# Exploring the implementation of virtual reality technology for the assessment of daily living activities

by

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B.S., Federal University of Rio Grande do Sul, Brazil, 2016

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Industrial and Manufacturing Systems Engineering
Carl R. Ice College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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# Abstract

Virtual Reality (VR) technology has created many simulation possibilities that were once either physically unfeasible, too expensive, or risky to be executed in real-life. Researchers have been taking advantage of this technology to help older adults prolong independent living and increase their quality of life. With an increased number of older adults, a major concern relates to detecting disease-related cognitive decline, which can manifest itself in the form of impairments in the ability to perform daily living activities. Currently, those abilities are measured subjectively as performance-based tests are impractical to be conducted. VR technology has the potential to facilitate those tests and improve screening techniques.

In testing for a real-life task with VR, it is imperative to understand the effect of using this technology so that task performance is the only variable being measured, and not the person's ability to use the technology and/or technology limitations. So far, very limited research has explored the validity and fidelity of VR simulations for daily living activities in combination with the feasibility and acceptability of this technology by older adults.

In this dissertation, implications of using VR technology to conduct assessments related to daily activities were evaluated. First, it was investigated how fine motor movements – an important component of daily living activities that has been understudied – replicate in VR with younger and older adults. A learning effect related to the technology was determined by having participants repeat the task in each real-life and in VR in a novel study design. Results showed high feasibility and acceptability of implementing the simulation with both groups and some limitations in fidelity related to longer times to complete the task in VR. No significant difference in number of errors was observed between real and virtual, as well as between younger and older adults.

In a second VR study, it was evaluated if gaming experience and training protocols influenced performance for simple daily activities, as well as VR-specific tasks in a sample of younger adults. Gaming abilities were found transferable when using the VR, with participants that were classified as “gamers” taking less time to complete tasks. VR for simulation of daily activities was considered very intuitive, with majority of participants being able to complete the tasks even without any instruction on how to use the VR system.

VR technology was found to be a feasible, intuitive, and acceptable tool to test for simple daily living activities and fine motor movements. The older adult sample could easily engage with the system and, with a little bit of practice, reduce the time gap in performance when compared to younger adults. The rising adherence of technology by older adults may also contribute to the acceptability of implementing new technologies as part of routine health exams. This will also reinforce the need to control for possible confounding factors, such as experience with video games, and keep exploring new ones as the technology evolves. Future studies using VR technology should incorporate findings from this dissertation to improve assessments with any age group and minimize bias in outcome variables of interest.

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# Dedication

To my father, who inspired me to become an engineer.

To my mother and brother, for all the love and support - even from another hemisphere.

To my grandparents, who taught me the importance of hard work.

And to Lucas, for all the patience, encouragement, care, and love.

# Chapter 1 - Introduction

Advancements in technology have shaped our society and how we live. Many opportunities have stemmed from new devices being introduced, which in turn pushed researchers to better understand their impact in people's lives, as well as explore potential applications that can increase quality of life.

One of the new technology trends that is starting to dominate the market is Virtual Reality (VR). It was only around 2016 that the first consumer VR headset was launched, and since then, multiple other big-name brands have developed their own devices with higher quality versions of it. Unsurprisingly, sales have gone up, and in the first quarter of 2022 the VR headset market grew by 241.6% compared to the previous year (Henry, 2022).

Although normally associated with gaming and entertainment, VR has been shown to be useful in multiple research domains due to its abilities to simulate experiences similar to the real world, as well as situations that could be unsafe, impractical, or impossible to observe in the real-life setting (Kearney et al., 2009). The advances in the software and equipment can now considerably reduce the interference from the real world, creating lifelike experiences so real that can trigger feelings such as anxiety (Canning et al., 2020a) and fear of heights (Ehgoetz Martens et al., 2014). VR also has the potential of promoting standardization in research, as well as reducing implementation costs related to testing infrastructure by not having to physically build testing environments.

A field of research that is currently exploring possible applications for VR technology is aging research. With increasing number of older adults, disease-related cognitive decline is expected to take a toll in society. Although dementias do not have a cure yet, early treatment and assessment can promote great benefits to the patient when an early diagnosis takes place. The biggest challenge is to detect the small changes in cognition and behavior that might be associated with the early stages of those diseases.

A common predictor of having a dementia-related disease is impairment in the ability to perform daily activities such as doing house chores, taking care of finances, or preparing meals (Atkins et al., 2018a). Having a functional impairment can impact not only the individual's health and safety, but also their families and loved ones.

Screening for impairments related to daily living activities is currently being assessed in routine health exams with older adults by using self-reports or informant-based reports, which might not detect small changes in cognition, nor effectively assess one's ability to perform those activities. VR can potentially improve those assessments by making tests performance-based, but its implications must be considered when using VR to evaluate someone's performance in a real-life task.

There is a widespread idea that older adults are technologically illiterate, and that this would be the main reason for this age group to eschew new devices available. Research has pointed to a variety of possible causes for older adults not adhering to some devices, including physical challenges, lack of comfort with it, lack of confidence, as well as not finding it useful (Anderson & Perrin, 2017; Vaportzis et al., 2017). This mindset related to older adults in combination with their exclusion from research and development of new technology contributes to something called "digital inequality" (Hargittai et al., 2019), which researchers should strive to overcome.

As the world shifts to online, adhering to a new technology might not even be an active choice, but something imposed. Society has been progressing to a state where things such as common daily activities are moving towards becoming technology dependent, and technology has become a means to maintain a relatively normal life when abnormal situations such as social distancing practices are in place. During the COVID-19 pandemic, getting your education meant going physical classrooms to Zoom meetings, and a lot of people started to socialize only virtually. In-store shopping became a fearful event for some, who kept their social distance by switching to only online shopping for groceries or other types of goods (Shen et al., 2022). Even doctor's appointments went online, which became an issue for some specific populations such as some older adults who are not very familiar with technology or experience a disability (Lam et al., 2020).

It was also recommended that people more vulnerable to lockdown loneliness were provided access to digital technology to connect with their loved ones (Shah et al., 2020). However, not everyone has access to the technology necessary to remain active and engaged with society in such situations.

Considering the latest data available of an older adult population in the US of 54.1 million, there are more than 13.5 million older adults in the US who might not use the internet. But they are catching up. Pew Research data from 2021 showed that 75% of adults 65+ say they use the internet, compared to 96% of adults ages between 50 and 64, 98% with ages between 30-49, and even 99% with ages between 18-29. Similar trends are also found when it comes to ownership of technology devices such as tablets and smartphones (Pew Research Center, 2022), what shows that older adults are adhering to new technology and it is very reasonable to consider incorporating new devices, including VR, into aging research.

Technology has in fact a lot of potential to help older adults achieve one of their main goals, which is to age independently (Wang et al., 2019). However, studies about older adults' relationship with technology are limited, especially when it comes to VR applications to aid the detection of disease-related cognitive decline and screening for functional impairment. Therefore, this dissertation explores the implementation of VR technology to assess abilities to perform daily living activities with older adults, and possible confounding factors related to the technology.

## Research Objectives

As part of daily living activities such as cooking and doing laundry, fine motor tasks that involve some precision and decision making have not been researched in depth when it comes to using VR technology to perform them. Therefore, the first main goal of this dissertation is to explore the implications of using VR technology to test for tasks that require fine-motor abilities. To isolate the VR effect, the task must be performed in real-life and in VR. For a more complete assessment, objective and subjective differences should be considered e.g., time and effectiveness in completing a given task (objective), and perceived cognitive load (subjective). Since a device is being introduced, its usability and acceptability should be evaluated as well.

Better screening techniques for abilities to perform daily living activities are also needed. Thus, the second main research goal is to evaluate how intuitive and easy-to-use VR systems are to complete simple daily living activities. Although more popular now, many people still have not used this technology. Its similar interface to other video games also poses a question about possible confounding factors of performance, which should be also evaluated.

Designing VR simulations is challenging, and multiple research studies have used software currently available to conduct feasibility studies. Although easier to implement, it limits the researcher's ability to conduct experiments that explore validity and replication of real-life conditions.

Based on an extensive literature review and the gaps identified in research (Chapter 2), the following research objectives were determined and will be addressed in this dissertation. Included with the statement of each objective will the description of required tasks planned to accomplish these objectives.

**Research Objective 1 (RO1) – Determine if fine motor tasks could be performed in VR**

A task that would require fine motor abilities such as reaching and selecting small objects e.g., sorting and selecting laundry or other small objects such as berries from a container. Those are tasks that people normally have no problem completing in a real-life setting, and hence they would be appropriate to evaluate in VR. After designing the task and creating the setting in real-life, the VR replica of the task was created using a game engine (Unity) to replicate all sizes, shapes, and colors of task-related objects.

A research experiment will be conducted with participants completing the same task in real-life and in VR. By having both tasks being completed in the laboratory, a clear comparison could be made, resulting in a more robust evaluation. Participants in the study will be college students and independent older adults with more than 65 years of age. High feasibility and acceptability resulting from this study would support the adoption of VR technology for testing with older adults.

**Research Objective 2 (RO2) – Evaluate age differences in VR performance for fine motor tasks**

With expected age-related changes in different cognitive domains involved in fine motor abilities, it is also relevant for researchers to understand what changes in performance might be expected due to aging processes. Therefore, in RO2, aging effects on VR performance will be assessed by comparing results from the study with younger adults and the results from the older adults' study.

**Research Objective 3 (RO3) – Determine the older adults' current adherence to technology and its use to perform daily tasks.**

To better understand the current relationship between older adults and technology, an online survey will be designed to explore what is the relationship of older adults with technology, including fears, adherence, learning preferences, as well as if and how they use technology to perform daily activities.

**Research Objective 4 (RO4) – Evaluate how intuitive and easy to use VR is for daily task, as well as tasks that are unique to VR systems.**

For RO4, a virtual environment will be designed for participants to complete simple daily tasks as well as some VR specific tasks e.g., teleporting between places. To evaluate how intuitive the system is, three levels of training instructions based on learning preferences from RO3 will be utilized (learning on your own, reading written instructions, or having demonstration). Performance will be assessed by the total number of tasks that participants are able to complete, as well as the time they take to complete them.

**Research Objective 5 (RO5) – Evaluate the transferability of gaming experiences to new VR experiences.**

With the current upward trends in technology usage and adherence, another analysis of interest is how transferable gaming skills are when it comes to using a VR device. Performance between gamers and non-gamers will be compared in an experiment to investigate possible confounding effects with using VR for daily activities' assessment.

## Dissertation Outline

Throughout this dissertation, younger adults will be referred to as YA, and older adults as OA. Figure 1.1 shows the flowchart for this dissertation.

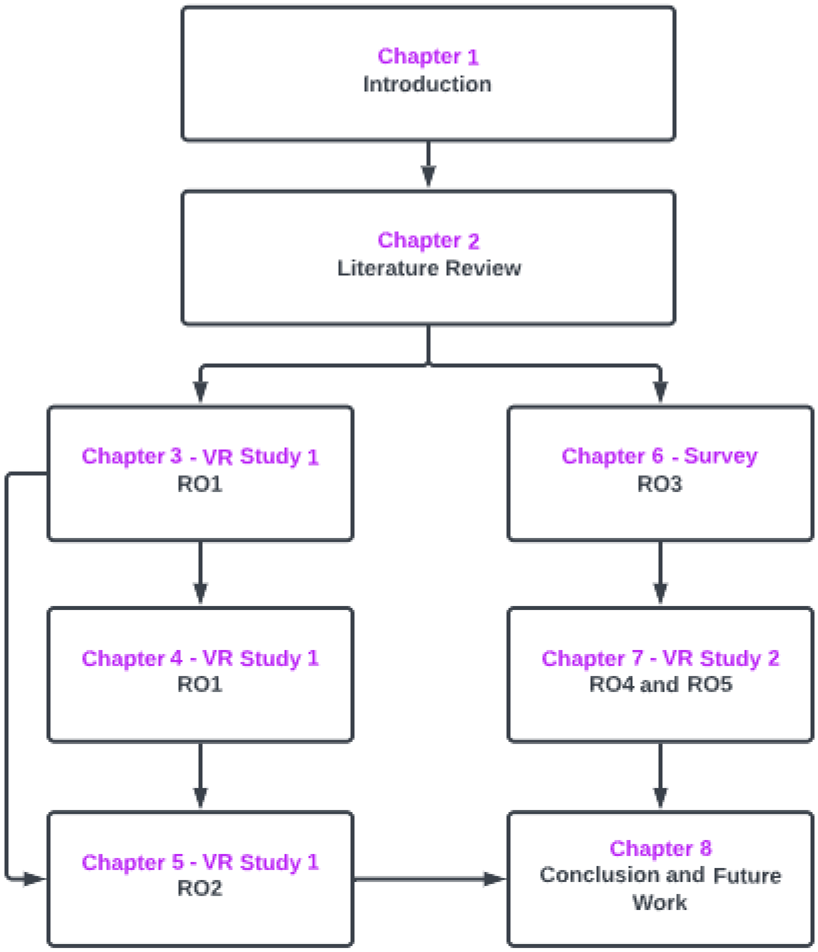


**Figure 1.1 – Dissertation outline**

Chapter 2 contains a literature review of relevant topics and outlines the current state of VR related research and current gaps to be assessed.

A total of three main studies were conducted to achieve the five research objectives: two VR experiments and a survey. Chapter 3 describes the first VR experiment assessing fine motor performance in a sample of YA (RO1). In Chapter 4, the same VR experiment was conducted with a sample of OA (RO1), so that in Chapter 5 both groups were compared and age-related changes in fine motor performance using VR technology was assessed (RO2).

Chapter 6 describes results from the survey distributed to a group of OA to assess their current relationship and adherence to technology (RO3). Then, chapter 7 focused on other aspects of VR technology including easiness of use and feasibility for daily task and VR-related tasks (RO4), as well as transferability of videogame-related skills (RO5). Lastly, Chapter 8 concludes this dissertation and provides the summary of key results, limitations, and future research topics.

# Chapter 2 - Literature Review

## Virtual Reality

### VR Technology Trends and Advancements

Virtual Reality refers to a simulated experience that does not physically exist and is only possible using technology. VR is a core component of the Extended-Reality (XR) concept, which encompasses three main technologies: Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR).

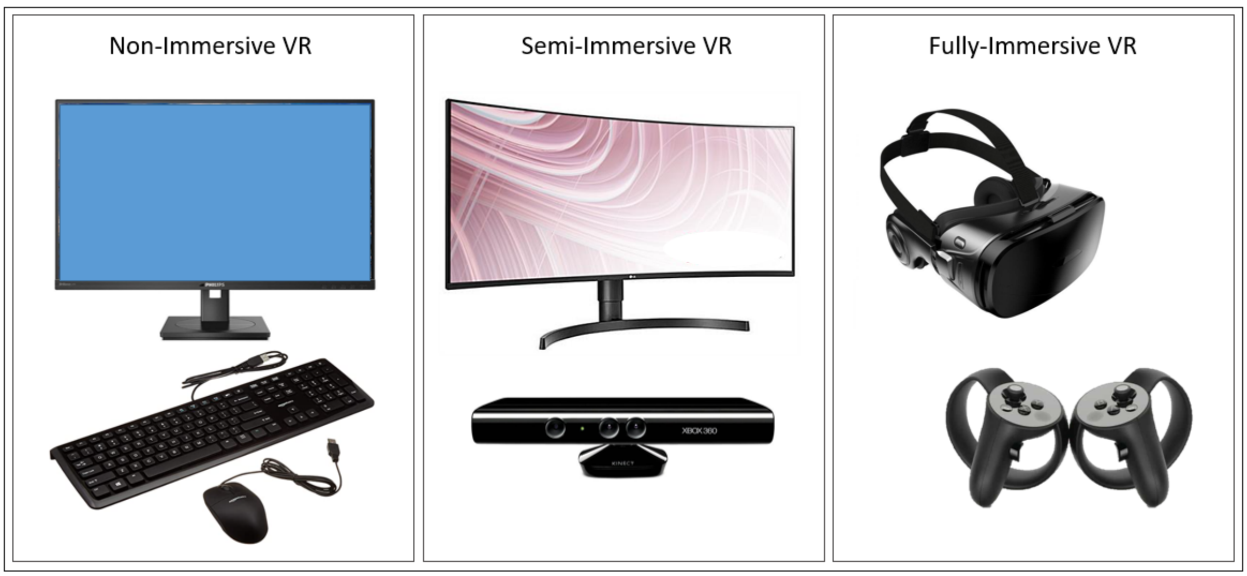


**Figure 2.1 - Different immersion levels of VR systems and example inputs and displays**

Figure 2.1 shows examples of different immersion levels commonly referred to in research studies. Sometime ago, research has referred to VR technology experiments when using a regular desktop display and keyboard and/or mouse as its input system. With improvements in tracking systems and sensors, VR experiences switched to using better input systems such as the Microsoft Kinect and better displays with larger sizes and higher quality. These types of VR systems have now been classified as non-immersive or semi-immersive VR, respectively. Given the current technology available, when researchers now mention fully immersive VR systems, it is referring to a Head Mounted Display or a multi-projected environment and its hand-held controllers or sensors for inputs.

The accessibility of VR technology has drastically increased in the past few years. Today, one can easily find a variety of commercially available VR devices (Figure 2.2) with different capabilities and selling prices. The cheapest alternatives normally include a Head Mounted Display that requires a smartphone device to be attached to it. It will likely not include positional tracking or input controllers. Some options require computer connection to render the VR experience, which normally results in higher quality simulations when using a computer with good graphics power. The stand-alone devices are the newest option, and its sales have been going up due to its ease of use and portability.


**Figure 2.2 - Different VR devices available today**

Given all the current advancements, it was no surprise to see sales going up. Figure 2.3 shows the projected sales in AR/VR headsets in future years, with sales expected to more than triple from 2021 to 2024. With better prices, portability, and higher quality technology, more people are becoming interested in getting their own device, and researchers are also incorporating this technology into scientific research, pushed by its increased adherence from people and potential applications.

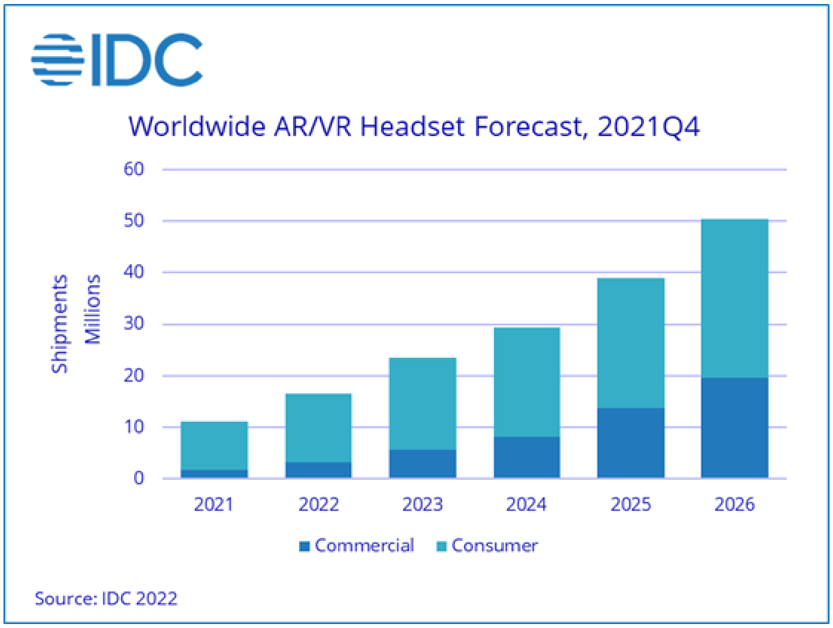


**Figure 2.3 - Projected shipments of VR devices**

There is also the new Metaverse concept that is being constantly brought up in media channels. The idea of "going into the internet" is based on "rendering the internet" and using extended reality such as VR to experience it in a fully immersive way, different from just looking at it on a screen. You can potentially connect with anyone in the world and have a whole virtual life separate from your real one.

## VR Applications

In research, standardizing data collection is a must, as well as a challenge, especially when it comes to human participants. Researchers need to come up with ways to maintain participants safe, the whole experiment under control, and make sure that data is being collected to achieve their research objectives. With VR, you can repeat tasks, get feedback about your performance, get different sensory stimulations, and stay in a highly controlled environment (Bohil et al., 2011).

VR has been used in multiple domains and has been proven to be a very flexible tool. In the medical field, VR has been used for training, diagnosis, and virtual treatment during critical situations (Javaid & Haleem, 2020). VR has been also used for higher educational purposes, increasing the learning experiences of students (Radianti et al., 2020). The ability to completely manipulate the virtual environments makes this technology an alternative for personalized rehabilitation including stroke patients (Aminov et al., 2018). In neuroscience applications, VR has been used to understand correlations between brain activation (using mobile EEG – electroencephalogram) and spatial navigation (Pacheco et al., 2017).

Although more accessible, access to this technology in any form (as a videogame or an assistive health technology) is still limited by socio-demographic and economic terms.

## Challenges of Using VR Technology for Research

One of the main challenges when using VR technology for research purposes is understanding the impact of the technology itself in the study design and outcome variables. Different methodologies have been used to evaluate the VR simulations and will be discussed in this next section.

### Feasibility

Studies that looked at VR feasibility normally evaluated if it was possible to implement the VR technology for its given purpose. In this type of analysis, the purpose of the VR might not be to replace a real-life alternative, but likely to evaluate the impact of VR in the desired outcome variables, e.g., if VR can improve intensive care experiences (Ong et al., 2020), improve pain management (Griffin et al., 2020), be a cognitive training/testing for patients experiencing cognitive decline (Porffy et al., 2022; Yun et al., 2020), or even promote well-being for people with dementia (D'Cunha et al., 2019).

**Validity and Fidelity**

When the purpose of VR is to replace another training or testing delivery alternative, people normally refer to task validity and fidelity. Validity would evaluate if the simulation is accurately representing the original task (Gray, 2019). One commonly used technique to assess validity of VR systems is comparing behavioral metrics between a task in real-life and in a virtual environment (Paljic, 2017).

Fidelity evaluates how well is the simulation reproducing the real-life task (Burdea & Coiffet, 2003), which could be 1) Physical, based on the realism of the virtual environment; 2) Psychological, based on perceived differences in emotions experienced when comparing both settings and 3) Ergonomic, based on similarity of motor-movements that could be done by comparing speed differences between real and virtual tasks (Harris et al., 2020).

Ergonomic validity is a significant challenge when utilizing VR technology to replicate real-life tasks due to its lack of haptic information (Lopes et al., 2017; Wijeyaratnam et al., 2019) which might create differences in the execution of motor skills in VR (Harris et al., 2019).

**Acceptability**

Although some experiences might be eliciting the same feelings and emotions as in real-life, or promoting a clear benefit to participants, it all goes to waste if people do not like to use the technology. Acceptability of VR technology by users has been assessed in terms of cybersickness, which is a common barrier of VR technology and it is commonly evaluated using the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993). Cybersickness depends on the type of experience the participant is having in VR. A mismatch between vestibular and oculomotor system can cause cybersickness. Research showed that its symptoms are more common in fully-immersive VR systems than using non-immersive or semi-immersive VR systems (desktop display) (Yildirim, 2020), but the trade-off between validity and cybersickness has been shown to be worth it as some experiences tend to induce minimal effects.

Acceptability can also be assessed in terms of a system's usability. Measures of usability include understanding the system's learnability, efficiency, memorability, errors, and overall satisfaction (Nikitina et al., 2018), and they are a must in health-related applications (T. Zhang et al., 2020). The System's Usability Scale (SUS) (Brooke, 1996) or open-ended qualitative feedback collected after the study (Chau et al., 2021; Griffin et al., 2020) are common usability measures utilized. Some research has also referred to User Experience (UX) evaluations, which includes similar measurements for quantitative and qualitative methods (Y. M. Kim et al., 2020).

When utilizing VR simulations in research, those criteria should be analyzed to understand the effect of using the VR technology in your results and future implementations. Table 2.1 exemplifies a possible research question related to each mentioned criterion.

**Table 2.1 - Criteria to evaluate VR simulations**

| Construct | Research Question |
|---|---|
| **Feasibility** | "The state or degree of being easily or conveniently done" |
| **Fidelity** | "The degree of exactness with which something is copied or reproduced" |
| **Validity** | "The quality of being logically or factually sound" |
| **Acceptability** | "The quality of being tolerated or allowed." |

### Considerations to improve VR simulations

Game designers have been aiming to increase the overall experience using VR technology by increasing "presence" in the virtual environment (sense of "being there") and at the same time minimize feelings of cybersickness. Review studies looking at associations between these two factors found that they might be negatively correlated, meaning that the more real the experience seems to be, the lower the effects of cybersickness (Weech et al., 2019). It has been recommended that future studies investigate presence, cybersickness, and other related factors.

