Canada (NSERC)

Introduction:

You are invited to participate in a research study entitled "An Experimental Study on the Effects of Adding Multiplayer to a Virtual Reality Exercise Game". The form includes details on study procedures, risks, and benefits that you should know before you decide to participate. You should take as much time as you need to make your decision. You should ask the Principal Investigator (PI) or study team to explain anything that you do not understand and make sure that all of your questions have been answered before signing this consent form. Before you make your decision, feel free to talk about this study with anyone you wish including your friends and family. Participation in this study is voluntary.

This study has been reviewed by the University of Ontario Institute of Technology (Ontario Tech University) Research Ethics Board #17409 on July 7, 2023.

Purpose and Procedures:

Purpose:

This project aims to assess the effects of adding a social, cooperative game design aspect to a virtual reality game that encourages participants to perform upper limb movements based on information provided by the facilitator outside of VR. These upper limb movements are comprised of linear and circular movements combining flexion/extension and adduction/abduction requiring a slow pace and a small number of repetitions.

The results of this study have the potential to improve and guide future works that aim to create similar games or applications. The game used in this study was designed to facilitate a co-operative asymmetric game experience between two players, one a caregiver and the other an individual with dementia. However, for the purposes of this study, data will only be collected from caregivers as future work will focus on individuals with dementia. The asymmetric game design will help us understand the caregiver's perceptions about the game as both facilitators and players.

Procedures:

This study will take place in person in one session lasting approximately 65 minutes. The study session will require you to work cooperatively with a research team member to complete various tasks. An anticipated total of 12 participants will take place in this study, though the study sessions will take place individually. If the number of eligible participants exceed the sample size, the selection will be made on a first-come/first-serve basis.

The procedures followed during the study are as follows:

1. You will be given at-least 5 minutes to review and complete this digital consent form if you had not completed it prior to arrival at the Gamer Lab (SIRC 4360) where all study activities will take place. More time will be given if needed to complete this step.
2. Prior to playing the game, we will ask you to answer a few questions about yourself in a questionnaire, including your age-range, gender, professional background/field of study, and VR use-habits. This will take approximately 5 minutes.
3. In this study, you will be tasked with playing a game in three different modes, each taking a maximum of 10 minutes to complete. Before playing each mode you will be provided instructions on how to play**.** After each of the modes you play, you will:
    - Be asked to fill out a questionnaire about the mode you just played on a predetermined computer in the lab. The questionnaire will consist of 3 sections that evaluate usability, cognitive load, and presence. These qualitative scales will provide further insight into your experience. Completion of the questionnaire will take approximately 5 minutes for each mode.
    - Be provided a short break (Approx. 5 mins.)
4. In the first mode, you will be tasked with communicating with a research member in order to discover hidden tasks. The research team member will be tasked with using the provided instructions/look-up sheet to relay the necessary information to you. During this time a research team member will take notes on your actions and what you see through the headset will be video-recorded in order to further examine the social interactions. This process captures only what is being displayed by the headset, it does not capture audio nor your likeness. This is done by mirroring the VR headset's display to the computer and capturing it with a video-recording application.
5. Once all in-game tasks have been successfully completed, or 10 minutes have elapsed since the game started, you will be asked to stop playing the game and will be presented with the aforementioned questionnaire, followed by a short break.
6. The second mode will consist of a similar form of multiplayer game-play as the first, however the roles will be reversed. The research team member will take up the role you previously had playing the game using the VR headset. You will be tasked with communicating with the research team member from outside of the VR world by using the provided instructions/look-up sheet to discover more hidden tasks. Similar to the first mode, a research team member will take observational notes, however there will be no recording this time.
7. Just like with the last mode, once all in-game tasks have been successfully completed, or 10 minutes have elapsed since the game started, you will be asked to stop playing the game and will be presented with the aforementioned questionnaire, followed by a short break.
8. In the final mode you will be tasked with playing a single-player version of the VR game, where instead of cooperating with a research team member, you will be given the necessary information to discover and complete hidden tasks from within the game. Through the same processes as the first mode, a research team member will be taking notes and what you see through the headset will be video-recorded.