Studies also reported that the cause for cybersickness can be due to differences in the user's virtual and physical head pose, with the lag between the actual head movement and the rendered VR head position triggering cybersickness (Palmisano et al., 2020). Optimizing game design and using good computer power can minimize this lag. This might be challenging for stand-alone VR devices such as the Oculus Quest 2 that does not require a computer to render the experiences, making realism a challenge whilst maintaining optimal game performance.

Another study looked at the Interpupillary Distance (IPD) effect on cybersickness (Stanney et al., 2020), and it was reported that women experienced higher levels of cybersickness which was likely due to the non-adjustments of the VR lenses. Females whose IPD could not properly fit the device reported higher levels of cybersickness.

Presence in the VR environment was found to be positively correlated with task performance, with studies reporting 95% of variability in presence explained by variance in time to complete an engineering task (Cooper et al., 2015). More research should explore other factors possibly mediating this relationship such as individual motivation, cybersickness, and even instructional support (Weech et al., 2019).

## Virtual Reality and Aging

### Aging Applications

Another important research area that has been boosted by the increased accessibility of VR technology is research related to older adults, which has been shown to be feasible by multiple studies in a variety of different domains (Appel et al., 2020; Chau et al., 2021; A. Kim et al., 2017; Nikitina et al., 2018).

### Diagnosis, Rehabilitation, and Training

Cognitive function was shown to benefit from VR training by older adults (Appel et al., 2020; Bauer & Andringa, 2020; Chau et al., 2021; Huang, 2020; Yen & Chiu, 2021). A systematic review (Yen & Chiu, 2021) looked at exergames, which are active video games to promote physical activity, as a means to improve cognitive function, memory, and depression in older adults. Results pointed to potential positive influences on those domains, especially depression, for higher intervention durations.

Rehabilitation for patients with Parkinson's Disease using VR technology was shown to have a similar effect as in physical therapy (Canning et al., 2020b) and to be a safe tool for gait training (A. Kim et al., 2017). For participants experiencing cognitive impairment related to gait performance, getting trained using VR technology was not only helpful, but better than when getting traditional physical and cognitive training (Liao et al., 2019). VR simulations have also been used to train older adults to improve collision-avoidance with objects while walking (Kondo, 2021).

### Loneliness and Social Isolation and VR

Lots of older adults today live in long-term care homes or assisted living houses. They usually have comorbidities that can limit their functional ability (Jerez-Roig et al., 2017) and consequently their social and physical experiences. Social isolation and loneliness can affect people's health at any age group (House et al., 1988), but the impact of social isolation can be worse for older adults, low income individuals, and minorities (Cacioppo & Hawkley, 2003).

Research has been optimizing strategies to overcome this isolation using VR technology (Appel et al., 2020; Thabrew et al., 2022). The experiences that are possible using VR environments can reduce feelings of boredom, apathy, and depression (Appel et al., 2020), as well as help with self-isolation (Baker et al., 2020). Increasing well-being in multiple dimensions (physical, social, and psychological) for older adults with VR has been the goal of multiple studies (L. N. Lee et al., 2019). As mentioned before, VR exergames can improve cognition, memory, and depression in the older adult population (Yen & Chiu, 2021).

After the onset of COVID-19 pandemic, loneliness and social isolation became a concern for all age groups. Technology became a decisive resource to maintain social connections between friends and family. Some older adults had to learn how to use different technologies and apps to accomplish instrumental activities of daily living such as grocery shopping and making bank transactions using the internet.

Enrichment of daily lives is beneficial to the mental health and recovery of older adults. Studies showed that having indoor plants in hospital rooms enhanced health outcomes of people recovering from surgery (S.-H. Park & Mattson, 2009), or even having a nice view from the hospital window can help recovery (Musselwhite, 2018; Ulrich, 1984). These studies point to the importance of having new experiences and exposure to nature (even if virtually), which might be facilitated by VR technology. Participants that are bedded could actually explore different environments safely, while having mobility and independence difficulties. VR can also improve mood and reduce apathy of older adults in nursing homes or long-term care facilities (Brimelow et al., 2020; Saredakis et al., 2020), being well accepted by most participants.

## Normal Aging Processes

With life expectancy increasing, the absolute number of older adults began to progressively increase throughout the years. The United States Census Bureau estimates that there will be more older adults than children by 2035, switching from 15.2% of the US population in 2016 to 23.4% of the total US population by 2060 (US Census, 2018).

Aging is associated with changes that impact sensory, mental, and physical functioning (World Health Organization, 2015). The aging of the population will increase the number of individuals unable to live an independent life as the risk for cognitive decline increases with age (Murman, 2015).

The effects of aging on human cognition are separated into three main categories: life-long declines, late-life declines, and life-long stability. Processing speed, working memory, and encoding of information usually decline throughout one's life, whereas tasks that are constantly being performed or that involve knowledge only start to show decline very late in life, along with vocabulary and semantic knowledge (Schaie & Willis, 2010). This preserved knowledge could assist older adults when performing tasks in a more efficient way, as younger adults would be making use of their processing ability (Dixon et al., 2001). These effects are part of the so-called normal aging processes, meaning the these are expected declines for most people (Hedden & Gabrieli, 2004a).

But declines can be also associated with neurodegenerative diseases such as Alzheimer's Disease and Parkinson's Disease, which are different types of dementia. Alzheimer's disease and related dementias were reported to affect as many as 5 million Americans in 2014, with numbers projected to nearly triple to 14 million by 2060 (Matthews et al., 2019). These progressive diseases begin with mild cognitive decline and can seriously affect a person's ability to carry out daily activities (*What Is Alzheimer's Disease?*, 2020).

Mild Cognitive Impairment (MCI) is usually defined as a transitional state between healthy cognitive decline and a diagnosis of dementia, and it does not notably interferes with common daily abilities (Gauthier et al., 2006). Because these changes are not very pronounced, it is sometimes hard to differentiate between normal cognitive decline and the early beginning of MCI.

Research has shown that individuals with MCI can progress to a dementia diagnosis (generally Alzheimer's Disease) at a rate of 18% per year (Kluger et al., 1999), making an early diagnosis important to start treatment as soon as possible.

## IADLs Definition and Testing Techniques

Instrumental Activities of Daily Living (IADLs) can be defined as "intentional and complex activities, requiring high-level controlled processes in response to individuals' needs, mainly related to novel and/or challenging daily living situations" (de Rotrou et al., 2012). Being higher order, complex activities, one would assume that there is a strong relationship between IADLs and cognition, which was already shown by different studies (Marshall et al., 2011; Reppermund et al., 2011). Even though cognitive variables were found to have some predictive ability of everyday functioning, most developed models did not have a very good predictive power (Royall et al., 2007), making IADL testing an important assessment to daily functioning. Table 2.2 shows the list of tasks that follow under the different categories of activities of daily living: IADLs, that were previously defined; Activities of Daily Living (ADLs), which are routine activities that most people do without any assistance such as bathing and dressing; and Enhanced Activities of Daily Living (EADLs), which are tasks required to keep an active lifestyle and can be supported by the use of technology (Rogers et al., 2020).

**Table 2.2 - Examples of activities classified as ADLs, IADLs, and EADLs.**

| ADLs | IADLs | EADLs |
|---|---|---|
| Bathing | Using phones | Social Activities |
| Dressing | Shopping | Enriching Activities |
| Toileting | Food preparation | Learning new skills |
| Transferring/Ambulating | Housekeeping | Hobbies |
| Continence | Laundry | |
| Feeding | Transportation | |
| | Taking Medications | |
| | Handling Finance | |

The inability to perform an IADL can have a negative impact in the subject's Quality of Life (QoL) (Gobbens, 2018), and poor QoL can be a predictor of both nursing home placement and death for older adults (Bilotta et al., 2011). As part of the diagnostic criteria for Mild Cognitive Impairment (MCI) and dementia (Albert et al., 2011; Y.-L. Chang et al., 2011), slight impairments in IADL can be an indicative of MCI, making this an important assessment to be made and potentially early detect neurodegenerative diseases. Understanding which activities one cannot complete independently is an important assessment to the subject's safety and quality of life, e.g., not being able to properly use the telephone during an emergency could be potentially fatal, and not being able to prepare a proper meal can lead to a poor diet.

Early detection of dementia is a healthcare priority in many countries as number point to about 60% of older adults living with dementia and without a diagnosis (Lang et al., 2017). An early diagnosis can also reduce patient's functional decline, cost of care, and caregiver's burden (Lin et al., 2013), making screening strategies important for early detection of cognitive and functional decline. The Alzheimer's Association Annual Report of 2018 projected savings of more than $7 trillion dollars in a model that simulated early diagnosis for all individuals alive in the United States in 2018 who will develop Alzheimer's Disease.

Until now, performance-based testing for IADLs have been difficult to implement due to the infrastructure required to conduct direct observations of daily activities, but its assessment in combination with other current methodologies such as self-reporting would help to capture nuances not currently being analyzed. Some IADLs such as using the telephone, managing medication, and managing finances, are not very complicated to be tested in a doctor's office as it requires minimal infrastructure. On the other hand, other instrumental activities are much more complex to be tested in real-life as they would require for example a kitchen and laundry room, or a fake mini-market to conduct the analysis (Figure 4.2).

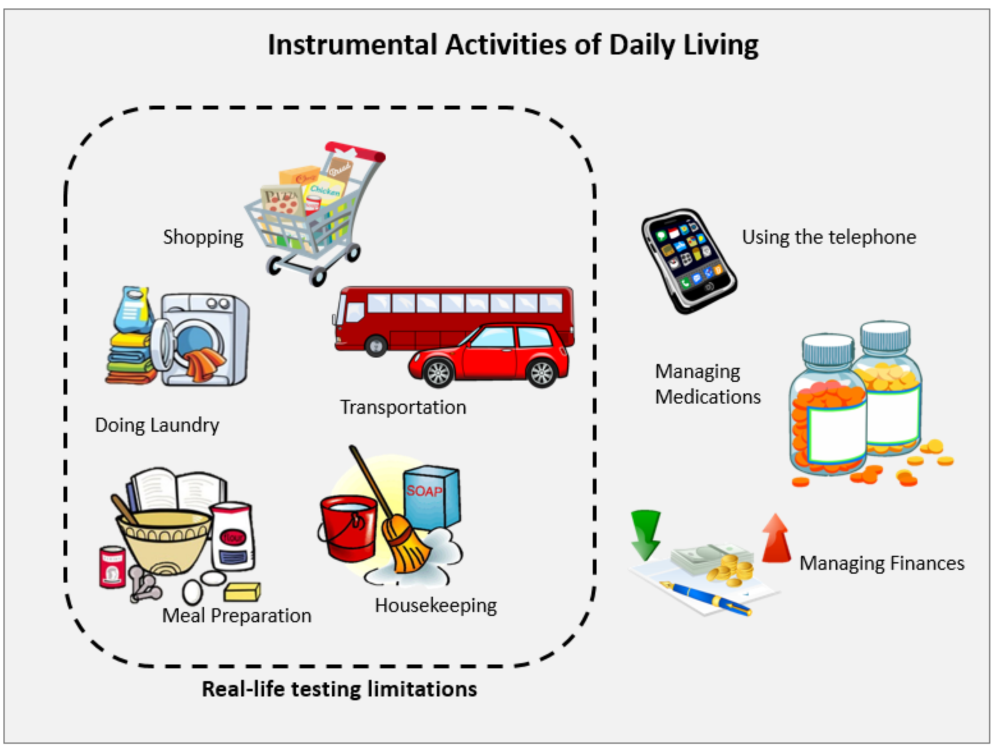


**Figure 2.4 - Challenging IADLs to be performance-based tested**

The literature has defined activities of daily living (ADLs) as the combination of Basic ADLs (BADLs) and Instrumental ADLs (IADLs), as well having only two nomenclatures with

ADLs being the equivalent to the BADLs, and then IADLs category. In this dissertation, the first definition mentioned will be used. BADLs include basic activities such as grooming, feeding, and toileting. These are activities that people learn to execute very early in life, and are highly correlated with motor functioning and coordination (Bennett et al., 2002). IADLs involve more complex behaviors that have a stronger relationship with cognition, and are affected much earlier when compared to BADLs in the course of dementia (Atkins et al., 2018a; Gobbens, 2018). There is not a clear consensus on the best measurement method for IADLs, but there are currently three different methods developed and being used to make this assessment, each one with its pros and cons.

Self-report questionnaires are the simplest method, relying on the subject's personal insights about its current abilities. When cognitive abilities are relatively intact, this is not such a problem, but when cognitive decline start to take place, it limits the disease insight and might bias self-reports (Graham et al., 2005). This technique is still used though, and it has potential to contribute to predicting dementia in patients (Pérès et al., 2008). The Lawton-Brody IADL Scale (Lawton & Brody, 1969) comprises eight different activities: ability to use the telephone, shopping, food preparation, housekeeping, laundry, mode of transportation, responsibility for own medications, and ability to handle finances. The scoring system is either 1 or 0 for each IADL, based on the item description that "most closely resembles the client's highest functional level". The overall independence score is the sum of each individual IADL score i.e., a score of 8 is assigned if the subject is totally independent.

Informant-based questionnaires rely on an informant, who can be a spouse, child, or close friend, to measure IADLs. This is an important technique to use specially when one starts to lose insight of current performance due to cognitive decline. The informant can sometimes provide a better assessment of the extent of the decline by comparing the subject's current state with how he/she used to be like. Evaluating if the informant is reliable is a challenge, with findings reporting caregiver stress and depression as potential bias generators of perceived functional ratings (Martyr et al., 2014)

Performance-based tests can provide an objective measure of the level of functioning by giving insights on which specific steps of each IADL the subject has been having the most difficulty with. Its results can be significantly different from self-reported functional status (Glass, 1998). This assessment is less black-and-white than the two previously discussed techniques, going over the different shades of gray in between being able and not being able to perform an IADL.

This methodology is not commonly utilized because it is very time-consuming (Moore et al., 2007) and it requires an infrastructure for the test to be conducted, therefore it is mostly used in academic rather than clinical applications. A trained rater is also required to directly observe the behavior in well-defined functional tasks. Paper and pencil tasks can be used to assess problem-solving skills by presenting real-world problems to be solved such as the Everyday Cognition Battery (Allaire & Marsiske, 1999), and behavioral simulation tasks require individuals to complete daily activities in a controlled environment such as the Revised Observed Tasks of Daily Living [OTDL-R], which only includes activities related to medication use, telephone use, and financial management (Diehl et al., 2005). The Direct Assessment of Functional Status-Revised (DAFS-R) was also developed to test participants on performing a variety of IADL tasks such as transportation, memory for grocery items, and shopping with a list (Loewenstein et al., 1989). Table 2.3 has examples of some of the performance-based tests being utilized in the DAFS-R.

Although called performance-based, some tests do not realistically represent the execution of the task in a real-life setting.

**Table 2.3 - DAFS-R test examples**

| IADL | Description |
|---|---|
| **Transportation** | The patient is presented with 13 commonly encountered road signs and asked how he/she would respond to each sign if driving an automobile. |
| **Shopping Skills** | The patient is orally presented with four grocery items and asked to commit these items to memory. Ten minutes later, he was taken to a mock grocery store where he/she had to select these four items from among 16 other distractor grocery items, some which were similar and others dissimilar from the to-be-remembered targets. The patient was subsequently asked to select four other grocery items using a written shopping list. |
| **Eating Skills** | The patient is given eating utensils and is asked to pour water into a glass, demonstrate how to drink from a cup, and to properly use a fork, spoon, and knife. |

### Correlates of IADLs

Knowing that a normative cognitive decline is expected, and age-related neurological diseases can augment this decline, it is also relevant to assess the effects of cognitive decline in the daily-life functioning. The lack of a golden standard of measuring daily-life functioning reduces the possibility of deeper analysis to make this assessment. That is why it is very important to develop better functional performance assessments, which can help to find clinical significance of medications that affect cognition as well.

Some IADLs have been found to have the highest correlations with cognition, which includes medication management, finances, and telephone usage (Fillenbaum, 1985). Research suggests that a variety of cognitive factors can contribute to functional impairment such as global cognitive functioning (Arevalo-Rodriguez et al., 2015), memory (Farias et al., 2003), processing speed (Teng et al., 2010), visuoperceptual abilities (Schmitter-Edgecombe & Parsey, 2014), and executive functioning (Marshall et al., 2011).

A systematic review analyzed cognitive correlates of BADLs and IADLs, and found a median of less than 20% for the total variance in functional outcomes being explained by cognitive variables (Royall et al., 2007). This raises concern regarding the utilization of cognitive measures to estimate BADLs or IADLs, which is not clear so far if this is due to cognition indeed being weekly associated with functional impairment or if the available measures are inadequate to demonstrate the true association. Age, memory, and executive control function, all seem to explain some variability in overall ADLs, but a large chunk of the variability's reasons remain unknown. Other factors can also influence BADL and IADL performance, such as sensory system and physical capacity (Prince et al., 2011), and should be taken into consideration when evaluating cognitive correlated of IADLs.

In a study comparing cognitive correlates with different measures of functional abilities in individuals with MCI, findings indicated the importance of different methods for evaluating functional status as they do not assess completely overlapping aspects of everyday functioning for this population, as well as the healthy older adult population (Schmitter-Edgecombe & Parsey, 2014).

**Motor-cognition vs IADLs**

Motor and cognitive abilities are sometimes simultaneously required to execute specific tasks. Simultaneous motor-cognitive tasks can be of two types: 1) Additional motor-cognitive task, when motor task added to the cognitive task, such as walking while solving an arithmetical task or 2) Incorporated motor-cognitive task, with the cognitive task becoming a pre-requisite to successfully solve or accomplish the motor-cognitive task, such as dancing, boxing, or solving a maze. Incorporated motor-cognitive abilities are also very closely related to daily life situations: "It is unlikely that an older person habitually solves an arithmetic task during walking, but it is likely that he/she walks through the supermarket while remembering what goods to buy and where to find those" (Herold et al., 2018).

The combination of cognitive and physical training has shown to improve most of the cognitive functions of older adults with mild cognitive impairment (MCI), even when physical and cognitive training are conducted time-separated (Hagovska & Nagyova, 2016). Simultaneous motor-cognitive training is the most promising approach to efficiently enhance cognitive reserve (Herold et al., 2018). Incorporated motor-cognitive tasks have been commonly used for motor-cognitive training, and pointed as more beneficial to stabilize neuroplasticity effects due to better cognitive improvement results (Moreau, 2015).

Being probable correlates of functional performance, motor-cognitive performance should also be considered when building predictive models of functional performance. Studies have already found significant correlations between IADL performance and cognitive and motor-cognitive testing scores (de Oliveira Silva et al., 2020), but results were analyzed using self-reported IADL data, requiring further investigation about its correlation with performance-based testing scores.

**VR and IADLs**

A study by Gamito et. Al (2019) investigated training of non-immersive virtual IADLs with older adults during 12 training sessions and found improved cognitive performance levels on participants with lower baseline cognitive decline. The use of desktop displays might affect transferability and therefore actual training of IADLs in real life.

Another category of activities should also be mentioned called Enhanced Activities of Daily Living. Those are activities that promote enrichment in our daily lives such as hobbies, leisure, entertainment, and relaxation activities, which can be supported by new technology developments (Rogers et al., 2020).

## VR Barriers for Adoption by Older Adults

The current top-down design process is impacting the adoption of technology by older adults. The idea of technology to support older adults in aging processes has been researched, and findings included barriers such as technology literacy, physical challenges as well as facilitators including "eagerness to learn, interest in co-design, and a desire to understand and control their data" (Wang et al., 2019). Digital illiteracy of older adults has been raised as a concern when using VR technology with this specific age group (Bauer & Andringa, 2020), but increased adoption of new technologies by older adults and the upcoming of a more technological generation will likely reduce this issue. Still, further research should be done to further evaluate the older adult's current relationship with technology.

Game design usually considers the younger population, which in turn reduces the adherence of inexperienced older gamers due to the lack of instructional support and complicated designs (Harrington et al., 2017). VR and AR tools have been developed for older adults specifically, but this group is rarely included in the design of these tools (Merkel & Kucharski, 2019).

Studies have been analyzing VR acceptance and usability in the healthy older adult population (Huygelier et al., 2019; Syed-Abdul et al., 2019). For short experiences (8min), older adults (mean age 80.5) have reported no negative side effects of VR when observing 360-degrees videos of nature scenes using a HMD (Appel et al., 2020). A study from Taiwan had two 15-min sessions twice a week for 6 weeks with healthy older adults, who reported high acceptance of the VR device (Syed-Abdul et al., 2019). Overall, VR cybersickness effects are generally low (Huygelier et al., 2019), and older adults sometimes report less cybersickness than younger adults (Dilanchian et al., 2021). It is unclear, however, how longer sessions could impact the usability of this product or feelings of cybersickness.

## Aging and Virtual Reality Table

Table 2.4 organizes relevant research with older adults that are related to real-life and VR comparisons. Only more recent research incorporated the now standard HMD and its fully immersive VR systems. Another common limitation observed is the sample size of studies, which are normally due to time constraints and challenges related to data collection.

**Table 2.4 - Relevant research on Aging and VR for replication of real-life tasks**

| Authors | Objective | Type of VR Device | Measures | Sample |
|---|---|---|---|---|
| (J. Chen & Or, 2017) | Compare VR, mouse, and touchscreen | 4m x 4m x 4m immersive environment | Time and error rate | 18 YA, 18 MA, 18 OA |
| (Bezerra et al., 2018) | Performance evaluation (VR/RL) | Computer display and Microsoft Kinect | Time and accuracy | 65 OA |
| (Mason et al., 2019) | Role of visual feedback in Virtual Environments | 3D tabletop virtual experience | Time and position | 10 Children, 10 MA, 10 OA |
| (Parra & Kaplan, 2019) | Validity (VR/RL) | Monitor and joystick | Accuracy and distance traveled | 22 OA, 22 YA |
| (Dilanchian et al., 2021) | Usability evaluation | HTC Vive | Presence, workload, Cybersickness | 20 OA, 20 YA |
| (S. Park et al., 2022) | Usability and training | Samsung Odyssey HMD | Emotions | 13 YA, 9 OA |
| (Arlati et al., 2022a) | Joint kinematics (VR/RL) | HTC Vive | Time and joint positions | 10 YA, 3 OA (60+) |
| (Porffy et al (2022)) | Feasibility and acceptability of VR for functional cognitive task | HTC Vive | Time, recall of items, completion rate | 45 OA (60+), 94 YA |

## Research Gaps

It has been pointed that more research is needed to further evaluate limitations to learning and performing actions in VR (Harris et al., 2020). The current growth trends of VR technology and research need to fully comprehend the implications of using this technology for whichever purpose intended.

There is also a need for better testing techniques for daily abilities in older adults, a group that is growing in absolute number. It was also pointed in a systematic review that the field of physical skills training with older adults in VR is understudied (Campo-Prieto et al., 2021). Therefore, research needs to be done to advance the knowledge of the implications of using VR to represent daily tasks and their components such as requiring fine motor skills and also conduct research directly with older adults.

In this chapter, it was shown that there is limited research with direct comparisons between real and virtual environments, especially with older adults, a group that can benefit from possible applications related to training and testing abilities for aging in place. Therefore, research should incorporate some specific analysis related to validity and fidelity, including learning and transferability of skills.

Table 2.5 summarizes the different evaluation criteria along with its definition, and how it translates into research questions asked throughout this dissertation. The last column shows which chapters will cover that specific dimension analysis.

**Table 2.5 - Criteria for VR evaluations and its definition, related research question, and chapters where each specific criteria analysis takes place**

| Dimension | Definition | Research Question | Covered in chapters |
|---|---|---|---|
| **Feasibility** | "The state or degree of being easily or conveniently done" | Will participants be able to complete the task in each setting, regardless of having or not past experience with the system? | 3, 4, 7 |
| **Fidelity** | "The degree of exactness with which something is copied or reproduced" | How real people think the VR task is? | 3, 4 |
| | | How harder will participants think the VR task is when compared to its RL counterpart? | 3, 4 |
| | | How easy to use and intuitive the system is? | 7 |
| **Validity** | "The quality of being logically or factually sound" | How much more time participants will take to complete the VR task in comparison to the RL task? | 3, 4 |
| | | Is there learning involved when using the VR system that is not related to learning the task itself? | 3, 4 |
| **Acceptability** | "The quality of being tolerated or allowed." | Will participants experience feelings of cybersickness from using this device? | 3, 4, 7 |
| | | How usable will people think the system is? | 3, 4, 7 |
| | | How is the current relationship between older adults and technology? | 6 |

# Chapter 3 - Evaluating the VR effect for fine motor abilities

## Introduction

Virtual Reality (VR) technology allows for the simulation of similar experiences to the real world, as well as situations that could be unsafe, impractical, or impossible to observe in a real-life setting (Kearney et al., 2009). Stand-alone VR devices are now commercially available and becoming cheaper and more portable as the years go by.