9. For the third and final time, once all in-game tasks have been successfully completed, or 10 minutes have elapsed since the game started, you will be asked to stop playing the game and will be presented with the aforementioned questionnaire.
10. After you complete the final questionnaire you will be informed of, and given one final chance, to view your raw data and/or withdraw from the study. After that point, the study session has been successfully completed, and you will be presented with a thank-you letter.

Potential Benefits:

By participating in this study you may gain an increased familiarity with virtual reality and its uses regarding physical activity.

You may also gain a better understanding of asymmetric games and how you can engage in social in-person gaming, where only one person has a virtual reality headset.

If our hypothesis is proven correct through this study, the efficacy of the exergame may increase.

Potential Risk or Discomforts:

Since the study is hosted on campus there is the possibility that you may be a student of one or multiple of the research team members. If this is the case, we will have other research team members, who are not in such a position, conduct the study session for you.

All other potential risks have been minimized, and as such we do not perceive any other potential risks to you.

Use and Storage of Data:

All data gathered for the purposes of the study will be saved in a secure, encrypted Google Drive folder that only the research team will have access to. Once the study session is complete, the data within this folder and all sub-folders will have any identifiable information removed and permanently deleted in order to keep you and your data anonymous. All data will not be shared outside of the research team until the data has
been aggregated and anonymized, at which point the data can be shared with you and used in academic papers.

Once you have expressed interested in the study over email, any correspondence with you will be kept in the research team's inbox until after the completion of your study session, at which point the emails will be deleted.

Your response to this consent form will automatically be saved in the same folder as the rest of your data and does not require a name or signature to be completed, keeping you anonymous.

The research team will collect data on your experiences and actions by video recording what you see through the headset during the session, and by taking observational notes. This recording will capture only what is being displayed by the headset, it does not capture audio nor your likeness. This is done by mirroring the VR headset's display to the computer and capturing it with a video-recording application.

The demographic information collected on you will be your age-range, gender, professional background/field of study, and how often you use a VR headset. The purpose of collecting this information is to see if it has any effect on the data we collect from the study session. It will not be possible to identify you from this data.

After being aggregated and anonymized, all data will be retained for one year in order to be used in the development of academic reports, after which all data will be permanently deleted.

Though this study is sponsored by the Natural Sciences and Engineering Research Council of Canada, they will not be receiving any data about and/or from the study or yourself.

All information collected during this study, including your personal information, will be kept confidential and will not be shared with anyone outside the study unless required by law. You will not be named in any reports, publications, or presentations that may come from this study.

Confidentiality:

Your data will be thoroughly reviewed and stripped of any identifying information in order to anonymize the data including video and questionnaire timestamps. Your information will then be associated with an ID number, rather than your name or any other identifiable information. Emails and the history of the lab computer used will also be deleted once the study session has been completed. The data will remain anonymized as no identifiable information will be retained.

During the session, what you see through the headset will be recorded. Though the recording will not show you yourself, it will show what you saw and the actions you took within the VR game. As such, you may be able to identify which recording is yours if you remember your actions and the sequence in which they were performed.

Your privacy shall be respected. No information about your identity will be shared or published without your permission, unless required by law. Confidentiality will be provided to the fullest extent possible by law, professional practice, and ethical codes of conduct. Please note that confidentiality cannot be guaranteed while data is in transit over the Internet.

This research study includes the collection of demographic data which will be aggregated (not individually presented) in an effort to protect your anonymity. Despite best efforts, it is possible that your identity can be determined even when data is aggregated.

The demographic data being collected has no relation to your appearance or preferences, only to their experience with virtual reality technology.

Voluntary Participation:

Your participation in this study is voluntary and you may partake in only those aspects of the study in which you feel comfortable. You may also decide not to be in this study, or to be in the study now, and then change your mind later. You may leave the study at any time without affecting your relationship with the institution or research team members. You will be given information that is relevant to your decision to continue or withdraw from participation.

You may refuse to answer any question(s) you do not want to answer, or not answer an interview question by saying, 'pass'.

Right to Withdraw:
You will be given information that is relevant to your decision to continue or withdraw from participation.

If you withdraw from the research project at any time, any data that you have contributed will be removed from the study and you do not need to offer any reason for making this request.

All collected data will be anonymized at the end of your study session, and thus cannot be withdrawn after that point. You will be informed of your last opportunity to view the data and/or withdraw from the study prior to the data being anonymized at the end of the study session.

If you choose to stop answering questions early or close the questionnaire form during the study, all incomplete question data and data collected in the questionnaire prior to closing will be deleted.

Conflict of Interest:
Researchers have an interest in completing this study. Their interests should not influence your decision to participate in this study. Your academic standing, grades, or relations with the university or research team members will not be affected in any way by participating in the study.

Compensation, Reimbursement, Incentives:

You will not incur any expenses as a result of your participation.
You will not be reimbursed for costs such as travel or transportation to the study itself.
There will be no punishment or disadvantage should you no longer wish to take part in the study.
You may withdraw at any time and do not need to offer any reason.
There is no compensation for your participation in the study.

Debriefing and Dissemination of Results:
Please reach out to the research team or the Principal Investigator, Dr. Uribe Quevedo, if you are interested in the results of the study or have any questions about the results. Shared aggregated data will become available within a year of finalizing the study (July 2024). As the data will be anonymized, researchers will not know which results are specific to each participant.

Participant Rights and Concerns:

Please read this consent form carefully and feel free to ask the researcher any questions that you might have about the study. If you have any questions about your rights as a participant in this study, complaints, or adverse events, please contact the Research Ethics Office at (905) 721-8668 ext. 3693 or at researchethics@ontariotechu.ca.

If you have any questions concerning the research study or experience any discomfort related to the study, please contact the researcher Alvaro Joffre Uribe Quevedo at (905)-721-8668 ext: 2615

or alvaro.quevedo@ontariotechu.ca.

By signing this form you do not give up any of your legal rights against the investigators, sponsor or involved institutions for compensation, nor does this form relieve the investigators, sponsor or involved institutions of their legal and professional responsibilities.

1. I have read the consent form and understand the study being described. *

   Check all that apply.

   - [ ] I agree
   - [ ] I disagree

2. I have had an opportunity to ask questions and my questions have been answered. I am free to ask questions about the study in the future. *

   Check all that apply.

   - [ ] I agree
   - [ ] I disagree

3. I freely consent to participate in the research study, understanding that I may discontinue participation at any time without penalty. A copy of this Consent Form has been made available to me. *

   Check all that apply.

   - [ ] I agree
   - [ ] I disagree

E

APPENDIX E: DEMOGRAPHIC QUESTIONNAIRE

Demographic Questionnaire

Please answer a few questions about yourself.

* Indicates required question

1. Age Range *

Mark only one oval.

- 18-24
- 25-34
- 35-54
- 55+

2. Gender *

Mark only one oval.

- Male
- Female
- Prefer not to say
- Other: ____________

3. What is your professional background or field of study? *

Mark only one oval.

- Humanities
- Computer Science
- Health Science
- Engineering
- Game Development
- Other: ____________

4. How often do you use a VR Head-mounted Display? *

Mark only one oval.

- Daily
- More than once a week
- Once a week
- More than once a month
- Once per month
- More than once a year
- Once a year or less
- Never

5. Have you previously provided care to an elderly individual? *

Mark only one oval.

- Yes
- No
- Maybe/Unsure

6. Do you plan to provide care to an elderly individual in the future? *

Mark only one oval.

- Yes
- No
- Maybe/Unsure

APPENDIX F: EXERGAME QUESTIONNAIRES F

Exergame Questionnaires

Please answer these questions about your most recent play session.

* Indicates required question

System Usability Scale (SUS)

Please answer the following questions to the best of your ability.

1. I think that I would like to use this system frequently *

   Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

2. I found the system unnecessarily complex *

   Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

3. I thought the system was easy to use *

   Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

4. I think that I would need the support of a technical person to be able to use this system *

   Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

5. I found the various functions in this system were well integrated *

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

6. I thought there was too much inconsistency in this system *

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

7. I would imagine that most people would learn to use this system very quickly *

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

8. I found the system very cumbersome to use *

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

9. I felt very confident using the system *

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

10. I needed to learn a lot of things before I could get going with this system *

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree

NASA Task Load Index (TLX)

Please answer the following questions to the best of your ability.

11. Mental Demand *
How mentally demanding was the game?

Mark only one oval.