VR has become attractive for more than only entertainment purposes and has been incorporated in multiple fields from healthcare to engineering. This technology can facilitate health-care delivering such as providing rehabilitation to people in need of it (Gerber et al., 2018; Schuster-Amft et al., 2018; Yun et al., 2020). Limited healthcare availability and public safety also contribute to the increased interest in this technology. With the COVID-19 pandemic, to reduce the risk of exposure to the virus or getting treatment when in quarantine, people had to get innovative. VR technology can provide telemedicine to avoid face to face interaction between infected patients and doctors while being the closest experience to an actual visit to the doctor's office (Singh et al., 2020), and was found to be more effective to deliver psychotherapy to workers than when using video-conferencing methods (Pedram et al., 2020).

VR is also commonly applied in simulations such as performing medical teaching, learning, and training (Howard et al., 2021; Izard et al., 2018). Virtual Reality technology has been compared to conventional therapy delivered by physical therapists (Bui et al., 2021), with stroke patients benefiting from treatment delivered through VR (Schuster-Amft et al., 2018), (Brunner et al., 2017; Hung et al., 2019). Although efficacy of some VR interventions might be associated with utilizing specialized VR systems (e.g., VR systems specifically developed for a certain type of rehabilitation) (Aminov et al., 2018; Maier et al., 2019), commercially available systems, that were initially designed for entertainment purposes, may benefit patients with other types of training needs (Greenhalgh et al., 2021).

## Validity and Fidelity in VR

One concern is if these systems are sufficiently realistic to replace its real-life alternatives. To demonstrate the effectiveness of VR technology, it is imperative that the simulations have validity (i.e., the simulation is accurate in representing the original task) (Gray, 2019) and fidelity (i.e., how well is the simulation reproducing the real-life task) (Burdea & Coiffet, 2003).

Validity is judged by how representative the virtual activity is of the real-life counterpart, but there is not a large amount of research objectively assessing the validity of some common daily life tasks such as manipulating objects (Paljic, 2017). One commonly used technique to assess validity of VR systems is comparing behavioral metrics between a task in real-life and in a virtual environment (Paljic, 2017). Real versus virtual comparisons have assessed different types of tasks such as perception of distances (Renner et al., 2013) and materials (Graça et al., 2015), and more interactive tasks such as playing with Lego bricks (Baradaran & Stuerzlinger, 2006), peg insertion (Yoshikawa et al., 2003), and reaching (Viau et al., 2004), but majority of them do not use the now more widely available immersive VR systems, and evidence suggests important differences of immersive over non-immersive VR systems, with immersive systems resulting in more intense emotional responses and presence than using a computer desktop (Pallavicini et al., 2019).

Different types of validity and fidelity can be analyzed to evaluate a VR system, including physical fidelity (Is there a high degree of detail and realism in the physical elements of the simulation?) which can be analyzed through measures of realism and presence, psychological fidelity (Does the simulation accurately represent the perceptual and cognitive features of the real task?) which can be measured by comparing mental effort between real and virtual tasks, and

Ergonomic/Biomechanical fidelity ( Does the simulation elicit realistic motor movements?), which can be measured by assessing the VR movement parameters such as speed (Harris et al., 2020).

Effectiveness of the VR system for its intended purpose can also be looked at from a task-technology fit (TTF) angle (Howard & Rose, 2019). For training purposes, VR effectiveness was found to be moderated by task-technology fit i.e., technology will perform better when matched to the context, such as using VR to train for surgical skills instead of using a regular computer with lower representation of the actual task (Howard et al., 2021).

## Barriers of Virtual Reality Adoption

Cybersickness is a common barrier of VR technology, and it depends on the type of experience the participant is having in VR. A mismatch between vestibular and oculomotor system can cause cybersickness (Ng et al., 2020), which is more frequently seen in experiences such as driving simulators. Studies also reported that the cause for cybersickness can be due to differences in the user's virtual and physical head pose, with the lag between the actual head movement and the rendered VR head position triggering cybersickness (Palmisano et al., 2020).

Cybersickness symptoms are more common in fully-immersive VR systems than using non-immersive or semi-immersive VR systems (i.e., desktop display) (Yildirim, 2020), but its effects are generally low (Huygelier et al., 2019). Cybersickness might also be age-dependent, with older adults sometimes report less cybersickness than younger adults in VR experiences (Dilanchian et al., 2021). Some effects can also negatively affect performance by changing reaction times (Mittelstaedt et al., 2019; Nalivaiko et al., 2015), which might negatively impact VR task validity.

Game designers have been aiming to increase the overall experience using VR technology by increasing "presence" in the virtual environment (sense of "being there") and at the same time minimize feelings of cybersickness. Review studies looking at associations between these two factors found that they might be negatively correlated, meaning that the more real the experience seems to be, the lower the effects of cybersickness (Weech et al., 2019).

Presence in the VR environment was found to be positively correlated with task performance, with studies reporting 95% of variability in presence explained by variance in time to complete an engineering task (Cooper et al., 2015). More research should explore other factors possibly mediating this relationship such as individual motivation, cybersickness, and even instructional support (Weech et al., 2019).

## Present Study

VR studies have evaluated the effect of VR for manipulating larger-sized objects (Arlati et al., 2022b, Elbert et al., 2018), but studies analyzing smaller-sized objects that involve fine motor movements have been understudied. Also, not many studies involved sequentially performing tasks in RL and VR (Arlati et al., 2022b; Bezerra et al., 2018; Elbert et al., 2018) to isolate the VR effect. Therefore, new studies evaluating the validity of fully immersive VR systems are necessary (Paljic, 2017), along with the identification of possible confounding variables with VR performance. In this study, the VR effect on task performance when reaching and grabbing small objects was explored by comparing a sorting task executed in real-life with its replica in VR.

It was hypothesized that participants would take longer to perform the task in VR, but that they would effectively complete the task in either setting. Participants may perceive the task in VR being harder than in RL, and due to the nature of the task (static scene), cybersickness effects were expected to be low.

# Methodology

## Participants

Twenty college students (5 females; Mage = 21 years old, SD = 2.56) participated in this study. All participants had normal or corrected-to-normal vision. Those who wore glasses kept them during the VR tests by adding a head mount extension.

## Ethics statement

This study was approved by the Kansas State University's Institutional Review Board (#IRB-10786). Consent was obtained by having participants read and sign the consent form after the nature of the study was explained to them.

## Task Design

A task that requires fine motor coordination (selecting objects jumbled in a bowl) and is easy to complete by participants in a real-life (which will be referred to RL) setting was designed for the study. Dealing with the same task in VR would require participants to learn how to interact with the system, which does not provide the same sensory feedback (touch) and requires more precision when selecting objects to complete a task.

The task designed for this experiment consisted of a simple sorting task. Participants were presented with a clear bowl with two types of objects with different colors each. A total of 54 1-inch cubes of six different colors (9 each color) and 45 1.5-inch balls of 9 different colors (5 each color) were randomly mixed in the clear bowl.

Participants were instructed to sort the clear bowl of objects in front of them into three different black rectangular containers according to specific pairs of colors e.g., one container with blue and green objects only, another with red and orange objects only, and the last one with red and purple objects only. Only one object could be selected at a time.

To account for learning abilities related to the task, each task was performed 3 times in each setting i.e., 3 times in RL and 3 times in VR. Data collected from each trial included time (using a stopwatch) and number of misplaced objects i.e., objects put in an incorrect container.

The task was designed to isolate the VR effect on the task performance and reduce practice effect. Practice effect was reduced by having the task change pairs of colors at every trial, so that participants could not memorize the correct order and would still have to go through the same amount of decision-making process time during each trial.

It was hypothesized that there would not be a significant difference in time performance between second and third trials in RL. If time differences between second and third trials are not significant, any time difference seen later in the VR could be attributed to the VR itself.

### Virtual reality apparatus and system training

The Virtual Reality environment was designed using Unity (version 2020.3.10f1), and it was built to accurately replicate the real environment i.e., same quantities, colors, and sizes for objects (Figure 3.1).

**Figure 3.1 - Real Life (RL) Set Up and Designed Task in Virtual Reality (VR)**

When designing virtual environments, the mechanism utilized to define the shape of an object for the purposes of physical collision is called an object's collider. The collider influences the position in which users need to be in order to interact with an object i.e., how close your hand needs to be in order to grab the desired object.

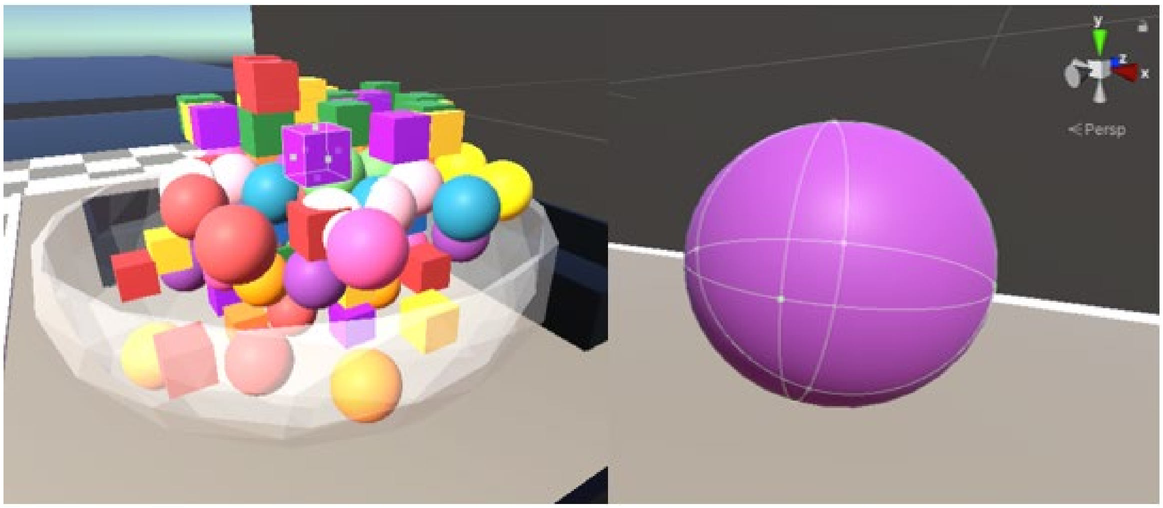


**Figure 3.2 - Colliders of objects that were sorted by participants**

Collider size has been found to affect reach-to-grasp movements (Furmanek et al., 2021), and in this study the collider size and shape was of the exact same dimensions of the visual representation of each object. Figure 3.2 shows the collider lines outlining each object.

The Oculus Quest 2 was the selected device for this study, which consist of a Head Mounted Display (HMD) and two hand-held controllers. The side trigger button (Figure 3.3) was chosen to be pressed in order to grab the object in the virtual environment. The device was connected to a computer that was rendering the virtual reality environment.


**Figure 3.3 - VR Setup and selected trigger button to grab objects**

A demonstration scene was prepared to train participants on how to use the controllers to grab objects (Figure 3.4). All colors and shapes of objects were displayed in front of the participant before starting the experiment to give a better understanding of correct color assignments and how to grab each object. After grasping and releasing at least half of the objects, participants could move forward to the actual sorting task. Pairs of colors for each trial were displayed on a gray wall in front of the participant.

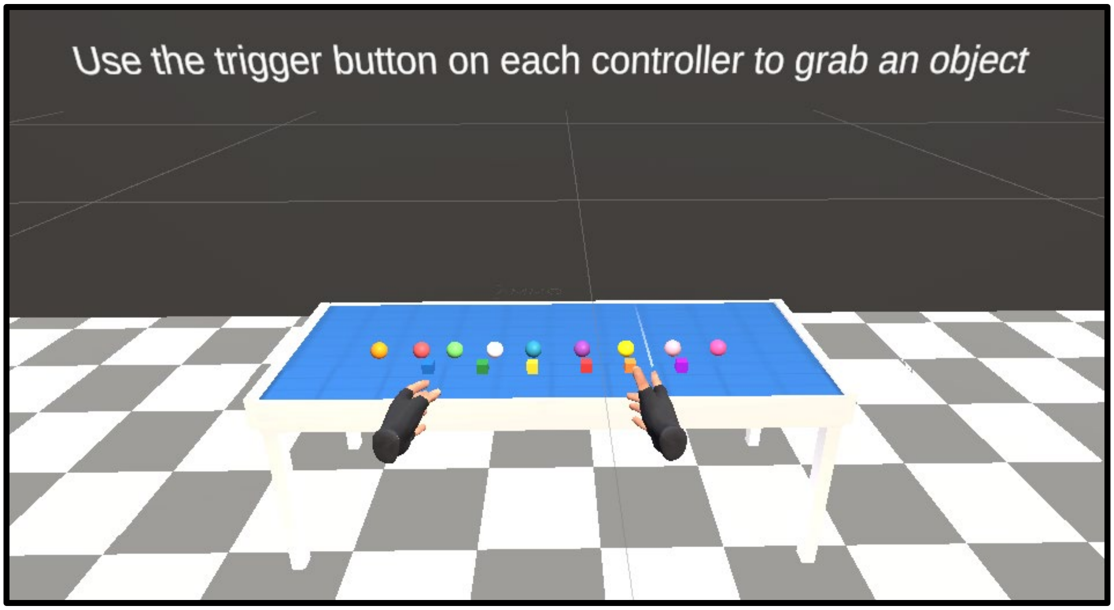


**Figure 3.4 - Demo Scene to train participants on use the correct buttons to grab and release objects**

## Procedure

Figure 3.5 describes the basic procedure followed by each participant in the study. The study was conducted in an ergonomics laboratory at the university. Participants gave consent to joining the study and started by answering a pre-experiment survey that included basic demographics (age, years of education, and gender). Participants also reported their familiarity with technology devices, including VR devices and answered the Computer Proficiency Questionnaire (Boot et al., 2015).

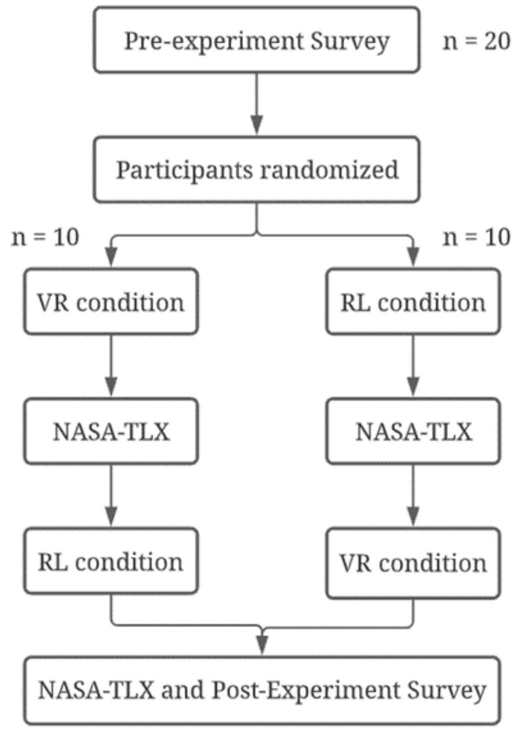


**Figure 3.5 - Flowchart of Study Design**

Participants were then instructed about the rules of the sorting tasks described before and were randomized between two possible groups: one starting the task in VR, the other starting with the RL task to evaluate if sequence was a factor in the design of this experiment. All participants were seating during both tasks.

Right after the end of the first setting, cognitive taxation was assess using the NASA-TLX questionnaire (Hart & Staveland, 1988). Participants then executed the other remaining setting, followed by another cognitive taxation questionnaire now referring to the latest task performed and a post-experiment survey. Some specific VR-related assessments included presence in the VR environment using the IGroup Presence Questionnaire (IPQ) (Schubert, 2003). Subscales included were related to Realism and General Presence. Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) measured cybersickness possibly caused by the VR experience. System Usability

Scale was also utilized to evaluate the feasibility and likelihood of participants adhering to this type of VR system. Lastly, participants answered open-ended questions related to likes and dislikes regarding the experience they had.

## Results

Majority of participants had used a VR system prior to the experiment (13 out of 20), but only two participants had a VR device of their own at some point in their lives. One participant reported being color-blind, so the task was modified into sorting objects based on shapes instead of colors.

### Time variability and effectiveness to complete the task

Time to complete the task in RL varied among participants, with times ranging from 99 seconds and 182 seconds in the first trial. By the third trial, the range reduced with the fastest subject completing the task in 90 seconds, and the slowest in 159 seconds. Figure 3.6 shows the boxplots for each trial. Y-Axis represents time in seconds, and X-Axis each of the total of 6 trials per participant.

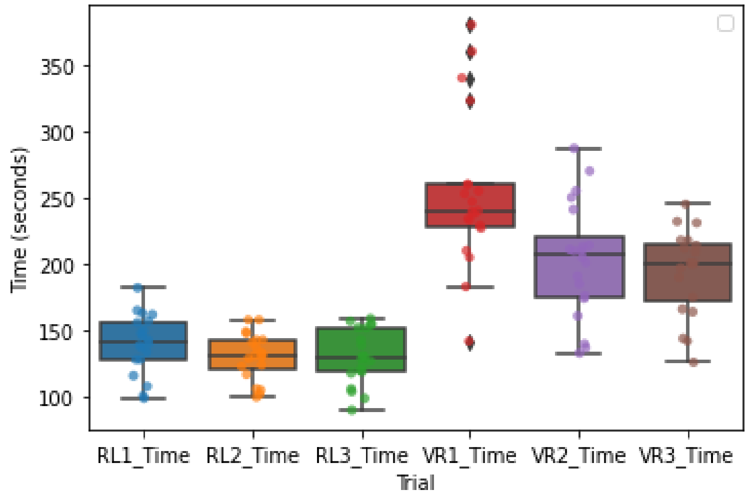


**Figure 3.6 - Boxplots of time to perform each setting in each trial.**

The trial with the highest number of mistakes was the first VR trial, but the participant with the highest number of misplaced objects was only 5 out 99. Participants could effectively execute tasks in both set ups with an average of 1.15 mistakes (SD = 1.6) in the first VR trial, and down to 0.5 (SD = 1.1) in the last VR trial. For the RL task, an average of 0.4 (SD = 0.94) mistakes was made in the first trial, and it went down to 0.2 (SD = 0.41). There was a significant difference in variance between RL and VR when comparing participant's average errors for each setting ($F(1,19) = 0.21$, $*p < .001$).

## Was order a factor?

Participants were randomized between starting with VR or RL to assess if order would be a significant factor in time to complete tasks. Figure 3.7 shows the two possible groups' times (n = 10 each). A much larger variability was observed in the first trial of participants that started with the VR setting than the group that started with the RL setting. Indeed, this group did not have the opportunity to practice first in the RL setting as the other group, but by the third trial in VR and RL, means from both groups became approximately the same.

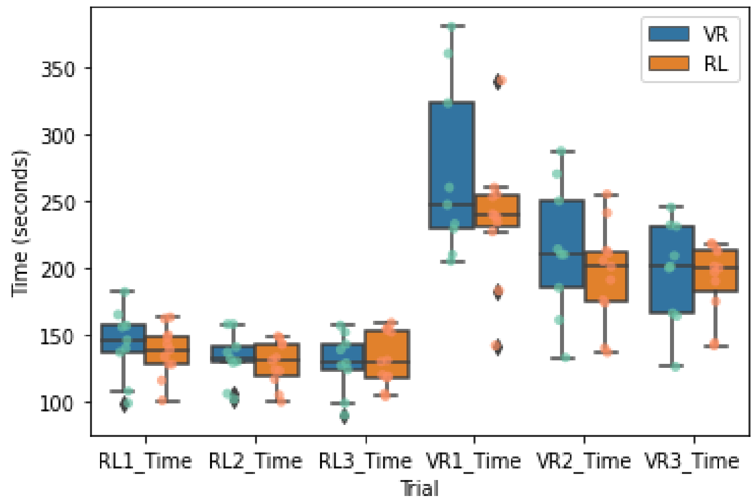


**Figure 3.7 – Boxplots of time for each trial based on which setting the participant started with.**

The difference between mean time in VR and mean time in RL for each participant was calculated and served as the dependent variable in a linear regression with order (VR or RL first) as the categorical independent factor. Participants that started with the RL task first, and then moved to the VR task had, on average, a smaller difference between settings, but the difference was not statistically significant (p = .23).

A full-factorial mixed method analysis was utilized to evaluate order given all variables in the study. Time was the response variable, with order (starting with VR or RL) as a between-subject factor, trial (1, 2 or 3) and setting (VR or RL) as within-subject factors, and each participant as a random component.

The False Discovery Rate p-value for each model effect calculated using the Benjamini-Hochberg technique, which adjusted the p-value for multiple tests. Order (FDR Logworth = 0.38, p = 0.41) and its interactions Order*Trial (FDR Logworth = 1.17, p = 0.07), Order*Setting (FDR Logworth = 0.49, p = 0.36), and Order*Trial*Setting (FDR Logworth = 0.44, p = 0.46) were all non-significant. Only Trial (FDR Logworth = 10.34, p < 0.01), Setting (FDR Logworth = 8.81, p < 0.01) and Trial*Setting (FDR Logworth = 7.43, p < 0.01) were significant factors and will be further analyzed in the next sections.

## Learning

Participants performed each task in each environment (VR and RL) three times, with a total of six trials. All trials were tested for normality using the Shapiro Wilk normality test to determine the appropriate statistical test for the analysis. All trials' tests resulted in p-values > 0.05, so the normality assumption was not rejected. Table 3.1 summarizes the average and standard deviations for each of those trials.

**Table 3.1 - Average Participant's Times and SD for each trial**

| Setting | Trial Number | Average | SD | Improvement |
|---|---|---|---|---|
| **RL** | Trial 1 | 145.75s | 22.46s | |
| | Trial 2 | 134.05s | 17.80s | 8.1% |
| | Trial 3 | 134.80s | 20.74s | 0% |
| **VR** | Trial 1 | 263.25s | 62.94s | |
| | Trial 2 | 211.85s | 45.52s | 19.5% |
| | Trial 3 | 199.80s | 32.88s | 5.6% |

A two factor repeated measures ANOVA was utilized with Trial (1, 2 or 3) and Setting (VR and RL) as its factors. Trial ($F(2,114) = 11.03$, $p < .001$) and Setting ($F(1,114) = 165.89$, $p < 0.001$) were both significant factors. Participants took longer in VR, and times improved in subsequent trials. The interaction term was also significant ($F(2,114) = 5.43$, $p = 0.005$), which demonstrates that the improvement in times also depends on each setting. Indeed, looking at Table 3.1, the learning rate was higher in VR than it was in RL. Average time decreased by 19.5% between the first and second trial, 5.7% between second and third trials, with a total 24.1% decrease in overall time between first to third trials.

A post-hoc analysis using a Bonferroni correction and a significance level of 0.0125 determined a significant difference between RL trials 1 and 2 (paired t-test, $t$ (19) = 4.59, *p < .01), but not between RL trials 2 and 3 (paired t-test, $t$ (19) = 4.59, p = 0.97). For the VR setting, a significant difference was observed between the trials 1 and 2 (paired t-test, $t$ (19) = 7.05, *p < .01) but not between trials 2 and 3 (paired t-test, $t$ (19) = 2.18, p = 0.04).

Since the average times for each setting include a learning effect, times for the third trial of each participant in each setting were also analyzed. There was an average reduction of 3.25 seconds in the RL setting, and 22.53 seconds in the VR setting. Although a smaller difference was identified after learning took place in both settings, there was still a significant difference between the two settings (paired t-test, t (19) = -12.66, *p < .01), meaning that the task was still longer in VR than in RL.

## Is technology score correlated with time to perform the task in VR?

To explore possible reasons for time variability when performing the task in VR, regression analysis was used to evaluate if VR familiarity (i.e., have used a VR device prior to the experiment) was a significant predictor of time to perform the VR task. Using mean time for all 3 trials as the dependent variable, VR familiarity was not a significant predictor (p = .39). Same result was found using the last trial's time as the dependent variable (p = .38). Technology score was also not a significant predictor of time to perform the VR task (p = .88).

## Perceived task difficulty

Results from the NASA Tax Load Scale was used to compare the task performed in each set up. The average task load in VR was of 38.66 (SD = 18.18), while the task load in RL was on average 30 (SD = 14.55). A paired T-Test (two-tailed) comparing the two set ups for each participant found a significant difference between perceived task difficulty, meaning that the task in VR was significantly more difficult than the task in RL ($t = 2.79$, $*p < .01$). This difference can be attributed to higher reported scores for mental demand (VR average = 43, RL average = 26) and task frustration (VR average = 32, RL average = 14).

Simple linear regression evaluated if people with higher technology scores were linked to lower perceived task difficulty using the VR system. Although them being negatively correlated (higher technology scores resulted in lower perceived difficulty), the correlation was not strong ($p = .65$). Having used a VR system before was also not correlated with lower perceived task load ($p = .39$).

## Usability, Cybersickness and Presence

The System Usability Scale provides scores ranging from 0 to 100, with higher values being interpreted as more usable systems. Scores above 68 are considered above average. Participants reported positive user experiences ($M = 76.87$, $SD = 14.48$). Only one participant had a score below average, which could be attributed to cybersickness symptoms experienced by the specific participant.