	1	2	3	4	5	6	7	
Very	◯	◯	◯	◯	◯	◯	◯	Very High

12. Physical Demand *
How physically demanding was the game?

Mark only one oval.

	1	2	3	4	5	6	7	
Very	◯	◯	◯	◯	◯	◯	◯	Very High

13. Temporal Demand *
How hurried or rushed was the pace of the game?

Mark only one oval.

	1	2	3	4	5	6	7	
Very	◯	◯	◯	◯	◯	◯	◯	Very High

14. Performance *

How successful were you in accomplishing what you were asked to do?

Mark only one oval.

	1	2	3	4	5	6	7	
Very	◯	◯	◯	◯	◯	◯	◯	Very High

15. Effort *

How hard did you have to work to accomplish your level of performance?

Mark only one oval.

	1	2	3	4	5	6	7	
Very	◯	◯	◯	◯	◯	◯	◯	Very High

16. Frustration *

How insecure, discouraged, irritated, stressed, and annoyed were you?

Mark only one oval.

	1	2	3	4	5	6	7	
Very	◯	◯	◯	◯	◯	◯	◯	Very High

Session Type

The social presence section is only needed after a cooperative, multiplayer session.

17. After which type of game-play session are you completing this questionnaire? *

Mark only one oval.

◯ Cooperative Session

◯ Singleplayer Session

Social Presence Gaming Questionnaire (SPGQ)

Please answer the following questions to the best of your ability.

The "others" in these cases refer to the research team member you cooperated with.

18. When the others were happy, I was happy *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

19. When I was happy, the others were happy *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

20. I empathized with the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

21. I felt connected to the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

22. I admired the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

23. I found it enjoyable to be with the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

24. I sympathized with the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

25. I tended to ignore the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

26. The other(s) tended to ignore me *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

27. I felt revengeful *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

28. I felt schadenfreude (malicious delight) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

29. I felt jealous of the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

30. I envied the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

31. My actions depended on the other's actions *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

32. The other's actions were dependent on my actions *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

33. What the other(s) did affected what I did *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

34. What I did affected what the other(s) did *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

35. The other(s) paid close attention to me *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

36. I paid close attention to the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

37. My intentions were clear to the other(s) *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

38. The other's intentions were clear to me *

Mark only one oval.

- 0 - Not at All
- 1 - Slightly
- 2 - Moderately
- 3 - Fairly
- 4 - Extremely

Questions & Comments

39. If you have any comments, please add them here

APPENDIX G: COOPERATIVE PERFORMANCE METRICS G

Cooperative Performance Metrics

To be completed during a live study session or recording of one.

For each Cooperative Performance Metric (CPMs):

- Using the table below, make note of any event that that falls under one of the CPMs and label it accordingly.

- For each label: identify a cause based on one of the following cooperative design patterns:
  - Complementarity
  - Synergies between abilities
  - Shared goals
  - Synergies between goals
  - Special rules
  - Camera styles
  - Interacting with the Same Object (ISO)
  - Shared Puzzles (SP)
  - Shared Character (SC)
  - Miscellaneous (PM)
    - Character Design
    - Animations
    - Cut Scenes
    - Interactive Objects

- Only label events happening in the same space *once* per cause. For example, if one instance of a specific character animation makes both participants laugh together twice, only label it once as 'LT' with the cause being 'PM' (Miscellaneous).

The specific CPMs, their labels (in brackets), and the conditions an event must meet to qualify, are as follows:

Laughter or Excitement Together (LT)

Whenever participants:

- Both laugh at the same time due to a specific game event;
- Express verbally that they are enjoying the game, looking for utterances, such as “sweet”, “it is a lot of fun”, etc.;
- Shake their heads and show facial nonverbal behaviors that clearly express happiness or excitement.

Worked out Strategies (WS)

Whenever participants:

- Talk aloud about solving a shared challenge;
- Divide a game zone to different parts in order to divide and conquer;
- Navigate the world while consulting with each other.

Helping (H)

Whenever *one* participant helps the *other* by:

- Talking about the controllers/controls, and how one can use the game mechanics;
- Telling the other the correct way of passing a shared obstacle;
- Saving and rescuing the other player while he or she is failing.