Cybersickness was assessed using the Simulator Sickness Questionnaire. Overall scores demonstrated acceptable levels of cybersickness when using the system ($M = 14.96$, $SD = 13.07$). Slight symptoms of fatigue ($n = 10$), sweating ($n = 9$), blurred vision ($n = 8$), and eye strain ($n = 7$) were the most reported.

**Table 3.2 – IPQ results from selected statements**

| Statement | Anchors | Results |
|---|---|---|
| **In the computer-generated world I had a sense of "being there"** | Not at all (-3) – Very much (+3) | Mean = 1.85 SD = 1.18 |
| **Somehow, I felt that the virtual world surrounded me.** | Fully disagree (-3) – Fully agree (+3) | Mean = 1.90 SD = 1.12 |
| **I felt present in the virtual space.** | Fully disagree (-3) – Fully agree (+3) | Mean = 1.95 SD = 1.19 |
| **How real did the virtual world seem to you?** | Completely real (-3) – Not real at all (+3) | Mean = 0.2 SD = 1.61 |
| **How much did your experience in the virtual environment seem consistent with your real-world experience?** | Not consistent (-3) – Very consistent (+3) | Mean = 0.65 SD = 1.35 |

Results from the IGroup Presence Questionnaire are shown in Table 3.2, with scales ranged from negative 3 to positive 3, in increments of 1 point, and anchors as stated. Participants reported high levels of presence and immersion in the VR, but realism scores were not as high. Since participants could experience both settings during the experiment, a more sensitive comparison was expected when comparing the consistency with the real-world experience. Overall, participants found the VR experience moderately consistent with the RL one.

## Discussion

This research highlights possible challenges when replicating a real-life task in VR. As expected, all participants effectively completed the task with an average 99% accuracy in both settings. There were individual differences in time to perform the task in real-life that could be related to differences in personality and motor-cognitive ability (Motowildo et al., 1997). This difference was more pronounced when analyzing the VR results, with higher variability within the data. Participants easily grasped the instructions in RL, but the same did not apply to the task executed in VR. There was a clear learning curve to perform the VR task, and all participants could lower their times by the third trial. The amount of variance in the VR setting was also reduced by the third trial, confirming that learning took place in the VR setting.

Most participants reported enjoying the VR experience. Usability scores were considered above average, pointing to higher likelihood of adherence and acceptance of this technology (Mlekus et al., 2020). Cybersickness effects were low for majority of the participants, in exception of one participant who reported moderate cybersickness after the VR setting. Longer VR sessions might increase the risk for cybersickness effects, which should also be considered when designing VR experiments (Kourtesis et al., 2019). VR induced symptoms and effects (VRISE) can significantly decrease reaction times and overall cognitive performance (Mittelstaedt et al., 2019), which could result in confounding effects when testing using VR tools. The VR session for this study was no longer than 15 minutes, and participants could take breaks as needed between trials. Although the session was short, approximately half of participants took a break to drink water or alleviate eye strain.

## Key differences affecting VR validity

Out of the important validity and fidelity components to define effectiveness of VR simulations by Harris et al. (2020), physical fidelity could be confirmed by high levels of presence and realism reported by participants. From the psychological and ergonomic/biomechanical fidelity perspectives, important gaps were identified when comparing time performance, strategy for task completion, and perceived task load between settings.

A total of 70% of participants (n = 14) reported changing their strategy when performing the task in VR versus in RL. The main reason for changing the strategy was because of the difficulty of selecting specific objects from the clear bowl in the virtual environment. In real-life, participants could easily reach for and grasp a specific object they had in mind, but in VR it was not as simple to execute the same precise selection. The higher perceived task difficulty has been a common effect when comparing VR with other available testing alternatives (Neguţ et al., 2016), but this difference is expected to continuously diminish as a consequence of the increase Task-Technology Fit levels of newer and fully immersive VR technologies.

Advancements in VR technology have considerably improved the quality of virtual experiences, but depending on the specific task designed, ergonomic issues may still arise (Y. Chen et al., 2021). In this task, participants had to bend their necks to look down at the bowl and sort the objects. When adding the VR apparatus, more specifically the Head Mounted Display, participants reported some degree of neck discomfort from the weight of the equipment.

Tasks that require less precision can potentially result in lower performance impact when designed in VR and should be further analyzed, but precision and selection is part of daily life in multiple daily tasks such as sorting laundry, cooking, and housekeeping. In this study, the selected task was replicated with the highest possible visual fidelity to the original real-life scene, therefore the program designed did not include any enhancement to facilitate the task being performed in VR. To solve the difficulty in selecting specific objects, system improvements can be done, although they would not be an exact replica of the real-life task. Shadowing the object, making it glow, or contouring it with a black line to specify the selected object could be programed and may help with time performance.

It is debatable if performance-based tests should incorporate this type of enhancement as advancements in Augmented Reality (AR) might be transforming some daily activities. Research has been evaluating the use of AR for cooking, and results showed that participants were slower in the VR setting when compared to the AR setting (Chicchi Giglioli et al., 2019).

## Limitations and future work

Technology familiarity was not a significant predictor of time to complete the VR task, which could be attributed to the specific cohort tested. All participants reported having computers and smartphones, and only one participant never had a video game console before. Older adults might not be as familiar with video games and other technology devices (Dilanchian et al., 2021), which could in return take longer to learn how to use the VR interface and increase the time difference between settings. Performance impacts might be dependent on age group and technology familiarity, pushing the need for future studies of effectiveness of immersive VR simulations with different populations, and effects of different instructional levels on how to use the technology.

# Conclusion

VR was effectively used to simulate the designed sorting task, but not without setbacks. Depending on the type of task, time to perform it in real-life might be significantly different from performing it in a virtual environment. The novel design utilized successfully isolated the VR effect, and findings indicate that learning should be considered when testing with VR regardless of your previous experience or familiarity with using VR technology. Although the technology has considerably improved in the recent years, it can still get better when it comes to perfectly simulate the real world and all its sensory feedback. It is imperative that researchers that aim to use this technology to test participants on tasks normally executed in real life understand the technology limitations and its impact on performance of such tests.

# Chapter 4 - The effect of VR on fine motor performance of older adults

## Introduction

Life expectancy has gone up from 69.9 years in 1959 to 77.8 years in 2020 (Arias et al., 2021). Because of that, the absolute number of older adults began to progressively increase throughout the years. The United States Census Bureau estimates that there will be more older adults than children by 2035, switching from 15.2% of the US population in 2016 to 23.4% of the total US population by 2060 (US Census, 2018).

This aging of the population will increase the number of individuals unable to live an independent life as the risk for cognitive decline, including changes that impact sensory, mental, and physical functioning, increases with age (Murman, 2015; World Health Organization, 2015). But even with expected declines, research has showed that older adults can still learn new performance skills and can preserve motor memories acquired later in life (Smith et al., 2005).

Newly developed technologies can help to increase the quality of life of older adults providing medical rehabilitation (Bui et al., 2021; Canning et al., 2020b; Pedram et al., 2020; Perez-Marcos et al., 2018a; Stamm et al., 2022), increasing physical activity engagement (Campo-Prieto et al., 2021; Gao et al., 2020), and even decreasing loneliness and social isolation (Appel et al., 2020; L. N. Lee et al., 2019). Virtual Reality (VR) technology can simulate environments that are very realistic, which can also contribute with the development of better diagnostic tools for detecting changes in cognition such as mild cognitive impairment (Cavedoni et al., 2020) even remotely (Zygouris et al., 2017).

When deciding to incorporate VR into training or testing applications, researchers must understand how representative a VR task is of a real-life one, which is commonly defined as validity, and it can be measured by comparing behavioral metrics in VR versus real-life (Paljic, 2017). Indeed, immersive VR systems have been recently used to compare real-life and VR performance in the fields of prosthetics (Joyner et al., 2021) and manual training (Elbert et al., 2018), but not with older adults.

Using VR for training purposes has a goal of facilitating the training and making sure that its results will transfer to its real-life applications (Bezerra et al., 2018; Elbert et al., 2018). Elbert et al (2018) looked at order picking performance transferability between real-life to VR using a task replica and an immersive system in a sample of working-age adults. Another study looked at differences in kinematics when picking up objects from a supermarket shelf in real-life and in a virtual environment (Arlati et al., 2022b). Bezerra et al (2018) did not use a fully immersive system (Microsoft Kinect) but experimented with older adults specifically to evaluate the transferability of VR skills.

Not many studies had participants performing a task in real-life as well as in a replica in VR (Arlati et al., 2022b; Bezerra et al., 2018; Elbert et al., 2018), which should give a better comparison especially looking at subjective measurements i.e., how people feel about the different settings. It is much easier to judge how much harder a task is when done in VR when you have just done the real-life one instead of having to recall from your previous experiences, which is known to be part of late-life cognitive decline (Hedden & Gabrieli, 2004b).

One factor commonly overlook is the effect of VR on performance of fine motor skills, and how learning the system takes place in a VR setting. Past research has used time as a measure of performance (Bezerra et al., 2018; J. Chen & Or, 2017; Mason et al., 2019; Porffy et al., 2022), which learning the system itself might have a direct influence upon. Studies normally have a demonstration or a training portion of the study, but even with that, research should incorporate multiple trials, which was part of some past studies (Bezerra et al., 2018; Elbert et al., 2018). The challenge is dealing with practice effects, which might be due to factors such as memorization and learned strategies, something commonly seen in cognitive tests (Calamia et al., 2012).

When making a direct comparison between real and virtual environments, one must also understand its acceptability and feasibility. Past research has looked at VR versus real-life (Bezerra et al., 2018; Parra & Kaplan, 2019), but not necessarily using immersive environments and/or motor-cognitive tasks related to daily abilities commonly referred to as the Instrumental Activities of Daily Living (IADLs). These can be defined as "intentional and complex activities, requiring high-level controlled processes in response to individuals' needs, mainly related to novel and/or challenging daily living situations" (de Rotrou et al., 2012). Being higher order, complex activities, one would assume that there is a strong relationship between IADLs and cognition, which was already shown by different studies (Marshall et al., 2011; Reppermund et al., 2011). Those complex tasks include fine motor-cognitive skills required for things such as cooking and sorting your laundry.

Another important component when considering the utilization of different technologies in any field is understanding how it can affect research goals. Therefore, VR development should use a human-centered design approach, understanding the usability of the system and its possible limitations and effects such as cybersickness (Dilanchian et al., 2021; Mittelstaedt et al., 2019). Being present in the VR environment was found to be negatively associated with feelings of cybersickness (Weech et al., 2019), so having the sense of "being there" should be maximized when designing experiences that focus on performance.

Understanding the effect of the VR system on performance, including learning its use, is decisive to develop clinical applications intended to replicate tasks that are part of common cognitive abilities testing such as the IADLs. In this study, a task that requires fine motors skills was performed by older adults in both settings (real-life and VR) to evaluate differences. Participants were required to repeat the same task in each setting to determine if and how learning would take place in VR. Both objective (time and effectiveness) and subjective (perceived task-load) measures of comparison were collected, as well as usability and acceptability measures related to the VR equipment and environment.

## Methodology

### Participants

A total of 20 participants were recruited from the Memory and Aging Laboratory at Kansas State University. This study complied with the American Psychological Association Code of Ethics and was approved by the Kansas State University's Institutional Review Board (#IRB-10786). Consent was obtained by having participants read and sign the consent form after the nature of the study was explained to them.

The sample had an average age of 72.4 (SD = 5.0, MIN = 65, MAX = 84), with 12 males, 7 females, and 1 participant who did not want to report gender. The sample was on average highly educated with a mean of 17.2 (SD = 2.6) years of education. Majority of participants were retired (16 retired, 4 still working).

### Task Design and Virtual reality apparatus and system training

Please refer to the methodology section from Chapter 3 for the task design and virtual reality apparatus and system training utilized in this study.

### Procedure

The study was conducted in an Ergonomics Laboratory at Kansas State University. Participants were informed of the location of the study and came independently to the laboratory.

Participants gave consent to joining the study and started by answering a pre-experiment survey that included basic demographics. Participants also reported their familiarity with technology devices by selecting which devices they have from a list e.g., tablet, smartphone, computer, and VR devices, and answered the Computer Proficiency Questionnaire (Boot et al., 2015). Figure 4.1 describes the basic procedure followed by each participant in the study.

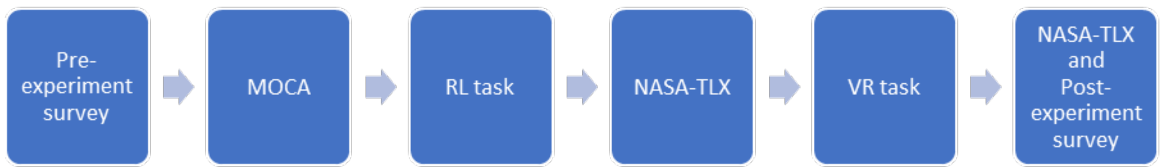


**Figure 4.1 - Flowchart of Study Design**

Each participant took the Mini Montreal Cognitive Assessment (MOCA) Version 2.1. It was administered by a MOCA certified rater (ID USKAUCR7093499-01). Results were not interpreted by the researcher and participants were not informed of their scores since the purpose of the study was not to evaluate possible cognitive decline effects. The MOCA score was only used to control for cognitive abilities in the modeling process. No participant was removed from the analysis if they were able to complete the task effectively in RL and in VR, despite of the MOCA score.

All participants were seated during both tasks. Participants were allowed to continue to the first trial of the VR setting after successfully completing the training session as in Chapter 3.

Right after the end of the 3 trials in RL, task load was assessed using the NASA-TLX questionnaire, which is comprised of 6 sub-dimensions related to mental, physical, and temporal demands, performance, effort, and frustration levels (Hart & Staveland, 1988). Participants then executed the other remaining 3 trials in the VR setting, followed by another task load questionnaire now referring to the latest task performed and a post-experiment survey. Specific VR-related assessments in the survey included presence in the VR environment using the IGroup Presence Questionnaire (IPQ) (Schubert, 2003) (subscales included were related to Realism and General Presence), Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) measured cybersickness possibly caused by the VR experience, System Usability Scale (Brooke, 1996) was also utilized to evaluate the feasibility and likelihood of participants adhering to this type technology, and, lastly, participants answered open-ended questions related to strategy changes between the real and virtual settings and likes and dislikes regarding the VR experience.

## Results

All 20 participants completed the entire experiment with no difficulties nor technical issues. The study took approximately one hour to complete by participants. MOCA scores had an average of 12.80 (SD = 1.73), with 11 and above out of 15 points being considered normal cognition. Two participants scored less than 11 points, mostly due to the recall portion of the test, but were not excluded from the analysis since they successfully completed the study. All participants reported having a computer and a cellphone, and 14 participants had a tablet. The average technological device ownership was of 3.15 (SD = 0.87) devices per participant, ranging from 2 to 5 devices total.

### Performance Results

Completion rates from all participants were extremely high and with a very low number of mistakes in both settings. The average number of misplaced objects in each setting was of 0.73 per trial in RL, and 0.86 per trial in VR. Majority of mistakes were due to similarity of colors such as pink and purple.

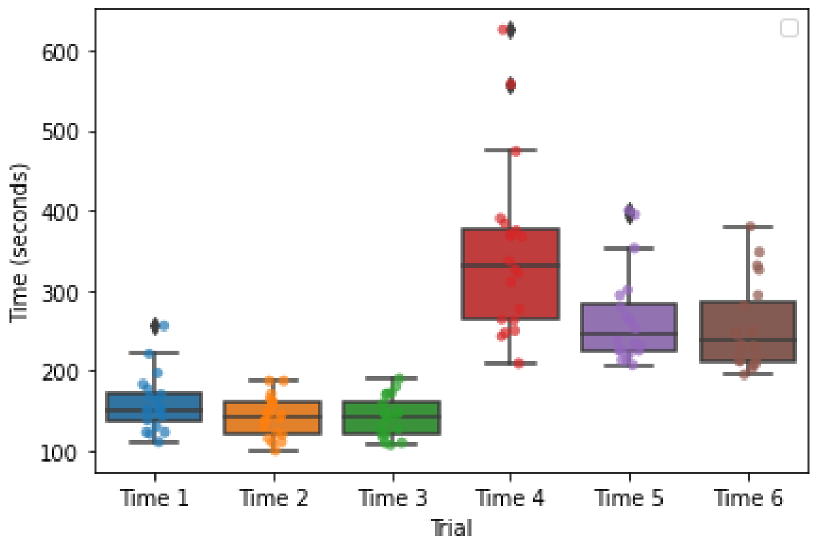


**Figure 4.2 - Boxplots of time (in seconds) to complete each trial**

Figure 4.2 shows the boxplots of time (measured in seconds) to complete each trial. There was a small improvement in time during the first 3 RL trials for many participants (17 out of 20 total). Mostly, the improvement happened between first and second trial, with more consistent results between second and third trial, demonstrating that participants had already mastered the task by then. All 20 participants improved their times during the VR task.

**Table 4.1 - Average time and SD (in seconds) for each trial and average improvements**

| | Trial | Average | SD | Improvement |
|---|---|---|---|---|
| **RL** | Time 1 | 158.95s | 35.31s | |
| | Time 2 | 142.45s | 25.11s | 10.38% |
| | Time 3 | 142.70s | 24.90s | 0% |
| **VR** | Time 4 | 348.05s | 106.23s | |
| | Time 5 | 265.05s | 57.16s | 23.84% |
| | Time 6 | 254.85s | 54.08s | 3.84% |

Table 4.1 summarizes mean times and standard deviation for each trial in the study. Average improvement in time was observed between first and second trial in RL (10.38%) but became consistent between second and third trial (0% change). A sharp learning process took place

using the VR as seen in Figure 3. In VR, larger improvements were observed between first and second trial (23.84%), and still some improvement between second and third trial (3.84%).

To evaluate if there were significant differences between trials, a repeated measures statistical analysis was conducted. Data was tested for normality using the Shapiro Wilk Test, which was rejected for most trials due to its right-skewness. Therefore, the non-parametric Friedmen test was utilized. Differences between all 3 trials in RL showed a statistically significant difference ($\chi^2(2) = 4524$, p <.001), and the same was observed during the VR trials ($\chi^2$ (2) = 4000, p < .001).

The Wilcoxon signed-rank test was used as a paired t-test alternative in a post-hoc analysis with a Bonferroni correction and statistical significance level of 0.0125. Comparing first and second trials in RL, a significant difference was observed (T = 29.0, p = 003), but no improvement was observed between second and third trials (T = 101.50, p = 0.89). Analyzing the VR setting, again a significant effect was observed between the fourth and fifth trial (T = 3.0, p < .001) and no significant difference between fifth and sixth trial in VR (T = 44, p = 0.04).

The first trial in RL therefore involved more learning of the task than between the second and third trial due to its simplicity. With a 0% improvement between second and third trials in RL, we could not reject the initial hypothesis that participants had already learned the task and therefore all changes observed during the VR trials were related to the VR system. In the VR task, a much lower p-value was observed, meaning that there was likely still improvement taking place, although at a lower rate than between trial 4 and 5. Using a Bonferroni correction with a significance level of 0.025, we did not meet the significance threshold and therefore the improvement between fifth and sixth trial was not statistically significant.

## Task Load comparison

Each participant rated the RL and the VR tasks using the NASA Task Load Index immediately after completing the trials of each setting, with a mean score of 12.54 (SD = 12.80) and 22.21 (SD = 17.04) out of 100 total points for RL and VR respectively. Data from NASA-TLX scores failed the Shapiro Wilk test, so the non-parametric Wilcoxson test was selected to run the analysis. Results showed a significant difference ($T = 24.00$, $p = 0.001$) between settings. Participants, on average, reported an increase in task load when performing the same sorting task in the virtual environment.

### Individual Scores

Average times for each dimension of the task load index seemed to get worse for the VR setting in exception for the pace of the task, which demonstrates that participants perceived they were, on average, slower in the VR task. All individual variables were tested for normality and failed the Shapiro Wilk test; therefore, the Wilcoxson test was run for each specific question, and with a Bonferroni Correction for multiple testing, the threshold used for significance was of 0.008 (0.05/6). Table 4.2 summarizes the statistical results of the analysis. Mental and physical demand, along with perceived stress, were considered statistically significantly different in the analysis, all with higher means in the VR portion of the study. Overall, participants did find the same task harder in the virtual environment, but they all on average rated their performance very high in both settings (lower scores represent higher success).

**Table 4.2 - Individual Scores for NASA-TLX**

| Dimension | RL Average | VR Average | Significance |
|---|---|---|---|
| **Mental** | 16.95 | 35.35 | **$p < 0.001$** |
| **Physical** | 11.00 | 28.70 | **$p = 0.007$** |
| **Pace** | 20.45 | 15.80 | $p = 0.903$ |
| **Performance** | 2.65 | 8.85 | $p = 0.049$ |
| **Load** | 20.45 | 33.55 | $p = 0.014$ |
| **Stress** | 3.75 | 11.05 | **$p = 0.001$** |

## System Usability, Realness, and Cybersickness Effects

Data related to usability of the system was collected using the System Usability Scale. SUS scores above 68 are considered above average. Participants gave the system's usability an average score of 78 (SD = 13.40). It was clarified to participants that the score should be related to using the VR to complete the task. Majority of participants thought the system was easy to use and felt confident using the system. Another key component was that, although most participant were using the system for the very first time, most participants did not think that they needed to learn a lot of things before they could get going with the system.

Realness scores, measured using the IGroup Presence Questionnaire, had an average score of 6.95 (SD = 2.64), with scores ranging from -15 to 15. Higher scores represent a more realistic VR experience. Participants felt present in the virtual environment performing the tasks, and thought the environment looked relatively real. On the other hand, there were mixed answers related to the system's consistency with its real-world counterpart, which goes in line with task load scores reported in the previous section.

Scores for the Simulator Sickness Questionnaire were low, with a mean score of 5.42 (SD = 8.62). Scores over 20 indicate "perceptible discomfort", and it was only reported by one participant in the sample.

## Exploratory Data Analysis

In an exploratory data analysis, a K-Means cluster technique was utilized to find natural grouping amongst participants. Data was standardized prior to the cluster analysis to reduce bias from variables with larger dimensions. The elbow method showed a sharp angle at two clusters, and given the small sample size, this was the number of clusters selected for further analysis.

Table 4.3 shows the means and standard deviations of participants allocated in each of the 2 clusters. The first cluster had participants with an average age of 69.6 years old, with an average of 3.58 devices, and high overall usability scores of 86.25. The second cluster had slightly older participants (76.5 years old) that had a lower average number of devices and found the system to be less usable. MOCA score was not a good source of differentiation between groups.

**Table 4.3 - Mean values of each cluster**

| Variable/Group | Cluster 1 (n = 12) | Cluster 2 (n = 8) |
|---|---|---|
| **Age** | 69.66 (SD = 3.08) | 76.50 (SD = 4.53) |
| **MOCA** | 12.66 (SD = 1.92) | 13.00 (SD = 1.51) |
| **Tech Score** | 72.66 (SD = 7.43) | 69.37 (SD = 3.81) |
| **SUS** | 86.25 (SD = 8.62) | 65.00 (SD = 8.45) |
| **SSQ** | 1.87 (SD = 3.74) | 7.01 (SD = 6.76) |
| **VR Realness** | 8.33 (SD = 1.92) | 4.87 (SD = 2.23) |
| **NASA-TLX difference** | 7.11 (SD = 10.45) | 8.39 (SD = 19.62) |
| **Ratio VR/RL** | 1.86 (SD = 0.37) | 1.70 (SD = 0.19) |
| **Learning Rate** | 0.79 (SD = 0.14) | 0.77 (SD = 0.08) |
| **Number of Devices** | 3.58 (SD = 0.79) | 2.50 (SD = 0.53) |

## Strategy Changes

One key component reported by some participants was related to changes in strategy to complete the given task when switching to the virtual environment. A total of 60% said that they changed their strategies, which was mostly related to an initial difficulty in selecting the exact object that they were initially planning on selecting and grabbing, which increased their decision time and made them reassess in which container the selected color should be put in.

### Post-experiment feedback and other comments

Participants reported positive experiences with the study. Most demonstrated enthusiasm for the VR equipment: “fun” and “interesting” were common feedback provided. When asked about what components of the study participants disliked, common topics brought up included the controller itself and how to use it. Some participants had a hard time holding the controllers and pressing the correct buttons, which might have distracted them when doing the task. The weight of the headset was also brought up by some participants who reported neck discomfort even though the whole VR portion of the study lasted on average 15 minutes.

## Discussion

In this study, it was demonstrated that older adults can still learn new performance skills, agreeing with past findings (Smith et al., 2005), and that they all could interact with the VR system by having a very high completion rate of the task with a very low number of mistakes. VR indeed seems to be a feasible tool to be used by older adults (Appel et al., 2020; Chau et al., 2021; Gerber et al., 2018; Zygouris et al., 2017), and therefore, findings contradicted the ageism concept that older adults have difficulties with new technologies (Rosales & Fernández-Ardèvol, 2019).

In this study, participants did not make more task errors in the VR than in RL, by they did have a harder time selecting objects in VR. This effect was observed in the increased time spent in the VR trials, even after completing the task a couple of times. Past studies comparing VR performance also found that participants took longer to complete a real-life task in VR (Elbert et al., 2018), and the same happened when comparing VR to a regular desktop display (Guzsvinecz et al., 2022), although fine motor movements were not the focus of those studies.

Cybersickness levels were low and consistent with past research (Dilanchian et al., 2021), but when grouping participants in the cluster analysis, the older group actually reported higher levels of Cybersickness than the younger group. This could be related to other clinical measures or health conditions not incorporated in the study such as smoking (H. Kim et al., 2021), which was found to be linked to lower levels of Cybersickeness.

The ergonomics of the device can be improved with lighter headsets and more intuitive controllers. Haptic gloves have been developed to enhance the user experience but its options have been very limited (Perret & Vander Poorten, 2018), and it is unclear if they would increase performance when compared to regular controllers. Future designs will have to be light, compact, and with precise sensors so that tactile stimulations like the ones experienced in real-life can be replicated. Also, depending on the type of task designed, reducing the amount of controller buttons available could potentially help participants. The current controllers from the chosen device included multiple other buttons that were not necessary for this study and therefore could have increased the difficulty to execute the task.

Past research has also evaluated the use of VR technology to promote well-being in older adults experiencing mild cognitive impairment or related dementias, with results showing that virtual experiences were well accepted and had improved mood and apathy of participants (D'Cunha et al., 2019). Learning rates and task feasibility in those cases should be further investigated, especially if the goal is to measure cognitive decline using VR tests, which could have a confounding factor related to learning how to use the VR technology. The VR market has been growing, and future studies should evaluate if learning rates for VR users could be different than for non-users. This will also help to determine how much training one should get to use the VR system.

Other skills that relate to daily activities should also be tested in VR to evaluated feasibility and validity by comparing real and virtual environments. Training of Instrumental Activities of Daily Living using non-immersive systems was already able to improve neuropsychological measures of older adults (Gamito et al., 2019), so further research should test for daily abilities but incorporating the currently available immersive systems.

## Study Limitations

Although the sample had a similar size to other VR studies with older adults (J. Chen & Or, 2017; Dilanchian et al., 2021; Mason et al., 2019; S. Park et al., 2022; Parra & Kaplan, 2019), larger sample sizes would provide stronger statistical power and insights. This study also had a sample with high educational levels, which might yield different results when compared to other subgroups of older adults (Brazil & Rys, 2022). But even with a relatively similar group in education and technology usage, a high variability in time to perform the task in both settings was observed.

To properly model the learning rate, more trials would be necessary as the learning rate models normally work in a logarithmic scale. For this study, object-picking was not analyzed independently, but all simultaneously in the task as whole (sorting all the objects in the bowl). Each participant spent about 15 minutes doing the tasks in VR, which is a common length for VR sessions with older adults (D’Cunha et al., 2019; Jones et al., 2016). A shorter task will allow for more trials, and therefore be better suited to mathematically model a learning curve.

The time difference between RL and VR in this study could have happened because of two reasons. One reason would be due to participants aiming for a specific colored-object but ending up getting a different object and having to reassess which container it should go in. The second possible reason would that participants made multiple attempts to get the specific object for which they were aiming. Participants were asked to maintain the same pace for all trials, therefore it was assumed that the learning effect observed in the VR trials was not due to learning the task, but because participants got better at picking up the desired objects. Future work should focus on that specific component by having only one sorting strategy allowed.

## Conclusion

In this study, virtual reality's validity for a fine motor task was assessed by directly comparing older adult's performance in a sorting task in real-life and then in VR. The effect of learning how to use the VR system was objectively assessed, which was observed even after participants were provided with instructions and went through a demonstration scene. The task was deemed feasible using VR, as all participants effectively completed it with a small number of mistakes. This demonstrates that older adults can learn how to use the system even for fine motor tasks. VR is therefore a powerful tool that can potentially be used to test older adults when it comes to instrumental activities of daily living (IADLs) and help to detect functional and cognitive decline.

It is decisive to incorporate the VR effect in performance analyses for older adults, especially if the measure of performance is time to complete a task as all participants improved their VR times by the third trial. Learning rates varied, but the task took longer for all participants to complete it in VR than in real-life, which should also be considered when designing VR tests for this population.

# Chapter 5 - Age differences in fine motor task performance and acceptability in VR

## Introduction

### Age-related changes in cognition

Aging processes include cognitive changes that are expected to take place in healthy individuals and that are not related to any pathologies. These changes are also known to affect different domains of cognition at different rates (Hedden & Gabrieli, 2004b). Abilities related to vocabulary and knowledge normally remain stable or gradually improve until you reach about your 70s (Salthouse, 2012), which might put older adults in advantage at related tasks when compared to younger adults. On the other hand, abilities such as executive function, processing speed, and psychomotor ability, normally peak around the age of 30 and continuously decline with age (Salthouse, 2012), and can impact performance of other cognitive domains (Harada et al., 2013).

The ability to perform fine motor skills is also known to decline with age due to changes in sensory-motor control and executive functioning that can have multiple causes (Hayden & Welsh-Bohmer, 2012; Seidler et al., 2010). Larger cerebral volume was found to be related to better fine motor skills in a study where participants went through and MRI scanning and draw a spiral based on a template (Hoogendam et al., 2014). Overall, higher age was associated with overall lower brain volume, more time to complete the task, and more deviations from the template.

### Aging effects on performance and VR experiences

VR has been shown to be highly accepted by the older adult population (Huygelier et al., 2019), and with clear benefits from it. For example, for neurorehabilitation purposes, VR technology can provide motor-cognitive training that incorporates benefits from gaming that includes empowerment and motivation to increase adherence to rehabilitation protocols (Perez-Marcos et al., 2018b). Not many research studies have compared younger and older adults when it comes to VR technology, and most of those studies did not incorporate the currently available technology of immersive VR systems.

The studies conducted so far have investigated differences between younger and older adults regarding movement patterns as well as experiences in VR environments. A common metric used has been time to complete each task and number of errors (J. Chen & Or, 2017). In a study comparing VR and a traditional mouse and touchscreen showed more errors using the VR device for all age groups, and with older adults taking longer and making more errors than younger and middle-age adults (J. Chen & Or, 2017). It also found that VR for displaying scenes might be more suitable for older adults than tasks requiring manipulation of small objects, but that there was still potential for them to adapt to it.

Perra et al (Parra & Kaplan, 2019) compared younger and older adults (58-74) in a study with a task done in an actual room and then in the same room as a virtual environment. This study has its virtual portion conducted using a virtual environment with a monitor and a joystick pad, not necessarily representing a fully immersive experience, which might not be as intuitive than navigating using a fully immersive VR device.

## Present Study

There is a limited amount of research that evaluates aging effects related to VR technology. Also, although it is expected to observe declines in fine motor abilities, how this translates to fine motor abilities using VR technology is unknown and should be investigated.

When looking at the criteria for evaluating VR simulations, chapters 3 and 4 had looked at VR feasibility, validity, fidelity, and acceptability for the same given sorting task that requires fine motor skills. Since not much is known about how age influences the usability and performance of VR devices, in this chapter, a cross-sectional analysis comparing results from previous chapters was conducted to evaluate age effects in fine motor task performance. It was investigated if there were significant differences in time to complete the task in each setting, learning rates, usability, and cybersickness effects.

## Methodology

### The Two Groups

After conducting the study with both younger and older adults, possible age effects on performance were investigated, including time differences between RL and VR, as well as learning rates for each group. Table 5.1 shows the main characteristics of the two groups of young and older adults being used in the cross-sectional analysis.

**Table 5.1 - YA and OA summary demographics**

| Variable | YA (n = 20) | OA (n = 20) |
|---|---|---|
| **Age** | 20.95 (SD = 2.6) | 72.4 (SD = 5.0) |
| **Gender** | 15 Males/5 Females | 12 Males/ 7 Females/ 1 non-reported |
| **Education** | 12.0 (SD = 0.0) | 17.2 (SD = 2.6) |
| **Technology Familiarity** | 76.3 (SD = 5.2) | 71.3 (SD = 6.3) |
| **Device ownership number** | 3.5 (SD = 0.9) | 3.1 (SD = 0.9) |

Despite the age differences, differences between groups included higher education levels for the older adults, and slightly higher technology familiarity and device ownership for younger adults.

## Analysis utilized

The first goal was to directly compare YA and OA in terms of all variables of interest, including time taken in RL, time taken in VR, learning rates in each setting (VR and RL), task load, usability, cyber sickness, and VR realness.

# Results

## Differences in Errors in RL and VR

The average number of errors made by YA during the RL task was of 0.33 errors (SD = 0.89), while OA had an average error of 0.73 (SD = 1.21). In VR, YA had an average error of 0.60 (SD = 1.19), while OA had an average error of 0.86 (SD = 1.86). Although the average error was higher for OA in both settings, it was still a relatively small number of mistakes given the total number of objects (99) participants had to sort.

## Observing the time difference in RL

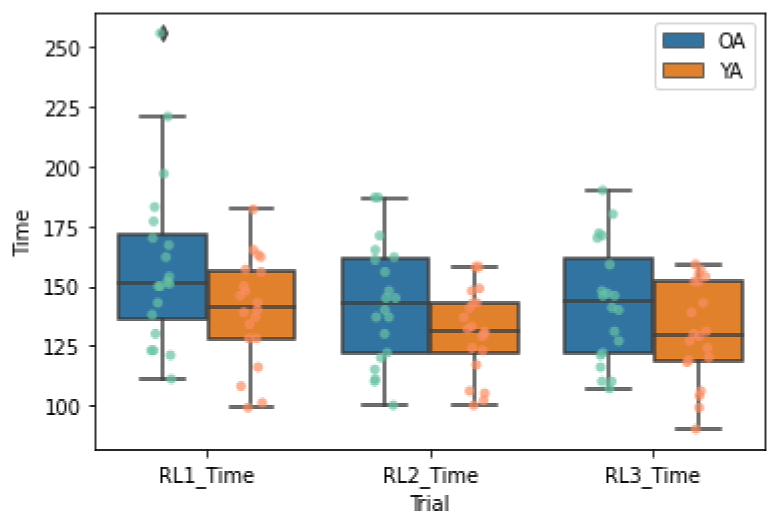


**Figure 5.1 - Boxplots for each group with time (in seconds) for each trial in RL**

Figure 5.1 shows the trend in times for the RL setting of each group. As expected, older adults took on average more time than younger adults to complete the RL tasks. Only one outlier data point in the OA sample was observed, and only for the first trial. Table 5.2 summarizes means and variances for each trial. The observed difference between YA and OA after practicing the task was relatively small, of about a 15 second difference.

**Table 5.2 - Means and SD of each group for each trial**

| Trial/Group | YA | OA |
|---|---|---|
| **RL1_Time** | 140.10s (SD = 22.10s) | 158.95 (SD = 35.50s) |
| **RL2_Time** | 130.45s (SD = 17.63s) | 142.45 (SD = 25.09s) |
| **RL3_Time** | 130.40s (SD = 20.78s) | 142.70 (SD = 24.89s) |
| **All Trials** | 133.65 (SD = 20.44s) | 148.03 (SD = 29.47s) |

To compare differences between time taken in the RL by YA and OA, a two factor repeated measures ANOVA was utilized with RL Trial (1, 2 or 3) and group (YA and OA). Trial ($F(2,114) = 3.62$, $p = 0.029$) and Group ($F(1,114) = 9.94$, $p = 0.002$) were both significant factors, with a stronger effect between groups meaning that older adults took statistically more time than younger adults on average did. Also, both groups had slight improvements in time by the third trial of the RL setting, which was mostly observed between first and second trials, and that improvement was deemed the same for both groups when analyzing the interaction term ($F(2,114) = 0.24$, $p = 0.78$).

## Observing the time difference in VR

Looking now into a comparison of VR times, Figure 5.2 shows the trend in times for the VR setting of each group. When introducing the technology, more outliers were observed, now in both groups. By the third trial, no data point was considered an outlier anymore. Therefore, it was assumed that all variability was normal, and no participant was removed from the analysis.

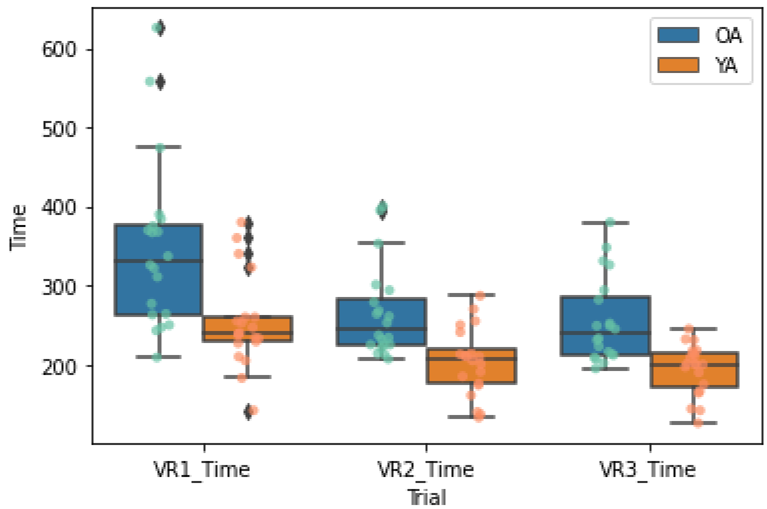


**Figure 5.2 - Boxplots for each group with time (in seconds) for each trial in VR**

Again, older adults took on average more time than younger adults to complete the VR tasks, but more changes in time during the 3 trials were observed, representing their learning of the VR tool. Table 5.3 summarizes means and variances for each trial. The mean difference between groups by the third trial was of approximately 73 seconds.

**Table 5.3 - Mean and variance for each group in each VR trial**

| Trial/Group | YA | OA |
|---|---|---|
| **VR1_Time** | 252.90 (SD = 58.10s) | 348.05 (SD = 106.23s) |
| **VR2_Time** | 203.20 (SD = 43.10s) | 265.05 (SD = 57.85s) |
| **VR3_Time** | 194.25 (SD = 32.09s) | 254.85 (SD = 53.55s) |
| **All Trials** | 216.78 (SD = 44.43s) | 289.31 (SD = 86.16s) |

To compare differences between time taken in the VR by YA and OA, a two factor repeated measures ANOVA was utilized with VR Trial (1, 2 or 3) and group (YA and OA). Trial ($F(2,114) = 17.22$, $p < 0.001$) and Group ($F(1,114) = 39.74$, $p < 0.001$) were both significant factors, with a strong effect between groups meaning that older adults took statistically more time than younger adults on average did. Also, both groups had considerable improvements in time by the third trial of the VR setting, which differently from the RL task, was still observed between trials 2 and 3. The improvement in times was considered the same for both groups when analyzing the interaction term ($F(2,114) = 0.96$, $p = 0.38$).

Exploring in better detail the learning ratios and to verify the interaction results, the ratio of improvement in time for each participant in the VR setting was calculated (Time improvement from VR1-VR2 and VR2-VR3) and is shown in Table 5.4.

**Table 5.4 - Average improvement in time between trials for each group**

| Trial/Group | YA | OA |
|---|---|---|
| **VR1-VR2** | 0.81 (SD = 0.1) | 0.78 (SD = 0.1) |
| **VR2-VR3** | 0.96 (SD = 0.08) | 0.96 (SD = 0.09) |

The two factor ANOVA confirmed a significant difference only between trials ($F(1,79) = 54.76$, $p < 0.001$), and not group ($F(1,79) = 0.34$, $p = 0.56$) nor interaction ($F(1,79) = 0.32$, $p = 0.57$).

### Observing the ratio difference between RL and VR

To evaluate how much more time the task took to be completed in VR versus RL, the minimum value for the RL and VR tasks of each participant were used to estimate the ratio between the two settings in an attempt to remove as much as possible learning effects taking place at each task.

An F-Test was used to assess equality of variances which was not rejected ($F(1, 19) = 0.71$, $p = 0.23$) and therefore a two-sample t-test assuming equal variances was used. With a mean ratio of 0.67 (SD = 0.07) for YA, and 0.56 (SD = 0.08) for OA, a statistically significant difference was found ($t(1, 38) = 4.39$, $p < 0.001$), showing a smaller difference in time for YA than OA, and therefore a smaller VR effect for YA than for OA.

It is useful for future research analysis to be able to estimate how much more time someone is expected to take in a VR task when compared to its RL counterpart. A linear regression model can be used to estimate this ratio based on the two groups available and yielded the equation below:

$$Ratio \sim 1.50 + 0.32\ OA$$

Therefore, YA participants are expected to take on average 50% longer to complete a fine motor task in VR than in RL (95% CI [1.38, 1.61]). Being an older adult will increase the expected ratio by 0.32 (95% CI [0.16, 0.49], p < .001). It is important to note that this is an expected ratio after the learning effect takes place i.e., after a couple of VR trials.

## Differences in Usability, Realism, Cybersickness

Looking into differences in subjective measures during the studies for each group, relatively similar results were observed (Table 5.5).

**Table 5.5 -- Differences in subjective measures**

| Variable/Group | YA | OA | Range | 2 sample t-test |
|---|---|---|---|---|
| **SUS** | 76.87 (SD = 14.47) | 77.75 (SD = 13.52) | 0 to 100 | t (38) = -0.19, p = 0.84 |
| **SSQ** | 14.96 (SD = 13.07) | 5.42 (SD = 8.62) | 0 to 235 | t (22) = 2.15, p = 0.04 |
| **NASA-RL** | 30.00 (SD = 14.55) | 12.52 (SD = 12.80) | 0 to 100 | t (38) = 4.02, p < 0.01* |
| **NASA-VR** | 38.66 (SD = 18.18) | 22.21 (SD = 14.65) | 0 to 100 | t (38) = 1.68, p < 0.01* |
| **Task load difference** | 8.66 (SD = 13.87) | 9.67 (SD = 14.65) | | t (38) = -0.22, p = 0.82 |
| **VR Realness** | 6.55 (SD = 3.53) | 6.95 (SD = 2.64) | -15 to 15 | t (38) = -0.40, p = 0.68 |

Both groups found the system highly usable, reported relatively low cybersickness levels, and the task in either setting not to be very demanding. There was no significant difference between groups for usability, realness, and, if using a Bonferroni correction for multiple testing (0.05/6), also the cybersickness. The only variables with a statistically significant difference between groups were overall perceived task load in each setting. As a subjective measure, results can vary considerably based on individual perceptions, therefore the most interesting analysis would be the increase in task load when comparing VR and RL. In this case, the task load difference was not statistically significant between groups ($p = 0.82$).

## Discussion

Previous studies have reported that older adults have more difficulty with the VR interaction than younger adults (J. Chen & Or, 2017), which was not necessarily true for this study, depending on the variable of interest being assessed. Although time was slightly higher for older adults, the number of errors was not that different, which goes in line with a research by Perra et al (2019) where accuracy was not significantly different between OA and YA.

It was observed that healthy older adults might take up to twice as much time to complete the VR task than the RL one, which should be an important consideration when designing any virtual task aiming to test older adults on time performance, but when it comes to learning effects, we could expect to see similar results in both YA and OA.

A possible reason for the two groups having an overall very small difference in time in RL might be associated with the older adult sample. First, the OA sample was, on average, physically active: a total of 15 participants out of 20 reported exercising regularly. Longitudinal studies have reported a positive association between physical exercise and cognition (Liu et al., 2022; Mandolesi et al., 2018). Literacy (Y.-H. Chang et al., 2021; Manly et al., 2005) and cognitive reserve (Hindle et al., 2014) were also found to protect older adults from cognitive decline and changes in executive function. This might explain why, although older, the two groups didn’t have a large difference in time performance during the RL task. In this study though, technology widened the gap in performance between YA and OA. This poses a question related to why OA did not perform as well as YA in the VR task: it might be that using the technology requires different cognitive domains, or maybe there are other confounding factors not incorporated in the analysis. Further research should investigate this relationship. One possibility relates cognitive flexibility, which relates to the ability to adapt to new situations and environments, which normally declines with age (Magnusson & Brim, 2014).

When looking at the criteria to evaluate VR simulations, fidelity was therefore more impacted for OA than it was for YA when considering the replication of the fine motor task designed, but mostly for the ergonomic fidelity of the task. Physical fidelity, measured by how real people thought the VR experience was, was similar for YA and OA, and psychological fidelity, measured by differences in perceived task load, was actually more prominent in YA than OA. Both groups highly accepted the VR technology with low reported levels of cybersickness, and high overall usability of the system. With similar results to Bezerra et. al. (2018), OA experienced less cybersickness than YA.

It should be also noted that the data collected from YA in Chapter 3 did not require any transformations to assume normality, whereas the OA data was not normally distributed and required different statistical analysis to be conducted. Data from the OA was mostly right skewed, and with higher overall variance than YA data. It is unclear the exact reason for this higher variability, but it is hypothesized that it goes along with the lines of the older adult group being highly heterogeneous in a myriad of domains including technology (Rosales & Fernández-Ardèvol, 2019; Taipale et al., 2021; van Boekel et al., 2017), as well as in health measures (Nguyen et al., 2021).

An important limitation to be considered is related to the study design. Studies that evaluate age effects on cognition and functional performance are preferably conducted using a longitudinal instead of a cross-sectional design given all possible forces of development that can influence aging processes (biological, psychological, and sociocultural), which results in a high variability among individuals and their respective aging effects (Hedden & Gabrieli, 2004b). Future work therefore should be done in longitudinal designs to directly evaluate age effects on VR in quasi-experimental designs.

## Conclusion

In this chapter, the YA and OA groups were compared to evaluate age-effects of using VR technology to complete fine motor tasks. Differences in errors between RL and VR were not observed for either group, showing that OA could effectively engage with the VR system. In the RL portion of the task, time differences between groups were relatively small, which may indicate similar populations in terms of abilities required to complete the given task. Difference in performance was extenuated when using the VR system to complete the task, which might be due to other confounding factors such as video game experiences. Both groups showed a similar learning effect. Therefore, regardless of the ratio difference between RL and VR and other possible confounding factors, different age groups can get better at using the system.

# Chapter 6 - Technology adherence and incorporation to daily living activities by older adults

## Introduction

Life expectancy in the U.S. has been increasing, going from 69.9 years in 1959 to 78.9 years in 2016 (Woolf & Schoomaker, 2019). Because of that, the absolute number of older adults began to progressively increase throughout the years. Combined with the declining birth rates, the United States Census Bureau estimates that there will be more older adults than children by 2035, switching from 15.2% of the US population in 2016 to 23.4% of the total US population by 2060 (US Census, 2018).

### Technology to support Aging in Place

A major concern as people age is if one will be able to maintain their independence. Instrumental Activities of Daily Living (IADLs) can be defined as "intentional and complex activities, requiring high-level controlled processes in response to individuals' needs, mainly related to novel and/or challenging daily living situations" (de Rotrou et al., 2012). These higher order, complex activities, have a strong relationship with cognition (Marshall et al., 2011; Reppermund et al., 2011). The inability to perform an IADL can have a negative impact in the subject's Quality of Life (QoL) (Gobbens, 2018), and poor QoL can be a predictor of both nursing home placement and death for older adults (Bilotta et al., 2011). It is important that older adults retain their ability to perform those daily activities for as long as possible, which might be facilitated by technology advancements that support aging in place and promote independence (Yousaf et al., 2020).

A systematic review by Valenzuala et al. (2018) looked at adherence to technology-based exercise programs in older adults. It indicated that this might be a sustainable way to promote physical activity with good adherence levels of older adults (Valenzuela et al., 2018). Mobile health trends are seen in multiple domains including cardiovascular disease monitoring (Searcy et al., 2019), medication intake monitoring (Aldeer et al., 2018). Extended-Reality technologies can promote healthy aging and independence with systems that can assist you to provide user-centric recommendations for healthy purchases when grocery shopping using Augmented Reality technologies (Alhamdan et al., 2020), and Virtual Reality (VR) can be used to improve the online grocery shopping experience (Ketoma et al., 2018).

After the onset of the COVID-19 pandemic, multiple countries implemented emergency lockdowns, and people depended on technology to accomplish multiple daily activities including communicating with friends and family to cope with isolation (Juvonen et al., 2021). A balanced used of technology helped to alleviate feelings of loneliness (Y.-C. Lee et al., 2021), and frequency of using social media had a positive effects in loneliness, with middle-aged adults that used social media more often reporting lower social loneliness (Bonsaksen et al., 2021). Smart technology was reported to be decisive on promoting significant relations, rewarding activities, spirituality, and physical activity for older adults from different regions around the globe (von Humboldt et al., 2020). People also started grocery shopping online more often, and those people are more likely to continue with this shopping alternative (Shen et al., 2022). When people feel less safe to go shopping in-store (e.g., when there is a surge in cases), people tend to shop online much more (Grashuis et al., 2020).