Global Strategies (GS)

Whenever participants:

- Take different roles during gameplay that complement each other’s responsibilities and abilities.

Waited for Each Other (WO)

Whenever *one* participant:

- Waits for the other to catch up.

Got in Each Others’ Way (GW)

Whenever *one* participant:

- Leads and the other lags behind;
- Wants to do an action, and the other wants to take a different action, and whereby taking these actions will inevitably interfere or hinder each other’s goals.

APPENDIX H: SYSTEM USABILITY SCALE RESULTS

ID	Game Version	SYSTEM USABILITY SCALE (SUS)										FINAL SUS SCORE
		I think that I would like to use this system frequently	I found the system unnecessarily complex	I thought the system was easy to use	I think that I would need the support of a technical person to be able to use this system	I found the various functions in this system were well integrated	I thought there was too much inconsistency in this system	I would imagine that most people would learn to use this system very quickly	I found the system very cumbersome to use	I felt very confident using the system	I needed to learn a lot of things before I could get going with this system	
P1	Singleplayer	4	2	3	2	3	1	3	2	2	2	65
P2	Singleplayer	4	1	5	2	5	4	4	1	5	2	82.5
P3	Singleplayer	4	1	5	1	5	1	5	1	5	1	97.5
P4	Singleplayer	4	2	3	2	4	1	4	1	5	2	80
P5	Singleplayer	4	2	4	2	4	2	5	4	4	1	75
P6	Singleplayer	4	2	5	1	5	1	5	1	5	1	95
P7	Singleplayer	5	1	5	1	5	1	5	1	5	1	100
P8	Singleplayer	3	2	4	2	4	2	5	2	4	2	75
P9	Singleplayer	3	4	3	4	5	1	3	4	3	2	55
P10	Singleplayer	1	1	4	1	5	1	4	1	5	1	85
Average	Singleplayer	3.6	1.8	4.1	1.8	4.5	1.5	4.3	1.8	4.3	1.5	81
P1	Coop (VR)	4	2	3	3	5	1	2	1	4	3	70
P2	Coop (VR)	4	1	5	2	5	1	4	1	5	2	90
P3	Coop (VR)	4	1	5	1	5	1	5	1	5	1	97.5
P4	Coop (VR)	4	2	5	3	5	1	3	2	5	2	80
P5	Coop (VR)	4	1	4	1	5	1	4	1	5	1	92.5
P6	Coop (VR)	4	1	5	2	4	1	5	1	5	1	92.5
P7	Coop (VR)	5	1	5	1	5	1	5	1	5	1	100
P8	Coop (VR)	4	1	5	2	5	1	5	2	5	2	90
P9	Coop (VR)	5	1	5	4	5	1	4	1	5	2	87.5
P10	Coop (VR)	4	1	5	2	5	1	5	1	5	1	95
Average	Coop (VR)	4.2	1.2	4.7	2.1	4.9	1	4.2	1.2	4.9	1.6	89.5
P1	Coop (External)	4	3	3	2	5	1	3	2	3	3	67.5
P2	Coop (External)	4	1	5	1	5	1	1	1	5	1	87.5
P3	Coop (External)	5	1	5	1	5	1	5	1	5	1	100
P4	Coop (External)	4	1	5	2	4	1	3	1	5	2	85
P5	Coop (External)	4	1	4	1	4	1	4	1	5	1	90
P6	Coop (External)	5	2	5	1	5	1	5	1	5	1	97.5
P7	Coop (External)	5	1	5	1	5	1	5	1	5	1	100
P8	Coop (External)	3	1	5	1	5	1	5	1	4	2	90
P9	Coop (External)	5	2	4	2	5	1	3	2	4	2	80
P10	Coop (External)	3	1	4	1	4	2	5	1	4	1	85
Average	Coop (External)	4.2	1.4	4.5	1.3	4.7	1.1	3.9	1.2	4.5	1.5	88.25