### Technology adoption and adherence

Although younger adults are more likely to use technology in general (Czaja et al., 2006), older adults are now being more online and technological than ever: in a survey conducted in 2021, 31% of U.S. adults reported almost constantly being online and 85% of Americans say they go online every day (Pew Research Center, 2021). More than half of adults 60-70+ use smartphones and computers (AARP, 2016), and numbers show an upwards trend. Data from 2021 showed that 61% of older adults age 65 or above owned a smartphone, 45% used social media, and 44% owned a tablet computer at the time of the survey (Pew Research Center, 2022).

This age group can be enthusiastic about adopting a new technology if they perceive a benefit from it (Andrews et al., 2019; Heinz et al., 2013; Vaportzis et al., 2017) and that the technology is reliable and useful (Ismatullaev & Kim, 2022). When it comes to technology acceptance, it might be domain-dependent (Mator et al., 2021) e.g., a technology that can help with fall preventions is treated differently than riding a self-driving car, which involves some type of risk.

Other common barriers that technology developers found when it comes to adherence of older adults include fear regarding data privacy, uncertainty when using devices, and lack of knowledge (Volkmann et al., 2020). These barriers can result in older adults prioritizing non-digital tools over digital tools for things such as health-tracking, which might also be related to not knowing newest available technology alternatives (Pang et al., 2021).

Geographic location might also influence technology adoption (Taipale et al., 2021). Older adults residing in rural areas are less likely to use internet or have favorable perceptions of technology when compared to older adults living in urban areas (H. Y. Lee et al., 2020). Cognitive ability was reported to mediate technology adoption (Czaja et al., 2006), which is an important control factor when analyzing older adults' data.

The first encounter with a new technology can directly affect the decision of adopting it. This is directly related to learning how to use a new device. Overall, different learning method preferences seem to be changing for older adults. Although previously being reported that instruction manuals are the preferred learning method for adults 65+ (Leung et al., 2012), trial-and-error is now more accepted by older adults (Czaja et al., 2006; Pang et al., 2021). The lack of physical instruction manuals with new technologies might be forcing this trend, making buyers access instructions through the internet instead.

## Present Study

Research should explore in depth how specific groups of older adults are adhering and using technology in their daily lives. Older adults are a very heterogeneous group, and research should look beyond simple users and nonusers when it comes to technology (van Boekel et al., 2017; van Deursen & Helsper, 2015). After someone becomes an internet user, there is a huge spectrum of possible differences between how these people are using the internet, a phenomenon named digital inequality (DiMaggio et al., 2004). Possible different uses of the internet after going online include learning, communication, leisure, or easing the everyday life.

Older adults seem to overall recognize the value of these technologies when it comes to overcoming aging barriers (Hill et al., 2015), but more research should be done controlling for different user types. Literature in fear of technologies for example tend to focus on new users instead of people who are already users (Nimrod, 2018), and studies related to online activities such as shopping patterns, although including older adults, had mean ages of 37 years old (Grashuis et al., 2020).

In this study, the relationship between older adults and technology adherence was explored, as well as their perceptions on a variety of topics including self-driving cars, video games, learning how to use new technologies, and frustrations with devices. It was also evaluated how daily activities and technology interlaced for this particular group of older adults.

# Methodology

## Recruitment and Design

Recruitment happened through different Medias, including a website, social media, physical flyers posted around town, as well as referrals. This study complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board (IRB #8843.5) at Kansas State University, and all participants had given consent prior to participating in this study. To qualify for this study, participants were over 65 years old and cognitively healthy. Cognition was evaluated using the mini version of the Montreal Cognitive Assessment (MoCA) with participants scoring at least 11 out of 15 points. The survey was the first part of a longer intervention study that was conducted mid COVID-19 pandemic in July 2021 and took place through the Zoom platform.

## The Online Survey

This study consisted of an online survey through the Qualtrics platform, which took an average of 15 minutes to complete. Participants were mostly already internet users. The survey consisted of the following parts:

I. Basic demographics: information including age, gender, education in number of years, if the participant was still working, and if still driving or ever driven.

II. Technology usage, familiarity, and openness: included willingness to ride a self-driving cars, previous experience with virtual reality (VR) technology, adherence to video game, devices, and social media.

III. Daily activities behavior: to better understand how older adults are performing instrumental activities of daily living, participants were asked to report which daily activities they currently do using technology (smartphone, tablet, or computer). The activities surveyed included:

bank transactions, ordering meals, shopping online, asking for transportation, grocery shopping (delivery and pick up), setting medication or appointment reminders, using maps, looking for exercise instructions, controlling calorie intake, managing money, reading the news, checking the weather forecast, listening to music, watching television, and playing games.

IV. Learning and frustration with technologies: it was investigated how worried participants were with having their private information leaked by using technology devices, if ever been a victim of a fraud, preferred methods to learn how to use new devices and past experiences related to frustration with devices.

## Sample Description

The data was imported and analyzed using R-Studio, and basic demographics results can be seen in Table 6.1.

**Table 6.1 - Frequencies and percentages for demographic characteristics of the participants**

| Demographics Variables | | Frequency | Percentage |
|---|---|---|---|
| **Gender** | Female | 60 | 69.0% |
| | Male | 27 | 31.0% |
| **Education** | High School Diploma | 18 | 20.7% |
| | Bachelor's Degree | 27 | 31.0% |
| | Master's Degree | 29 | 33.3% |
| | Doctorate's Degree | 13 | 15.0% |
| **Still working** | Yes | 28 | 32.2% |
| | No | 57 | 65.5% |
| | Preferred not to answer | 2 | 2.3% |

The sample consisted of 87 older adults (ages 65+) recruited for an experiment at the Memory and Aging Lab at K-State. The average age of participants was of 71.8 (SD = 5.6), with the maximum age of 87 years. Participants were highly educated. More than half of the participants (79.3%) had at least a bachelor's degree, with 48.3% participants with a graduate degree. Majority of participants were retired (65.5%). A larger ratio of women reported being retired than men (71.6% of females versus 44.4% of men).

## Results

### Smartphones and tablets

Most participants reported having a smartphone (88%), and 90% of those have had a smartphone for more than 3 years. Only 2 participants got their smartphone within a year from taking the survey. Table 6.2 summarizes the results of the reasons participants had to get a smartphone.

**Table 6.2 - Main reasons why participants adopted a smartphone**

| Reason | Frequency | Percentage |
|---|---|---|
| **To connect with family and friends** | 59 | 68% |
| **Thought it would be useful** | 48 | 54% |
| **To work** | 25 | 29% |
| **To play games and/or read the news** | 18 | 20% |
| **Thought it was an interesting device** | 14 | 16% |
| **Because people expected you to get one** | 9 | 10% |
| **It was given to me by family or friends** | 8 | 9% |
| **Lack of non-smartphone options** | 5 | 6% |

The most selected reason was "to connect with family and friends", followed by "thinking it would be useful". "To work" was chosen by 29% of participants. Some participants reported also the "lack of non-smartphone options" (6%) which is a trend seen at stores around the country. Another interesting response was "because people expected you to get one" (10%).

Approximately 35% of participants who owned a smartphone reported using voice-commands, which was reported to work most of the time for 63% of participants, always for only 11%, and about half of the time for 26%. A total of 45 (81.7%) participants reported having a tablet, and 81 (93.1%) a computer.

When it comes to time spent online, 31 reported spending between 1 and 2 hours daily using either their smartphone, computer, or tablet. Only 6 reported using these technologies for less than 1 hour daily, 18 between 2 and 3 hours daily, and 21 for more than 3 hours daily. Video calls were done by 47 participants.

Participants were mostly engaged with social media apps, with only 15 participants reporting not using any form of social media, with over 82% of this sample having a social media account. The most used social media apps reported by participants were Facebook (66), followed by Instagram (17), LinkedIn (11) and Twitter (8).

## Instrumental Activities of Daily Living

Results for the technology usage to perform daily activities are summarized in this section. Participants reported from a list of daily activities which ones they perform using a technology device and which specific device(s) do they use.

Table 6.3 summarizes the results for instrumental activities of daily living that participants perform using either a smartphone, a tablet, or a computer.

**Table 6.3 - Instrumental activities of daily living using technology devices**

| Activity Category | Question | Smartphone | Tablet | Computer | Do with tech % |
|---|---|---|---|---|---|
| **Personal Finance** | Execute Bank Transactions | 39% | 16% | 87% | 77% |
| | Manage your money | 35% | 18% | 94% | 56% |
| **Cooking** | Order Meals | 72% | 20% | 50% | 53% |
| | Grocery Shopping - Delivery | 42% | 26% | 68% | 22% |
| | Grocery Shopping - Curbside Pick-up | 52% | 24% | 64% | 38% |
| **Transportation** | Ask for transportation | 84% | 11% | 21% | 22% |
| | Use maps | 81% | 14% | 55% | 89% |
| **Taking Medication/Self Care** | Set medication reminders | 92% | 0% | 33% | 14% |
| | Set appointment reminders | 80% | 8% | 37% | 59% |
| | Control calorie intake | 57% | 21% | 50% | 16% |
| | Look for exercise instructions | 41% | 30% | 68% | 43% |
| **Shopping** | Shop Online | 36% | 25% | 87% | 89% |
| **Leisure** | Read the news | 66% | 27% | 74% | 84% |
| | Listen to music | 63% | 19% | 54% | 55% |
| | Watch television | 24% | 33% | 57% | 24% |
| | Play games | 60% | 42% | 46% | 55% |
| **Others** | Check the weather forecast | 78% | 18% | 42% | 95% |

For each task, the number of people using each device for each task was divided by the total of people who perform the task using technology. Checking the weather forecast is done by 95% of participants using some form of technology. Most people that check the forecast prefer using their smartphone to do so (78%). Shopping online also an activity done by most participants (89%) and it is preferably done in their computers (87%). Approximately 85% of this sample was taking medications, but surprisingly only 12 (15.8%) of these 76 participants reported using one of those three devices to assist with remembering to take their medications.

It was also assessed the total number of online activities done by each participant, with an average of 9.5 (SD = 3.5) online activities reported, and an average of 2.4 (SD = 0.66) devices owned by each participant. In a linear regression analysis, age and number of owned devices were significant predictors of total number of online activities done ($F(3,83) = 6.278$, $p < .001$). There was a positive relationship between the number of owned devices and number of online activities, and a negative relationship between age and number of online activities.

## Self-Driving Cars

Self-driving cars are becoming more common since the last couple of years. Only one participant reported currently not driving anymore after relocating to a new state, meaning that 98.8% of participants were still driving at the time of the survey. Participants were asked if they would consider riding a self-driving car. Although majority (49 or 55%) said that they would drive or ride one, 30 reported that they would not, and 8 preferred not to answer.

To test if education is correlated with willingness to ride a self-driving car, a contingency table (Table 6.4) was built based on three educational levels: having at most a high school diploma, having an undergraduate degree, or a graduate degree.

**Table 6.4 - 3-way contingency table for acceptance of self-driving cars**

| | | Yes | No/Prefer not to answer | Total |
|---|---|---|---|---|
| **Female** | High School | 5 | 8 | 13 |
| | Bachelors | 12 | 9 | 21 |
| | Graduate Degree | 12 | 14 | 26 |
| **Male** | High School | 3 | 2 | 5 |
| | Bachelors | 5 | 1 | 6 |
| | Graduate Degree | 13 | 3 | 16 |
| **Total** | | 50 | 37 | 87 |

The odds of rejecting riding a self-driving when comparing females to males progressively increased from 2.4 times with a high school degree, to 3.75 with a bachelor's degree, and even higher of 5.05 times when having a graduate degree. Analyzing each gender table separately using the Fisher's Exact Test, no effect was found between different education levels and self-driving car acceptance ($p = 0.6$ for females and $p = 0.67$ for males). Another Fisher's Exact Test directly compared females and males regardless of education level, with gender and acceptance found to be conditionally dependent ($p = 0.01$). Females are more likely to reject the idea of riding in a self-driving car.

## Video Games and Virtual Reality

A total of 46 (52.8%) participants reported ever playing video games, but only 22 (25.3%) reported still playing. The most reported type of game was computer games, with 30 participants reporting playing at some point in life with computer games, and 24 participants reported playing games using their smartphone. Consoles such as Nintendo (7), Xbox (7), and PlayStation (8) were also reported as video game consoles played.

Only 6 participants had a Virtual Reality experience, and while 4 of them reported enjoying the experience, 2 people reported that they did not enjoy it because it was "too real" and "tried it when it was new, it needed improvement". But willingness to have a VR experience was relatively high, with 56.3% of the participants saying that they would be interested in having a VR experience.

## Fears of Fraud

Participants were asked about fears related to having their information leaked when using a technological device and if they were ever victim of a fraud. A contingency table was created with participants who responded with yes or no to both questions (excluding "prefer not to answer" results in either one of the questions). Pearson's Chi-squared test had $p = 0.75$. Being tricked and fear of having leaked information are independent.

Learning and frustration with technology devices

One of the biggest barriers for a successful technology adoption by older adults includes the process of learning how to use the new device as well as frustrations while using them. Participants were asked how frequently they feel frustrated using technology devices (Table 6.5), and 58.6% responded that they sometimes feel frustrated, and 17.2% often feel that way.

**Table 6.5 - Contingency table of frustration's frequency and educational level**

| | Never | Rarely | Sometimes | Often | Always |
|---|---|---|---|---|---|
| **High School Diploma** | 0 | 4 | 17 | 4 | 0 |
| **Bachelor's Degree** | 2 | 13 | 20 | 7 | 0 |
| **Graduate Degree** | 0 | 2 | 14 | 2 | 0 |
| **Total** | 2 (2.2%) | 19 (21.8%) | 51 (58.6%) | 15 (17.2%) | 0 (0%) |

These numbers are certainly above ideal, and this might contribute to decreased adoption of new technologies by older adults, which can be analyzed by the next question: did you ever give up using a device because it was too hard or complicated to use? A total 21 participants reported giving up already because of the complexity of the device.

For those who said “yes”, an extra question was asked regarding why and which device(s) that happened to. Responses included smart and interconnected devices and lack of patience to figure out how to use it. Participants also reported having difficulties with specific websites and phone applications.

### Learning preferences

When participants were asked to select how they usually learn to use a new device (Table 6.6), learning by using it was the most selected option, with 69 responses. In second place, having friends or family teaching you with 60 votes. Less selected options were finding a class/course and going to a physical store. Participants could select multiple options.

**Table 6.6 – Most selected alternatives for learning preferences**

| When you get a new technology device, how do you usually learn how to use it? | Counts |
|---|---|
| **Learn by using it** | 69 |
| **Family or friends usually teach you** | 60 |
| **Read the manual** | 51 |
| **Look for instructions online** | 45 |
| **Go to a physical store** | 19 |

In an open-ended question, it was asked about the best method, in their opinion, to learn how to use a new electronic device. Most answers included some sort of demonstration of the product, either by a family member or friend, online video, or being taught by a vendor from the store you are purchasing the device.

## Discussion

As expected, the highly educated and cognitively healthy older adults of this sample have mostly adhered to smartphone and computers and were all internet users. Comparing adherence with nationally reported data, it was seen a much higher adherence than average, which showed how heterogeneous this age-group can be. With an average of 61% of American older adults owning a smartphone (Pew Research Center, 2022) and our results of 88% ownership, it likely means that the share of older adults with less years of education (and probably lower income) have below average ownership of smartphones. Approximately 23% of this sample uses social media, compared with 45% national average (Pew Research Center, 2022), again demonstrating the high variability of technology adherence in different subgroups of older adults.

From those results, older adults are using their smartphones for more than just social purposes, in line with past research on older adults and smartphone usage (Busch et al., 2021). Older adults might also be less prone to problematic smartphone usage (Horwood et al., 2021), being a potentially great tool to help with socialization.

Tablets, on the other hand, had an approximate 50% adherence. Intervention studies have evaluated older adults' experiences learning how to use tablets (Vaportzis et al., 2018) or even the effects of intensive tablet-usage training on cognition (Chan et al., 2016), with results pointing to a medium acceptability of this device. Older adults might not see a clear benefit from owning a tablet when already having a smartphone and a computer.

Majority of participants reported being online for at least 1 hour daily, and while studies have showed that younger adults tend to underestimate time spend on their smartphones (Brazil & Rys, 2020; Hodes & Thomas, 2021), it is unclear if older adults follow the same pattern.

## Daily Activities and technology usage

Overall, participants are actively using technology to complete daily activities. A total of 77% of participants reported doing bank transactions online. In times when quarantines might be necessary, it will be extremely helpful to know how to do online baking. When looking at technology alternatives to grocery shopping, findings pointed to a relatively small number of participants choosing not to physically go to the store. A trend of people starting to online grocery shop more often is expected (Shen et al., 2022), with its patterns shifting depending on the rate of spread of COVID-19 (Grashuis et al., 2020). Most participants from this study live in relatively small towns (less than 60 thousand habitants). Studies reported fewer behavioral changes related to preventive behaviors in people that live in rural areas in China (X. Chen & Chen, 2020) which might justify the lower adherence to online grocery shopping methods from participants in this study.

Another possibility was that preventive behaviors adopted by the participants included different shopping patterns in exchange of completely avoiding trips to the grocery stores. After the onset of the pandemic, a common preventive behavior alternative to completely avoiding trips to the grocery stores was to reduce shopping frequency and adopt quick and efficient trips to the grocery store (Shamim et al., 2021). Dissatisfaction with poor quality produce items picked up by supermarket employees were also an obstacle to online grocery shopping (Palmer et al., 2021).

Although most activities could be done through your smartphone or tablet, some participants still preferred using their computers. It might be because people are more familiar with certain activities being done in a computer and believe that might be a lot of work to learn a new way of accomplishing the exact same task. Studies evaluating perceptions and barriers of the adoption of table computers reported apprehension regarding instructions and support for using tablets (Vaportzis et al., 2017).

Higher educated older adults were found to be more likely to use internet for information purposes like reading the news (van Deursen & Helsper, 2015), and indeed 84% of this sample reported using technology to read the news and stay updated on current events.

## Technology Frustrations

Even amongst highly educated older adults, more than half of participants reported at least sometimes feeling frustrated learning how to use a new device. It is necessary to provide enough support for new technologies and have easy access to training (Pirhonen et al., 2020).

Agreeing with past research on learning preferences (Czaja et al., 2006; Pang et al., 2021), the most preferred method of learning is now an independent approach using trial-and-error (learn by using it). Older adults have reported in prior work (Lindley et al., 2009) concerns when it comes to asking for friends or family for technology support, worrying about being inconvenient. This could be facilitated by improving training instructions and including video tutorials (Pang et al., 2021) or even more modern hands-on training using technologies such as Virtual Reality which can result in highly transferable skills between the virtual and real worlds (Dobrowolski et al., 2021).

An increased number of older adults is using online services that come with security and privacy risks such as some of the activities reported by this study e.g., banking. Phishing has happened to 25.8% of the participants, but it was not correlated with fear of having information leaked by using technology devices. Although older adults have been reported to be very cautious when classifying emails as scams (Sarno et al., 2020), this age group was still more affected by cybercrimes than younger adults since the onset of the COVID-19 pandemic (Payne, 2020).

## Self-driving cars

Female older adults have been found to be more likely to prefer non-autonomous cars (Haboucha et al., 2017). Past research regarding willingness to ride in a self-riding car showed women being less willing to ride compared to men (Rice & Winter, 2019), but educational level was not reported. Results agreed with the fact that older women tend to be less open to riding a self-driving car, and when incorporated the educational level, results remained the same. Women are less likely to ride a self-driving car regardless of their educational level. Although is not possible to predict if people will change their minds while technology keeps improving, older adults seem to be skeptical about this new technology for now.

### Future directions

This study did not investigate disability status and health issues, as suggested to also be a factor influencing technology usage and adherence by older adults (Hargittai et al., 2019). A study limitation was that there was a selection bias since the survey was conducted online. This is likely represented in the education level of the sample, which is positively correlated with higher income levels (U.S. Bureau of Labor Statistics, 2018) and consequently higher likelihood of being online (Pew Research Center, 2017).

Disseminating knowledge about the aging market is a must, and will help to increase the dialog between technology developers and the older adults population (Naor et al., 2021). Co-designing new technologies such as health and fitness apps (Harrington et al., 2018) or social care (Toms et al., 2019) with older adults included in the process should be the standard procedure to ensure higher adherence of this age-group. By facilitating access to technologies and adhering to them, older adults can be empowered to stay independent and socially connected (Hill et al., 2015), which has been shown to supported late-life wellness (Yang et al., 2021).

## Conclusion

This study has explored older adult’s technology usage, acceptance, and adherence. As a very heterogeneous group, this study focused specifically on highly educated older adults that were cognitively healthy. Results showed that participants in this sample had higher usage of technology than reported American averages, supporting the digital divide within this age-group.

Even highly educated older adults are not taking all possible advantage of their technological devices, and frequently experience frustration with learning how to use a new device. There were clear preferences of types of devices to perform specific daily activities such as using their phones to check the weather forecast, and their computers to perform bank transactions. Tablets had the lowest adherence rate compared to smartphones and computers, and were the least used device to perform daily activities.

There is still a clear gap between the design of products and its older adult users. Acceptance of new technologies such as self-driving cars seem to be gender-dependent, with older women being less likely do adopt this technology regardless of educational level. More research needs to be done to better understand why women tend to be less prone to adopt some technology domains than men.

This research raises concern about usage and adherence of older adults from different subgroups. With the trend of daily activities becoming online, it is decisive to look at all spectrums of older adults to make technologies more accessible and accepted, makings sure that all older adults are included in technological changes in society.

# Chapter 7 - Exploring how intuitive VR is for daily life tasks and effects of gaming skills on performance

## Introduction

Virtual Reality (VR) has opened a lot of doors with its immersive technology. With VR, researchers and designers can create realistic environments that can replicate similar sensations as in the real-world. You can also repeat tasks, get feedback about your performance, get different sensory stimulations, and stay in a highly controlled environment (Bohil et al., 2011). It did not take long for people to realize all the opportunities related to its use besides gaming, including training of firefighters (Engelbrecht et al., 2019), doctors (Javaid & Haleem, 2020), and students (Radianti et al., 2020), and even using it in rehabilitation programs for stroke patients (Aminov et al., 2018; Brunner et al., 2017; Bui et al., 2021).

### Transferability of gaming skills

Even the most modern technologies will involve some human-computer interaction and learning how to use the new system, but the fact that VR devices are now much more realistic could potentially reduce difficulties related to its interface when compared to previous simulation alternatives. Doing a task with a computer and mouse can be very different from doing a task using immersive VR systems, where the movements you make are similar to the ones you would also do in real life. Indeed, using fully immersive VR systems have been found to have higher user experience and easiness of use when compared to regular screens (H. Zhang, 2017), and more intense emotional responses and presence when compared to a traditional desktop setup (Pallavicini et al., 2019). In a study from Gerber et al (2018), differences between performing a tea preparation task with two different input devices, a hand-held VR controller or a mouse, were analyzed, with participants reporting lower workload and higher usability using the handheld controller (Gerber et al., 2018). Another study by O'Connor et. Al. (2018) used VR for interactive molecular dynamics, showing how molecular modeling tasks can be done more quickly in VR than using conventional interfaces (O'Connor et al., 2018), which demonstrates how usable those systems can potentially be.

The VR market is also growing consistently, with sales expecting to reach 13.9 million units in 2022, up 26.6% of the 2021 numbers. This means that the number of people with access to VR devices will likely increase, and it might even reach more consumers than regular video game markets given all different uses of the system besides gaming e.g., exercising and learning new skills.

Although better in terms of intuition than the old desktop and mouse setup, immersive VR systems still incorporate a device that people need to interact with and learn to use in order to complete the simulations. VR simulations also do not have a standardized design process, making user experience vary considerably between applications (Renganayagalu et al., 2021).

The current VR user-interface includes, in most cases, two hand controllers as the input system. Those controllers are required to interact with the scene in the form of tracking of the hands - which is done passively by simply holding the controllers – or to perform specific actions such as grabbing objects – which requires actively using different buttons. This human-computer interaction (active system) ends up being very similar to regular video game controllers (Figure 7.1).


**Figure 7.1 - VR and traditional video game controllers**

The term "transfer of training" refers to the transferability of VR skills between different simulations and experiences (Barnett & Ceci, 2002), which can influence performance and the amount of training required to learn the system. In a study with an aeronautical assembly task in VR, prior experience had a significant effect on user's self-assessed performance (Sagnier et al., 2020), but it was not analyzed its effect on objectively measured performance. Prior experience was also defined as having used the device only once before, which might not be enough to effectively gain expertise with the system. The study also did not consider other video game experiences of participants, which might have influence in performance as previously pointed due to similarities in its user-interface. Research therefore should be done to better understand how prior experiences with VR and other videogames can objectively influence performance during VR simulations.

## Learning preferences

Another component that can impact performance is how a system is being introduced to the user, which might also lead to different feelings regarding the device. Product aesthetics was found to influence usability ratings and performance (Sonderegger & Sauer, 2010), and research has found a positive relationship between performance and immersion and presence (Renganayagalu et al., 2021; Weech et al., 2019). Adequate training and practice can increase effectiveness of using VR devices in research studies (J. Chen & Or, 2017), which has been already shown in this dissertation with time improvements in VR after some trials.

VR studies evaluating performance constantly report training or practice trials prior to the actual data collection (Bezerra et al., 2018; Parra & Kaplan, 2019; Porffy et al., 2022). Indeed, the experiments from Chapters 3 and 4 included a demonstration on how to use the system, and even a training session prior to the actual task and data collection. Still, a significant improvement in performance (measured in time) was found when using the VR device after three trials due to the ergonomic fidelity limitations of the system for fine motor tasks.

Instructions can sometimes come as a video, in written form, as a demonstration, or not at all with some devices, and people can have different preferred methods to learn how to use a new piece of equipment (Pang et al., 2021). As discussed in Chapter 6, some older adults preferred learning on their own (trial and error), some by reading the manual, and some reported preferring a demonstration instead.

## Present Study

With all the current and prospective VR applications, researchers need to better understand possible confounding factors with VR performance during simulations. In this study, two key components were evaluated: how past experiences with VR and other videogames impact performance, as well as how different training protocols influence performance and overall perception of the system. To make these evaluations, two main types of VR tasks were utilized: tasks that are part of our daily lives, which were hypothesized to be easier and more intuitive to complete, as well as tasks that are VR specific and would only exist in the VR simulation, which were hypothesized to be less intuitive to complete without proper instruction as we do not have a real-life reference to base upon.

## Methodology

### Participants

90 younger adults were recruited from engineering classes in exchange for extra-credit. This study was approved by the Kansas State University's Institutional Review Board (#IRB-10786). Consent was obtained by having participants read and sign the consent form after the nature of the study was explained to them. Participants read and signed the informed consent form after arriving to the laboratory where the experiment was being conducted. Basic demographics was collected after consent was given. The average age of the sample was of 21.36 (SD = 2.24), and majority males (65 males/24 females/1 non-binary).

To control for technology familiarity, participants were asked about their previous VR and gaming experiences. Questions asked include if they ever used VR before (if yes, how many times), if they had or ever had a VR device or other video game console, and video gaming frequency. This information was further used in the analysis to classify participants into VR or non-VR users. Participants that used 4 or more times the VR with each session longer than 15min or owned a device were classified as VR users. Participants were classified as video game users (VG users) if they play video games at least weekly, or have their own video game device.

### Virtual Reality Apparatus and Virtual Environment

The Oculus Quest 2 was the selected device for this study, which consisted of a Head Mounted Display (HMD) and two hand-held controllers. The Virtual Reality environment was designed using Unity (version 2020.3.10f1). The environment was rendered using a computer with 9th Gen Intel Core i7-9750H, NVIDIA GeForce GTX 1660 Ti, and 32GB RAM.


**Figure 7.2 - Virtual Room**

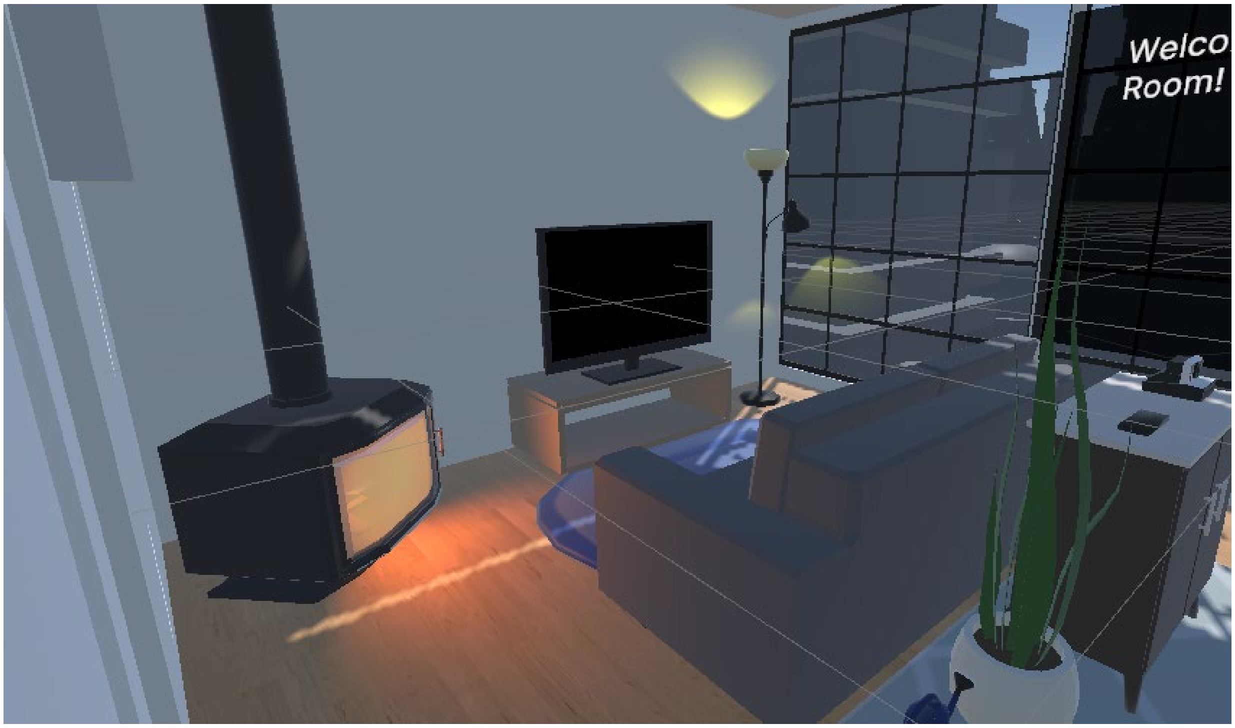


**Figure 7.3 - Virtual Room**

The room was designed to minimize possible distractions so that participants would stick to the actual tasks. Figures 7.2 and 7.3 show the room designed for this study. The only objects available to grab were the ones involved with the tasks. The room was 6m x 4m, with lighting baked into the system to increase game performance and avoid any lags that could cause symptoms of cybersickness in participants (Palmisano et al., 2020). For inclusiveness reasons, players' hands were colored blue, and the user had no avatar whatsoever.

The system had 3 different locomotion systems enabled, similarly to how most VR games are set up today: 1) Motion-based: this technique uses the user's movement in real-life to move around in the VR space. It is limited by the room size available. 2) Controller-based: this technique uses artificial interaction to move around like users would do at a normal videogame. It involves continuous movement in the VR space. In this environment, the speed was reduced to reduce cybersickness effects caused by a mismatch between visual and vestibular systems (Yildirim, 2020). 3) Teleportation: this technique also uses an artificial interaction in a point-and-choose type of locomotion. The player uses the controller to select the area that they would like to teleport to, and then locally uses the motion-based locomotion system.

## Virtual Tasks

The goal was for participants to complete a series of tasks in the virtual environment. The tasks were designed to be 1) simple daily activities i.e., things that participants could easily complete in a real-life setting and 2) components of VR systems that are not existent in real-life i.e., teleportation and virtual user interfaces.

Tasks were intended to explore different components of user's interaction with the system, e.g., the first task was designed to test the intuition related to the need for reaching for an object to grab it. Table 7.1 summarizes the list of tasks to be performed by each participant, the user-interface component associated with it, and the criteria used to define when each task was successfully completed.

**Table 7.1 - List of tasks, related VR component, and how completion was defined**

| Task Number | Task Goal | VR component | Definition of task completion |
|---|---|---|---|
| **1** | Water the plant | Reaching and grabbing objects | Participant watered the plant for at least 1 second – enough to see and hear the water pouring from the jug |
| **2** | Turn on the television | Pressing two buttons on the controller at the same time | The television start playing a video |
| **3** | Take a picture with the camera | Pressing two buttons at the same time combined with appropriate positioning of the grabbed object | Polaroid printed a picture containing the fireplace |
| **4** | Pick up a hat and put it on your head | Grabbing and controlling objects with one hand | When participant viewed themselves with the hat on their heads in the mirror |
| **5** | Set a table for two people | Moving and turning while grabbing objects | Table was set with an appropriate position of objects |
| **6** | Put the tennis ball on the net of the tennis racquet | Grabbing and controlling objects with both hands simultaneously | The ball had to balance on the net of the racquet |
| **7** | Teleport to the area next to the fireplace | Using teleportation anchors | Participant's position changed and is now on the carpeted area next to the fireplace where the teleportation anchor is located |
| **8** | Click on the OK button to close the UI board | Using pointers and clicking on virtual buttons | User interface instantly closes after OK button is pressed |

## Training Types

Each participant was randomly assigned to a random protocol for training that included three alternatives as described below. Participants were instructed regarding possible movements and movement restrictions within the VR system. All participants went through safety instructions on the equipment's internal safety guard regardless of training protocol and were informed to only make turning and bending movements or adjusting their position with small steps. Walking or making large steps was not permitted in the lab.

### No Training

Participants assigned to the group with no training only went through the safety instructions. They were informed about the system itself, composed by the head-mounted display and the two controllers. They were also informed that all tasks could be accomplished using the controllers, including walking if needed to complete the VR tasks.

### Written Instructions

The groups with only written instructions provided had access to a laminated paper with simple instructions regarding the buttons to be used in the controllers (see instructions in Appendix B). The instructions were designed using images and based on recommended ergonomic principles for creating senior-friendly products, which applies to any adult population (Fan & Truong, 2018). Participants had access to the card for a fixed amount of time of 2 minutes before they started completing the tasks. In this participant-dependent method, performance times were expected to be not as good as the demonstration.

### Demonstration

A simple demonstration was conducted by the researcher with the participant holding the controllers. It was covered which buttons to press to accomplish each specific task-related movements, including teleporting to another part of the room, grabbing and holding objects, pressing buttons in virtual objects such as the remote controller to turn on a television, and interacting with the user interfaces in the room. The material part of the demonstration came directly from the written instructions provided to make sure the exact same information was being conveyed to both groups. The average time to go over the demonstration was of 2 minutes.

## Study Design

After consenting to join the experiment, participants had the standard safety instructions and were randomly assigned to one of the three study groups. All tasks were performed with participants standing up. Participants were instructed to put the head-mounted display and adjust the straps in a way that the display was comfortable but stable i.e., not moving when participants were turning their heads. Participants were instructed on the system's boundaries to understand when they were leaving the safe gaming area and reduce potential risk when running the experiment. Participants were then handed the two remote controllers to start the tasks.

Tasks were read out loud for participants as soon as they entered the virtual room. Participants were asked to wait until the full task information was given before starting to work on the task. At this point, the virtual room would be loaded with all participants starting at the same location (the front door of the room) every time to standardize the data.

A timer was started simultaneously with the end of each task description. Completion of task was determined according to Table 7.1. Time was rounded to the nearest second before entered into the data collection system, and the researcher then classified if task was successfully completed or not. Tasks that were not completed had time left empty in the data collection system.

To avoid participant's frustration, all participants that could not figure out how to complete a task had the option of going through a demonstration to learn it after the study was over.

## Measurements and Scales

After all tasks were attempted, participants answered a short survey regarding the experiment. First, participants ranked tasks by difficulty from most difficult to least difficult and were asked to explain their number one choice (hardest task). Participants also answered to a partial NASA-TLX task load index (Hart & Staveland, 1988) that included 4 out of 6 possible dimensions. The two excluded questions were related to temporal demand and self-rating of performance. Then, the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) measured Cybersickness possibly caused by the VR experience. System Usability Scale (Brooke, 1996) was also utilized to evaluate the feasibility and likelihood of participants adhering to this type of VR system. Lastly, some specific VR-related assessments included presence in the VR environment using the IGroup Presence Questionnaire (IPQ) (Schubert, 2003). Subscales included were related to Realism and General Presence.

### Research Questions

Two main research questions were analyzed in this chapter. First, it was evaluated if having experience with VR systems and/or other video games has an influence on time and ability to complete the tasks. The second research question was if different levels of instruction would have an effect on VR performance for the daily living tasks and for the VR-specific tasks, as well as on overall perception of the system (usability, realness, and task load).

## Results

### Overall performance results

A total of 74 participants managed to complete all tasks of the study. 12 participants completed 7 out of 8 tasks. The lowest completion rate was of 6 out of 8 tasks, which was the case for 4 participants. The average completion rate was 7.77 (SD=0.51) tasks.

The task participants struggled the most with was the first task, where they had to water the plant. Due to the jug of water being on the floor, participants had to reach for the jug in order to grab it. Regardless of training protocol, some participants tried to remotely grab objects by using the red-ray light that is part of the teleportation and user-interface interaction tasks - although in the instructions it was made clear that grabbing objects while with the red-ray light on was not possible.

Table 7.2 shows how many participants completed each task under each training type. By Task 5 (set a table for two people), everyone could already complete the task regardless of training protocol. All participants who had the demonstration could complete the two VR-related tasks (teleportation and interacting with the virtual user interface).

**Table 7.2 - Total of participants who completed each task under each training protocol**

| | No Instruction | Written Instructions | Demonstration |
|---|---|---|---|
| **Task 1** | 27 | 28 | 27 |
| **Task 2** | 29 | 29 | 29 |
| **Task 3** | 29 | 29 | 30 |
| **Task 4** | 30 | 29 | 30 |
| **Task 5** | 30 | 30 | 30 |
| **Task 6** | 30 | 30 | 30 |
| **Task 7** | 27 | 29 | 30 |
| **Task 8** | 30 | 28 | 30 |

Participants also ranked which task they thought was the hardest one to complete (Table 7.3). The most selected tasks were the teleportation (24), the table setting task (22) and watering the plant (14). Participant's justifications for selecting teleportation as the hardest task were mostly related to not knowing or forgetting how to use the controllers to accomplish the task. Table setting was mostly selected due to it being the longest, and also due to the coordination required. Watering the plant was mostly selected for being the first task, when they were still figuring out how to interact with the virtual environment.

**Table 7.3 – Tasks selected as most difficult per training condition**

| Training | Task 1 | Task 2 | Task 3 | Task 4 | Task 5 | Task 6 | Task 7 | Task 8 |
|---|---|---|---|---|---|---|---|---|
| **No Training** | 4 | 0 | 1 | 1 | 8 | 1 | 11 | 4 |
| **Written Instructions** | 2 | 2 | 0 | 8 | 3 | 2 | 12 | 1 |
| **Demonstration** | 8 | 3 | 0 | 3 | 11 | 1 | 1 | 2 |
| **Total** | 14 | 5 | 1 | 12 | 22 | 4 | 24 | 7 |

Overall mean times for each level of training and each task level can be seen in the Table 7.4. Indeed, the longest task was Task 5 – Setting a table for two people. Differences in time observed between different training protocols seem not to vary much between conditions, except for the two VR-related tasks, with higher times associated with less instructions. Therefore, data should be further analyzed considering our hypothesis of past experiences influencing performance.

**Table 7.4 - Mean times for each task for each training protocol**

| Task /Instructional Type | No Instruction | Written Instructions | Demonstration |
|---|---|---|---|
| **Water the plant** | 14.05s | 17.07s | 19.65s |
| **Turn on the television** | 21.15s | 15.07s | 15.15s |
| **Take a picture with the camera** | 15.26s | 12.92s | 19.14s |
| **Put hat on** | 23.26s | 24.42s | 30.47s |
| **Set a table for two people** | 57.57s | 50.85s | 63.04s |
| **Play with the tennis racket** | 8.42s | 8.07s | 8.85s |
| **Teleport** | 14.76s | 10.15s | 5.80s |
| **Interact with the UI board** | 16.63s | 12.07s | 5.47s |

## Virtual Reality and Video Game Users Analysis

To properly evaluate the effects of gaming on participant’s performance, they were classified into VR and/or VG users and non-users (referred to as “VR/VG user” or “VR/VG non-user”) according to the defined criteria at the methodology. Total of participants allocated in each group can be seen in Table 7.5.

**Table 7.5 - Participants in each group analysis**

| Expertise level | Training | Count |
|---|---|---|
| **VR/VG Users (n = 53)** | No Training | 18 |
| | Written Instructions | 16 |
| | Demonstration | 19 |
| **VR/VG Non-Users (n = 37)** | No Training | 12 |
| | Written Instructions | 14 |
| | Demonstration | 11 |

In a gender analysis, it was also observed that participants who identify themselves as females were less likely to be VR/VG users when compared to males. A contingency table (Table 7.6) was created, and a Fisher’s Exact Test showed that males were significantly more VR/VG users than females (OR = 8.09, p = 0.00). Females were randomly distributed between different training techniques.

**Table 7.6 - Contingency table gamers/non-gamers females and males**

| | Males | Females |
|---|---|---|
| **VR/VG user** | 46 | 6 |
| **VR/VG non-user** | 18 | 19 |

Table 7.7 contains mean times for each of the 8 tasks considering the 2 possible factors: training type (no training, written instructions, demonstration) and being or not a VR/VG user, giving the total of 6 possible groups.

**Table 7.7 - Average total combined time, and average task time per group**

| | VR/VG User | | VR/VR Non-User | |
|---|---|---|---|---|
| | Total Time | Average Time | Total Time | Average Time |
| **No Training** | 161.05s | 20.44s | 261.41s | 34.98s |
| **Written Instructions** | 142.62s | 18.49s | 209.64s | 27.10s |
| **Demonstration** | 164.84s | 21.07s | 213.45s | 27.41s |

**All tasks combined**

Figure 7.4 shows a relatively consistent total time for VR/VG users regardless of training protocol, and for VR/VG non-users some improvement in time when comparing with and without training.

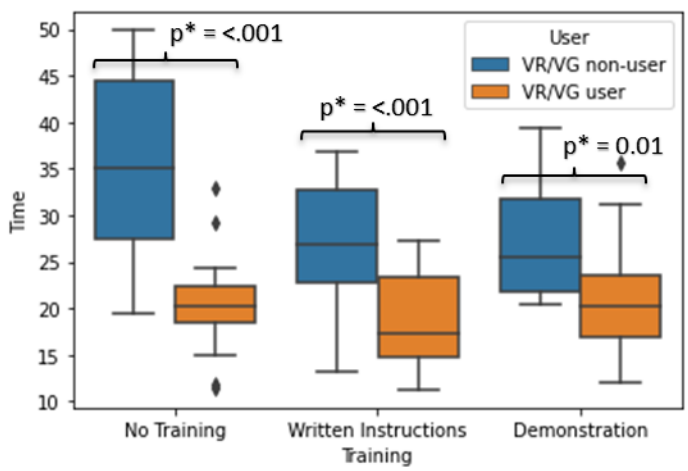


**Figure 7.4 – Boxplots of average time for each training and user types**

A Shapiro Wilk normality test rejected the hypothesis of a normal distribution of average time to complete tasks by participants (W = 0.92, p = < 0.001), which required a data transformation for posterior ANOVA analysis. Due to its right-skewness, a cube root transformation was used to not reject the hypothesis of the data being normally distributed (W = 0.97, p = 0.09).

The 2-way ANOVA assessed the effect of training type and being a VR/VG user on total time to complete the designed tasks. Being a VR/VG user was the most significant predictor of time. The ANOVA table (Table 7.8) showed a significant effect of the different training types, being a VR/VG user, as well as its interaction.

**Table 7.8 -2-Way ANOVA**

| | **Sum_sq** | **df** | **F** | **PR(>F)** | $\eta^2$ |
|---|---|---|---|---|---|
| **Training Type** | 0.36 | 2 | 2.60 | p < .001 | 0.04 |
| **VR/VG User** | 3.09 | 1 | 43.95 | p < .001 | 0.32 |
| **Training Type:VR/VG User** | 0.25 | 2 | 1.79 | p < .001 | 0.26 |
| **Residual** | 5.91 | 84 | | | |

In a post-hoc analysis, a linear model was fitted to better understand the effects of being a VR/VG user and training protocols. For VR/VG users, getting no training significantly increased the average time per task (p = 0.009), which was also observed for non-users with higher average times when no training was provided (p = 0.026). No significant difference was observed between getting the demonstration or the written instructions for either VR/VG users (p = 0.52) and non-users (p = 0.10).

**Daily life tasks vs VR specifics**

Out of the 8 designed tasks, 2 represented components part of the VR technology: teleportation, and user-interface interactions. Those tasks do not represent activities of daily life were separated from daily life tasks for a specific analysis. Table 7.9 shows which tasks were classified into each category for the analysis.

**Table 7.9 – Categories of tasks**

| Task Category | Task description |
|---|---|
| **Daily life tasks** | Water the plant |
| | Turn on the television |
| | Take a picture with the camera |
| | Put hat on |
| | Set a table for two people |
| | Play with the tennis racket |
| **VR specific tasks** | Teleport |
| | Interact with the UI board |

Average times for both daily life and VR specific tests (Table 7.10) failed the Shapiro Wilk normality tests (Daily life: $W = 0.97$, $p < .001$; VR-Specific: $W = 0.92$, $p < .001$) and were both right-skewed. For daily life tasks, a cubic root transformation could validate the normality assumption ($W= 0.97$, $p = 0.13$), and for the VR specific tasks, a box-cox transformation was used (box-cox value = -0.33, $W = 0.97$, $p = 0.05$).

**Table 7.10 - Average times for each group in each type of task**

| User type | Training | Average Time Daily Tasks | Average Time VR-Related Tasks |
|---|---|---|---|
| **VR/VG non-user** | No Training | 36.47s | 30.45s |
| | Written Instructions | 31.69s | 13.32s |
| | Demonstration | 31.92s | 14.13s |
| **VR/VG user** | No Training | 22.48s | 13.91s |
| | Written Instructions | 21.23s | 10.46s |
| | Demonstration | 26.57s | 5.31s |

Looking only at daily life tasks, for the two-way ANOVA only being a VR/VG user was a significant factor when predicting time ($F(1,79) = 32.83$, $p < .001$, $\eta^2$=0.26). No significance was found in the treatment type as well as interaction factor, which demonstrates that VR is a really intuitive tool for which training is not that important when it comes to daily life tasks that only involve grabbing and manipulating large objects.

When combining the two VR-related tasks, training type (F (1,79) = 8.65, $p < .001$, $\eta^2$=0.15) and being a gamer (F (1,79) = 16.31, $p < .001$, $\eta^2$=0.14) were significant factors, which shows that, for VR-related components, training does impact time to complete the task. Although most participants did figure out how to teleport and interact with the user interface board without any instruction, it took them much longer to complete the task through trial and error.

In a post-hoc analysis, a linear model was fitted to better understand the effects of being a VR/VG user and training protocols for the VR tasks only. Training was only significant for VR/VG users, with a significant difference between the three training conditions. The most effective training method in that case was a demonstration (p = 0.009) and the worst results from participants with no training ($p < .001$). These results demonstrated a much more effective training for VR/VG users than for non-users.

### Does training influence VR's overall perception by user?

Table 7.11 shows average subjective user scores for the different groups. Overall System's Usability Score was considered high for every treatment level. Scores above 68 are considered above average, and they range from 0 – 100. VR Realness scores range from -15 to 15. With all scores above 0, people thought the experience was relatively real.

In terms of cybersickness, we observed relatively low cybersickness level except for VR/VG non-users in the demonstration criteria. Indeed, the two outliers related to the SSQ results were part of that specific group. Due to the small sample size of this group (n = 11), data was kept in the analysis, but, if removed, mean SSQ score would be of 20.70, which represents "perceptible discomfort". Participants also reported low task load, which can range from 0 – 100, which also supports high easiness of use of this system.

**Table 7.11 - Average scores for SSQ, SUS, and Realness based on training type and being a gamer**

| Training Type | VR/VG user | SSQ | SUS | VR Realness | Task Load |
|---|---|---|---|---|---|
| **No Instruction** | No | 12.05 | 81.66 | 6.44 | 17.31 |
| | Yes | 8.90 | 83.96 | 5.85 | 13.22 |
| **Written Instructions** | No | 10.64 | 75.57 | 8.76 | 19.90 |
| | Yes | 14.52 | 76.17 | 7.23 | 13.42 |
| **Demonstration** | No | 27.54 | 80.00 | 7.44 | 23.47 |
| | Yes | 11.93 | 82.00 | 7.47 | 10.88 |

Most scores were relatively consistent between different groups, but it was observed that VR/VG users always reported lower task load than VR/VG non-users. Those results were not surprising given that VR/VG users were significantly faster than non-users, regardless of the training protocol they went through.

A cluster analysis was utilized to explore natural grouping within the sample. Table 7.12 summarizes cluster centers for each selected variable. VR/VG users showed higher completion rates, less average time to complete each task, less VR Realness, lower SSQ, and lower task load. Gamers are likely more familiar with videogames and graphics, so they might be more critical when it comes to evaluating the system's realness, but also more used to deal with controllers, which might result in overall higher usability scores.