I APPENDIX I: NASA TASK LOAD INDEX RESULTS

Participant ID	Version	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
P1	Coop (External)	1	1	1	6	2	1
P2	Coop (External)	1	1	1	7	7	1
P3	Coop (External)	1	1	1	7	1	1
P4	Coop (External)	4	3	1	6	4	1
P5	Coop (External)	5	1	1	6	3	2
P6	Coop (External)	2	1	1	7	2	1
P7	Coop (External)	2	1	1	7	1	1
P8	Coop (External)	2	1	2	6	2	1
P9	Coop (External)	5	1	3	6	3	1
P10	Coop (External)	3	1	1	7	2	1
Final Unweighted Average Score (0-100)	Coop (External)	26.66666672	3.33333334	5.00000001	91.66666685	28.33333339	1.66666667
P1	Coop (VR)	2	2	1	6	4	1
P2	Coop (VR)	2	1	2	6	7	1
P3	Coop (VR)	1	2	1	7	1	1
P4	Coop (VR)	3	5	1	6	4	1
P5	Coop (VR)	1	1	1	7	3	1
P6	Coop (VR)	1	2	1	6	1	1
P7	Coop (VR)	3	2	1	7	2	1
P8	Coop (VR)	2	2	2	7	2	1
P9	Coop (VR)	4	5	3	7	3	1
P10	Coop (VR)	2	1	1	7	2	1
Final Unweighted Average Score (0-100)	Coop (VR)	18.33333337	21.66666671	6.66666668	93.33333352	31.66666673	0
P1	Singleplayer	2	2	2	3	5	1
P2	Singleplayer	4	1	1	4	5	1
P3	Singleplayer	1	2	1	7	1	1
P4	Singleplayer	4	5	1	6	4	1
P5	Singleplayer	1	5	1	5	3	5
P6	Singleplayer	3	2	1	5	2	2
P7	Singleplayer	2	1	1	7	2	1
P8	Singleplayer	3	2	1	5	3	1
P9	Singleplayer	6	5	2	6	4	3
P10	Singleplayer	3	1	1	6	1	1
Final Unweighted Average Score (0-100)	Singleplayer	31.66666673	26.66666672	3.33333334	73.33333348	33.3333334	11.66666669

J APPENDIX J: SOCIAL PRESENCE GAMING QUESTIONNAIRE RESULTS

ID	Game Version	When the others were happy, I was happy	When I was happy, the others were happy	I empathized with the other(s)	I felt connected to the other(s)	I admired the other(s)	I found it enjoyable to be with the other(s)	I sympathized with the other(s)	Final Empathy Average (0-4)
P1	Coop (External)	4	4	4	4	4	4	3	3.857142857
P2	Coop (External)	3	3	4	4	4	4	4	3.714285714
P3	Coop (External)	4	4	4	4	4	4	1	3.571428571
P4	Coop (External)	4	4	4	4	4	4	4	4
P5	Coop (External)	4	4	4	4	0	4	3	3.285714286
P6	Coop (External)	4	4	4	4	4	4	4	4
P7	Coop (External)	4	4	4	4	4	4	4	4
P8	Coop (External)	2	2	2	3	2	3	2	2.285714286
P9	Coop (External)	4	4	4	3	4	4	4	3.857142857
P10	Coop (External)	2	2	2	1	1	3	1	1.714285714
P1	Coop (VR)	3	3	3	4	4	4	3	3.428571429
P2	Coop (VR)	3	3	4	4	4	4	4	3.714285714
P3	Coop (VR)	4	4	4	4	4	4	1	3.571428571
P4	Coop (VR)	4	3	3	4	3	4	3	3.428571429
P5	Coop (VR)	3	3	3	3	0	4	3	2.714285714
P6	Coop (VR)	4	4	3	4	4	4	3	3.714285714
P7	Coop (VR)	4	4	4	4	3	4	3	3.714285714
P8	Coop (VR)	2	2	2	3	2	3	2	2.285714286
P9	Coop (VR)	4	4	4	4	4	4	4	4
P10	Coop (VR)	2	2	0	0	0	2	0	0.8571428571

ID	Game Version	I tended to ignore the other (s)	The other(s) tended to ignore me	I felt revengeful	I felt schadenfreude (malicious delight)	I felt jealous of the other(s)	I envied the other(s)	Final Negative Feelings Average (0-4)
P1	Coop (External)	0	0	0	0	0	0	0
P2	Coop (External)	0	0	0	0	0	0	0
P3	Coop (External)	0	0	0	0	0	0	0
P4	Coop (External)	0	0	0	0	0	0	0
P5	Coop (External)	0	0	0	0	0	0	0
P6	Coop (External)	0	0	0	0	0	0	0
P7	Coop (External)	0	0	0	0	0	0	0
P8	Coop (External)	0	0	0	0	0	0	0
P9	Coop (External)	0	0	0	0	0	0	0
P10	Coop (External)	0	0	0	0	0	0	0
P1	Coop (VR)	0	0	0	0	0	0	0
P2	Coop (VR)	0	0	0	0	0	0	0
P3	Coop (VR)	0	0	0	0	0	0	0
P4	Coop (VR)	0	0	0	0	0	0	0
P5	Coop (VR)	0	0	0	0	0	0	0
P6	Coop (VR)	0	0	0	0	0	0	0
P7	Coop (VR)	0	0	0	0	0	0	0
P8	Coop (VR)	0	0	0	0	0	0	0
P9	Coop (VR)	0	0	0	0	0	0	0
P10	Coop (VR)	0	0	0	0	0	0	0

ID	Game Version	My actions depended on the other's actions	The other's actions were dependent on my actions	What the other (s) did affected what I did	What I did affected what the other(s) did	The other(s) paid close attention to me	I paid close attention to the other(s)	My intentions were clear to the other(s)	The other's intentions were clear to me	Final Behavioural Engagement Average (0-4)
P1	Coop (External)	4	4	3	4	4	4	2	3	3.5
P2	Coop (External)	0	3	3	3	4	4	4	4	3.125
P3	Coop (External)	4	4	4	4	4	4	4	4	4
P4	Coop (External)	4	4	4	4	4	4	4	4	4
P5	Coop (External)	2	4	1	4	3	3	4	4	3.125
P6	Coop (External)	4	4	4	4	4	4	4	4	4
P7	Coop (External)	4	4	4	4	4	4	4	4	4
P8	Coop (External)	1	3	1	3	3	3	3	3	2.5
P9	Coop (External)	3	3	4	4	4	4	3	4	3.625
P10	Coop (External)	3	3	2	3	2	2	2	2	2.375
P1	Coop (VR)	4	4	3	3	4	4	3	3	3.5
P2	Coop (VR)	0	3	3	3	4	4	4	4	3.125
P3	Coop (VR)	4	4	4	4	4	4	4	4	4
P4	Coop (VR)	4	3	3	2	3	3	3	3	3
P5	Coop (VR)	4	2	4	2	2	2	1	4	2.625
P6	Coop (VR)	3	2	3	3	4	4	4	4	3.375
P7	Coop (VR)	4	3	4	2	4	4	4	4	3.625
P8	Coop (VR)	3	1	3	1	2	3	3	3	2.375
P9	Coop (VR)	4	4	4	4	3	3	3	4	3.625
P10	Coop (VR)	3	3	2	2	3	2	1	2	2.25

APPENDIX K: COOPERATIVE PERFORMANCE METRICS RESULTS

Participant ID	Game Version	CPM Label	Cause/Cooperative Design Pattern	Brief Description of the Event
P1	VR	LT	PM (Visual Design & Interactive Objects)	Found cleaning the dirt to be quite novel and fun. "Good stress relief"
		WO	SP (Shared Puzzles)	Waited for the research team member to finish asking questions and explaining things.
		H	PM (Controls)	Had difficulties with the controls and needed a bit of help identifying buttons on the controllers
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
		H	PM (Visual Design)	The design of the look-up sheet was a bit confusing, resulting in reading the wrong tasks for the research team member.
P2	VR	LT	PM (Visual Design & Interactive Objects)	Enjoyed the cleaning aspect the most and found it to be "more fun than real life"
		WO	SP (Shared Puzzles)	Waited for the research team member to finish asking questions and explaining things.
		H	PM (Interactive Objects)	Needed a bit of help using the in-game tools
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
P3	VR	WO	SP (Shared Puzzles)	Waited for the research team member to finish asking questions and explaining things.
		LT	PM (Visual Design)	Thought the game was impressive both visually and technically.
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
P4	VR	LT	PM (Visual Design & Interactive Objects)	Shared their enjoyment of the cleaning aspect and novelty of VR.
		WO	SP (Shared Puzzles)	Waited for the research team member to finish asking questions and explaining things.
	EX	LT	SP (Shared Puzzles)	Shared their enjoyment of leading with the instruction and watching the research team member play.
		WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
P5	VR	LT	PM (Visual Design)	Enjoyed the visual effects & polish, especially the victory confetti.
		WO	SP (Shared Puzzles)	Waited for the research team member to finish asking questions and explaining things.
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
P6	VR	GW	SP (Shared Puzzles)	Interrupted the research team member on occasion to confirm information or explain things
		LT	PM (Visual Design)	Shared their enjoyment of the window/dirt cleaning
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
P7	VR	LT	PM (Visual Design & Interactive Objects)	Enjoyed throwing objects around the room and cleaning the dirt.
		GW	SP (Shared Puzzles)	Occasionally interrupted or spoke over the research team member to confirm information or explain things.
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw and asked questions to confirm information.
P8	VR	GW	SP (Shared Puzzles)	Occasionally interrupted or spoke over the research team member to confirm information.
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
		LT	SP (Shared Puzzles)	Shared enjoyment in watching the research team member perform the in-game tasks.
P9	VR	WO	SP (Shared Puzzles)	Waited for the research team member to finish asking questions and explaining things.
	EX	LT	SP (Shared Puzzles)	Shared enjoyment in watching the research team member perform the in-game tasks.
		WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
P10	VR	GW	SP (Shared Puzzles)	Occasionally interrupted or spoke over the research team member to confirm information.
		LT	PM (Visual Design & Interactive Objects)	Shared enjoyment in the game as a whole, thought it was "really cool"
	EX	WO	SP (Shared Puzzles)	Waited for the research team member to explain what they saw.
		LT	SP (Shared Puzzles)	Shared enjoyment in watching the research team member perform the in-game tasks.

Note:

Every participant, during each game version, Worked out Strategies (WS) and participated in Global Strategies (GS) by virtue of the game's design. Not a single one refused to communicate with the research team member, and as such WS and GS were not included in this list for brevity, though they do still exist.

CPM Label Key:

LT	Laughter or Excitement Together
WS	Worked out Strategies
H	Helping
GS	Global Strategies
WO	Waited for Each Other
GW	Got in Each Other's Way

APPENDIX L: OPEN-ENDED COMMENTS

L

ID	Game Version	If you have any comments, please add them here:
P1	Coop (VR)	
	Singleplayer	
	Coop (External)	
P2	Coop (VR)	
	Singleplayer	I think the hints could be a bit confused.
	Coop (External)	
P3	Coop (VR) Singleplayer Coop (External)	This is unrelated to the purpose of the experiment, but I want to say that what this student has done is perfect in his level. Developing a game is hard for one person and he for a one-man job, he has paid enough attention to the smoothness and quality of the game. Kudos to him.
P4	Coop (VR)	Really neat concept and I like being able to perform the game activities while seated.
	Singleplayer	
	Coop (External)	It was fun directing the user to their tasks by sort of decoding the information that was passed to me from the player.
P5	Coop (VR) Singleplayer Coop (External)	The movement around the room made me feel a bit of simulation sickness
P6	Coop (VR) Singleplayer Coop (External)	Overall, I found the experience enjoyable. The only issue I experienced was some difficulty holding the sponge, as it would rotate in my hand a bit and make it hard to clean the windows. I think the way the random selection of tasks was implemented is very interesting and well integrated.
P7	Coop (VR)	
	Singleplayer	
	Coop (External)	
P8	Coop (VR)	
	Singleplayer	
	Coop (External)	
P9	Coop (VR)	Very cool game for a very good cause. Everything was polished and I didn't see any bugs. I don't have any negative feedback!
	Singleplayer	
	Coop (External)	Being the one giving instructions was a cool experience and it was made pretty well. My only gripe is there were a lot of words I had to read as the game was already going so it would be cool if there were less words and more visual based instructions or something of the sort. Also, if the instruction page was themed in a cool way it would make it more fun (Something other than normal letter paper, and regular formatting). Everything else was really well done though.
P10	Coop (VR)	
	Singleplayer	
	Coop (External)	

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