**Table 7.12 - Cluster Centers**

| | SUS | SSQ | VR Realness | Average Time | Total Completed Tasks | VR/VG User | Task Load |
|---|---|---|---|---|---|---|---|
| **Cluster 1** | -0.20 | 0.16 | 0.42 | 0.80 | -0.49 | -1.11 | 0.50 |
| **Cluster 2** | 0.12 | -0.10 | -0.26 | -0.50 | 0.29 | 0.68 | -0.30 |

## Discussion

The first goal of this study was to evaluate how easy it is for users to interact with the VR system when completing simple daily living activities. This was assessed by providing two levels of training instructions and a condition with no training at all. High levels of task completion pointed to an easy-to-use system which can be used with simple written instructions. Not having to go over a demonstration or embedded training instructions in the system e.g., when the system itself has a dedicated software to teach you how to interact with the VR environment, can facilitate experiments by reducing time and programming required. It can also facilitate remote testing in situations such as during social isolation conditions.

The gender differences in video game experiences found in this study pointed to a smaller female population with video game experience. Also, gender was found to influence performance using VR technology for spatial ability tests with males completing tasks faster than females (Guzsvinecz et al., 2022), which was not necessarily a factor related to the VR technology itself, but likely due to the nature of the task: males normally outperform females in spatial abilities (Yuan et al., 2019). This has been discussed as a developmental trajectory influence due to different types of stimuli commonly experienced by males or females at a young age (Lauer et al., 2019)

Research has been looking at gender differences in other VR-related domains such as cybersickness, with mixed results found (Grassini & Laumann, 2020; Stanney et al., 2020). When looking specifically at performance, some studies did not find any gender effects (Khashe et al., 2018; Roettl & Terlutter, 2018), but gender-specific interest in some cases was found to potentially influence performance for military simulations (An et al., 2018).

With time, it is likely that this technology will become more common and of higher quality. When it comes to input systems and usability, different research has been evaluating different technologies. Hand Tracking technology has also been compared to traditional controllers, but no significant difference was found in interaction time and usability scores when performing a cooking task (Khundam et al., 2021). Haptic feedback was found to improve surgeon's performance when compared to no feedback (Girod et al., 2016). But haptic gloves are still not commercially available and still need improvements to replicate real-life sensations (Perret & Vander Poorten, 2018).

In comparison to the first VR study with the sorting task, participants in this study had to deal with an extra variable which was the locomotion system. Although overall cybersickness scores given by participants were still considered low in most cases, it can be improved by changing the design of the virtual environment utilized. In combination with the higher difficulty reported by participants for the VR-related tasks (teleportation and virtual user interfaces), it is recommended that studies aiming on assessing abilities related to daily living activities only incorporate the most intuitive locomotion system i.e., motion-based. This way, the VR task will more accurately represent its real-life counterpart and likely increase overall VR validity and fidelity.

## Limitations and Future Work

There was a higher number of participants that were gamers versus non-gamers in the analysis, resulting in smaller sample sizes for non-users' groups under each training protocol. Also, participants' effort and attention during the training protocols was not measured, and could also have influenced performance in tasks.

Different groups should also be considered for testing VR's intuition and the appropriate training. The older adult population can benefit from multiple VR applications including training daily life abilities (Gamito et al., 2019), which could be used to aid the detection of early cognitive decline in older adults (Atkins et al., 2018b). When designing daily living activities, researchers should probably avoid participants having to ambulate much around the scene. Different virtual environments should be designed to avoid awkward postures and better accommodate the older adult population. Studies with VR and older adults found a high acceptability of the system (Chau et al., 2021), therefore future research should also investigate how much training resources should be provided to minimize effects of the VR on performance and reduce confounding effects specifically with older adults. In chapter 6, older adults reported different preferred methods to learn how to use a new device. The most voted category was learn by using it, which was shown in this study to be a feasible alternative at least for YA when it comes to simple daily activities.

## Conclusion

In this study, it was shown that majority of participants could complete all tasks regardless of which training protocol they had, and if they had gaming experience or not. When it comes to time to complete tasks, VR/VG users performed significantly better than non-users, even without any specific training. This demonstrated high transferability between gaming experiences. The system is simple enough that written instructions were sufficient for non-users to perform as good as people who had access to an actual demonstration, which can facilitate research experiments and remote tests for daily living activities.

# Chapter 8 - Conclusions and Future Research

In this dissertation, the field of VR technology applications for assessing ability to perform daily activities was advanced. This chapter summarizes conclusions and outcomes of each of the Research Objectives presented in Chapter 1, goes over an overall discussion, limitations, and future work.

## Research Objectives

### Research Objective 1 – Determine if fine motor tasks could be performed in VR

The novel VR research design isolated the effect of VR on time to complete a fine motor task. Differences in time to perform the task in RL and VR were attributed to the ergonomic validity of the task, which improved after participants performed the same task 3 times. This showed that tasks requiring fine motor skills will likely also involve a learning effect that can be confounded with task performance. It was also demonstrated that VR is a feasible tool to perform fine motor tasks with younger and older adults as all participants completed the task in either setting with no significant difference in number of errors.

Both groups could learn and use VR technology to perform the tasks as all participants complete the experiment and could improve their times in VR. Low cybersickness levels, good usability scores, and high immersion levels were reported, supporting its application. This knowledge should be incorporated when designing experiments that will involve that important components of IADLs and reduce confounding effects related to the technology per se.

**Research Objective 2 – Evaluate age differences in VR performance for fine motor tasks**

The same phenomenon of learning effect and differences in time for YA and OA was observed, with OA taking longer to complete the task in each setting. The difference in time between groups for the RL task was smaller than for the VR task, showing a stronger technology effect on task performance for OA. Results were much more variable in the OA sample than in the YA, which was likely do due the high heterogeneity present in the older adult population.

The improvement in times when performing the task in VR was not statistically significant between groups (YA and OA), meaning that, although the expected time might be longer for OA, the learning effect might be the same.

**Research Objective 3 – Determine the older adults' current adherence to technology and its use to perform daily tasks**

Participants from this study were on average highly educated older adults (73.9% with at least a Bachelor's degree), and results showed that adherence to technology devices was high and above nationally reported averages for smartphones (81.7%) and computers (93.1%). Participants reported doing an average of 9.5 (SD = 3.5) online activities. Only 2.2% of participants reported never being frustrated with technology. The most common method to learn how to use a new device was learning by using it (79.3%), followed by having friends or family teaching you (69%). Overall, OA showed curiosity and openness to new devices and technology.

**Research Objective 4 – Evaluate how intuitive and easy to use VR is for daily task, as well as tasks that are unique to VR systems.**

Different levels of instruction on how to use the device (no instruction, written instructions, demonstration) were not a significant predictor of performance (measured in time) to complete the daily activity tasks. Therefore, the study showed that the VR system is very intuitive to use for testing of simple daily living activities. On the other hand, for tasks that are only VR-related and do not exist in real life such as teleportation, training was a significant predictor of time.

**Research Objective 5 – Evaluate the transferability of gaming experiences to new VR experiences.**

Gamers were found to perform significantly better than non-gamers, showing how this factor should be considered when the outcome variable of interest is time as a criterion of performance. In conjunction with the learning effect observed in the first VR study, previous experience with video games should be included as possible confounding factor with performance, and therefore influence the validity and fidelity of simulations.

## Overall Discussion

Results from each research objective showed that VR is a feasible, intuitive, and acceptable tool to test for simple daily living activities and fine motor movements. Limitations in fidelity were determined by the differences in time and perceived difficulty with the task in VR versus the task in RL. It was demonstrated that the lack of haptic feedback is a significant factor when designing tests that require fine motor abilities.

One of the main challenges with cognitive tests relates to practice effects: when the person gets better at the test, not what the test is attempting to measure. The study design of the sorting task helped to reduce practice effects of the task per se, therefore the learning effect observed in VR was classified as a VR effect i.e., participants were getting better at interacting with the VR system. A similar phenomenon was observed in the second study: practice, in the form of overall video gaming experience, also had a significant effect on time to complete tasks.

Those findings are an important contribution to aging research as they pose a challenge to researchers and practitioners when designing the assessments for daily living activities with participants having different experience levels with technology. As discussed in chapter 6, older adults are more technological than ever (Pew Research Center, 2021), but not all older adults adhered to smartphones and computers yet, and certainly not all older adults have experience with video games. On the positive side, VR makes the creation of different testing scenarios easily accomplished, which can contribute to reducing practice effects. Still, as observed in both studies, experience with the system resulted in better performance, and as participants repeat such tests in routine medical exams, not only practice effects must be considered, but also VR-related effects, that could end up becoming a false positive improvement in disease diagnosis.

Being unexperienced with the technology itself can be overcome by providing enough training and practice trials. Performance, measured in time, is likely an important variable to detect small changes in cognition for longitudinal analysis as a part of routine health exams. VR expected times might be determined for some screenings based on times to complete a given task in real-life. For fine motor tasks, time to complete it in VR might even double, which should be accounted for when designing tests. This can also influence cybersickness effects, which was found to be positively correlated with longer VR sessions (Kourtesis et al., 2019).

Screening for the ability to perform daily living activities might also be measured in terms of simply being able to effectively complete tasks. In that case, VR was found to be an intuitive tool to complete simple daily living activities, with simple written instructions being sufficient to grasp how to interact with the VR system, at least for the younger adults.

In summary, the implications of using VR technology to assess the ability to perform daily activities identified by this dissertation included a technology-related learning effect, transferability of video game related skills, and less intuition when VR simulations involve components not-existent in real-life.

## Limitations

Some important limitations of this dissertation are discussed in this section. The sample of older adults that participated in the VR study (Chapter 4) and the technology survey study (Chapter 6) were, on average, highly educated older adults, therefore results might not generalize to the entire older adult population. Future research should include participants with different educational and socio-economical levels.

Small sample size also influenced the power of the conduced analysis. Large sample sizes are a challenge in research with human participants, especially OA, due to time, budget restrictions, and special accommodations.

The use of a cross-sectional design also poses a limitation when it comes to analyzing age effects. Although preferred, longitudinal designs are challenging to be conducted, and with fast technology advancements also likely just starting to be feasible due to the technology becoming recently commercially available. On the other hand, VR devices are now more affordable and commercially available. Therefore, longitudinal studies evaluating the effects of age and technology experience in cognitive decline are expected to be conducted soon. With the current trends in technology usage, strong cohort differences are expected to be seen as well.

## Future Work

Future VR research should investigate ways to compensate for the hardware limitations by improving the input system and/or improving the current software to reduce the gap between fine motor abilities in VR versus RL. It should be investigated if implementing enhancement techniques (such as highlighting the object when player's hand collider and object's colliders are in contact) to the game design could facilitate fine motor tasks in VR. Hand-tracking position could be utilized to compare precision between the different enhancement alternatives as participants aim for a specific object. This can potentially compromise the physical fidelity of the task by making the experience less like the real-life one, but it might reduce the difference in perceived task load.

Hand-tracking data can also help to detect tremors in people with Parkinson's Disease. If incorporated to longitudinal models, it could help with disease-detection and progression by looking at changes in object-selecting precision and variation in hand positioning in terms of frequency, amplitude, and patterns known to be correlated with this disease.

It should also be investigated why there was a gap in performance between younger and older adults. Although observed in the second VR study that gaming experience can significantly affect time, the complexity of the human-computer interaction in the first VR study was not as high as in the second one, which involved using multiple buttons and a locomotion system. It is possible that different cognitive domains influence the interaction with the VR system, therefore a future study should properly identify predictors of VR task performance by incorporating a battery of cognitive tests and evaluate if different cognitive domains can explain variation in performance. Researchers have developed VR devices that can record physiological signals such as electroencephalogram (EEG), which would provide a much clearer analysis of cognitive load. The difference in brain activation when doing the task in RL versus in VR could be investigated, as well as if it activates different brain regions.

The designed task for the first VR study helped participants improve their VR skills for fine motor movements, which was observed by the learning effect present in VR trials. It should be investigated if that specific task could be used to train participants on fine motor skills so it could transfer to VR experiences related to other daily living activities. A longitudinal study should also evaluate retention of the VR-related skills to assess if training prior to assessments should be done on a yearly basis.

Future studies should establish a testing methodology for IADLs that will account for the learning and practice effects, as well as incorporating findings from the conducted survey related to IADL-related tasks. The results from Chapter 6 showed a group of older adults actively using technology to aid on some IADLs such as doing grocery shopping by using delivery or pick up services. This poses an important question related to the criteria defined in IADL assessments to determine if a person is functionally impaired or not. Appropriate assessments of IADLs should be designed based on how the person does a given activity e.g., when grocery shopping, one could physically go to the store or use a technology device to shop.

These IADL assessments can also be combined with other important components of screening techniques to detect disease-related cognitive decline such as cognitive tests e.g., the Montreal Cognitive Assessment (MOCA). The IADL category for food preparation includes planning, preparing, and serving adequate meals. A VR test to assess this specific ability could potentially include a grocery shopping task with memorization of a shopping list; preparing the meal could involve following a specific recipe for a soup or salad, which might involve cutting ingredients (fine motor movements); and lastly, it would be required that the person serves an appropriate meal quantity on a plate. It might not even be necessary to test all activities to identify cognitive deficits, which could facilitate testing in terms of time and resources when implemented at a population-level.

Although this dissertation focused on applications related to older adults, it is relevant to mention other areas of research that could benefit from those studies, including children with neurological disorders, where VR can be used in the form of serious games, i.e., games not only meant for entertainment (Ashwini et al., 2021). In such cases, VR can be used to motivate children when trying to improve hand-eye coordination and fine motor skills. These proposed rehabilitation techniques will also need to be analyzed in terms of feasibility, validity, fidelity, and acceptability and could follow a similar approach conducted in this dissertation.

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# Appendix A - Scales

## Computer Proficiency Questionnaire

**Part 1-** Do you agree or disagree with the following statements

Anchors: (almost) never, rarely, sometimes, often, and very often.

1. In general, I often have difficulty when using my smartphone, apps, websites or computer programs

2. In general, I am not able to solve questions or problems on my own when using my smartphone, apps, website or computer apps

3. In general, I find it hard to adjust settings of my smartphone, apps, websites, or computer programs (for example, privacy or safety settings)

4. In the past six months, how often did you worry that future developed smartphones, apps, websites or computer programs will be too difficult for you to use?

5. In the past six months, how often did you worry that you will find it hard to keep up with using smartphones, apps, websites or computer programs in the future?

**Part 2 -** This questionnaire asks about your ability to perform a number of tasks with a computer, tablet, or smartphone. If you have not tried to perform a task or do not know what it is, please mark "NEVER TRIED", regardless of whether or not you think you may be able to perform the task.

Anchors: never tried, not at all, not very easily, somewhat easily, and very easily

1. Send the same e-mail to multiple people at the same time
2. Use search engines (e.g., Google)
3. Find information about local community resources on the Internet

4. Store e-mail addresses in an e-mail address book or contact list

5. View pictures sent by e-mail

6. Make purchases on the Internet

7. Find information about my hobbies and interests on the Internet

8. Send e-mails

9. Open e-mails

10. Bookmark web sites to find them again later (e.g., make favorites)

11. Read the news on the Internet

**NASA-TLX**

Use the sliders below to report about the task you just did:

Range: 0 – 100

1. How mentally demanding were the tasks?

2. How physically demanding were the tasks?

3. How hurried or rushed was the pace of the task?

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

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

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

**IGroup Presence Questionnaire (IPQ)**

Looking back at your VR experience:

| Statement | Anchors |
|---|---|
| **In the computer-generated world I had a sense of "being there"** | Not at all (-3) – Very much (+3) |
| **Somehow, I felt that the virtual world surrounded me.** | Fully disagree (-3) – Fully agree (+3) |
| **I felt present in the virtual space.** | Fully disagree (-3) – Fully agree (+3) |
| **How real did the virtual world seem to you?** | Completely real (-3) – Not real at all (+3) |
| **How much did your experience in the virtual environment seem consistent with your real-world experience?** | Not consistent (-3) – Very consistent (+3) |

**Simulator Sickness Questionnaire**

Comparing how you were feeling before using the Virtual Reality device and after using it, did you experience any of the following?

Anchors: none, slight, moderate, severe

| | Weight | | |
|---|---|---|---|
| SSQ Symptom | N | O | D |
| General discomfort | 1 | 1 | |
| Fatigue | | 1 | |
| Headache | | 1 | |
| Eyestrain | | 1 | |
| Difficulty focusing | | 1 | 1 |
| Increased salivation | 1 | | |
| Sweating | 1 | | |
| Nausea | 1 | | 1 |
| Difficulty concentrating | 1 | 1 | |
| Fullness of head | | | 1 |
| Blurred vision | | 1 | 1 |
| Dizzy (eyes open) | | | 1 |
| Dizzy (eyes closed) | | | 1 |
| Vertigo | | | 1 |
| Stomach awareness | 1 | | |
| Burping | 1 | | |
| Total | [1] | [2] | [3] |

$$N = [1] \times 9.54$$
$$O = [2] \times 7.58$$
$$D = [3] \times 13.92$$
$$TS = ([1] + [2] + [3]) \times 3.74$$

**System Usability Score**

SUS statements

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

# THE LAWTON INSTRUMENTAL ACTIVITIES OF DAILY LIVING SCALE

### Ability to Use Telephone

1. Operates telephone on own initiative; looks up and dials numbers ....1
2. Dials a few well-known numbers ....1
3. Answers telephone, but does not dial ....1
4. Does not use telephone at al ....0

### Shopping

1. Takes care of all shopping needs independently ....1
2. Shops independently for small purchases ....0
3. Needs to be accompanied on any shopping trip ....0
4. Completely unable to shop ....0

### Food Preparation

1. Plans, prepares, and serves adequate meals independently ....1
2. Prepares adequate meals if supplied with ingredients ....0
3. Heats and serves prepared meals or prepares meals but does not maintain adequate diet ....0
4. Needs to have meals prepared and served ....0

### Housekeeping

1. Maintains house alone with occasion assistance (heavy work) ....1
2. Performs light daily tasks such as dishwashing, bed making ....1
3. Performs light daily tasks, but cannot maintain acceptable level of cleanliness ....1
4. Needs help with all home maintenance tasks ....1
5. Does not participate in any housekeeping tasks ....0

### Laundry

1. Does personal laundry completely ....1
2. Launders small items, rinses socks, stockings, etc ....1
3. All laundry must be done by others ....0

### Mode of Transportation

1. Travels independently on public transportation or drives own car ....1
2. Arranges own travel via taxi, but does not otherwise use public transportation ....1
3. Travels on public transportation when assisted or accompanied by another ....1
4. Travel limited to taxi or automobile with assistance of another ....0
5. Does not travel at all ....0

### Responsibility for Own Medications

1. Is responsible for taking medication in correct dosages at correct time ....1
2. Takes responsibility if medication is prepared in advance in separate dosages ....0
3. Is not capable of dispensing own medication ....0

### Ability to Handle Finances

1. Manages financial matters independently (budgets, writes checks, pays rent and bills, goes to bank); collects and keeps track of income ....1
2. Manages day-to-day purchases, but needs help with banking, major purchases, etc ....1
3. Incapable of handling money ....0

**Scoring: For each category, circle the item description that most closely resembles the client's highest functional level (either 0 or 1).**

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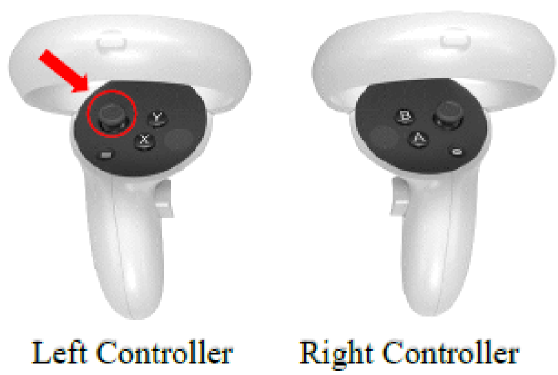
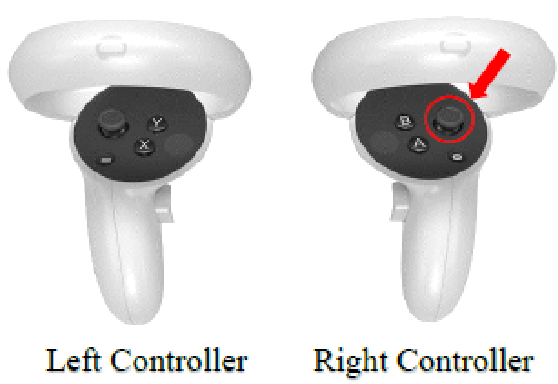
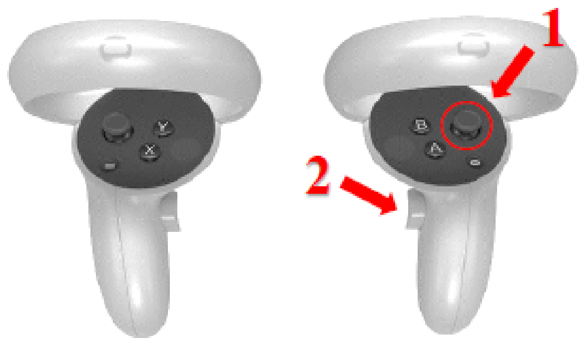
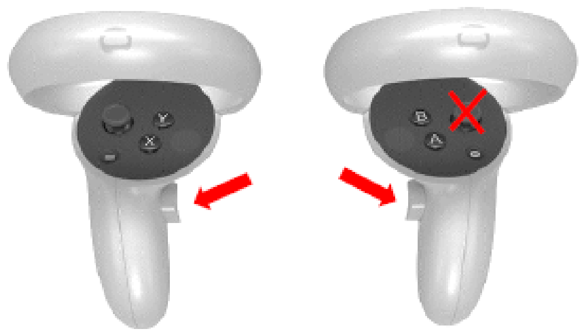
# Appendix B - Instructions for VR Study 2

Overview of the controller elements:

Each controller has a tracking sensor that will follow your hand position. In this game, the only buttons used will be the **trigger buttons**, **grip buttons**, and **joysticks**.


| Goal | Buttons Used | Instruction |
|---|---|---|
| Moving around the scene |   | 1. Use the joystick on the left controller to point towards the direction you want to go. |
| Turning around your player (with the controller) |   | 1. Use the joystick on the right controller by pushing it to the right or to the left. |

<table>
<tr><td>Teleportation to a different area on the scene</td><td><br>Left Controller Right Controller</td><td>1. Rest your thumb on top of the right-hand joystick (1) to enable the red ray light.<br>2. While still touching the joystick, point to a carpeted area. You should see a black target.<br>3. Press the grip button (2) to teleport to the targeted area.</td></tr>
<tr><td>Grabbing objects</td><td><br>Left Controller Right Controller</td><td>1. Make sure your thumb is not resting on the right controller (ray light is not being shown)<br>2. Use the grip button to grab any object.<br>3. Keep holding the button if you want to continue holding the object.</td></tr>
<tr><td>Activating objects (e.g., pressing a button in the scene)</td><td></td><td>1. Grab the object using the grip button (1)<br>2. Press the trigger button (2) to activate the object.</td></tr>
<tr><td>Activating rays to interact with User Interface board</td><td> </td><td>1. Rest your thumb on top of the right-hand joystick (1) to enable the red ray light.<br>2. Use the back trigger button (2) to click on a user interface button.</td></tr>
</table>

# Appendix C - IRB Approvals

KANSAS STATE UNIVERSITY | University Research Compliance Office

TO: Margaret Rys
Industrial & Manufact Sys Engg
Manhattan, KS 66506

FROM: Lisa Rubin, Chair
Committee on Research Involving Human Subjects

DATE: 08/26/2022

RE: Proposal #IRB-10786, entitled "Best practices for Virtual Reality environments used for performance tests of young and older adults."

MODIFICATION OF IRB PROTOCOL #IRB-10786, ENTITLED, "Best practices for Virtual Reality environments used for performance tests of young and older adults"

EXPIRATION DATE: 08/09/2024

The Committee on Research Involving Human Subjects (IRB) has reviewed and approved the request identified above as a modification of a previously approved protocol. **Please note that the original expiration remains the same.**

All approved IRB protocols are subject to continuing review at least annually, which may include the examination of records connected with the project. Announced in-progress reviews may also be performed during the course of this approval period by a member of the University Research Compliance Office staff. Unanticipated adverse events involving risk to subjects or to others must be reported immediately to the Chair of the IRB, and / or the URCO

It is important that your human subjects activity is consistent with submissions to funding / contract entities. It is your responsibility to initiate notification procedures to any funding / contract entity of any changes in your activity that affects the use of human subjects.

Electronically signed by Phill Vardiman on 08/26/2022 4:18 PM ET

**KANSAS STATE UNIVERSITY** | University Research Compliance Office

TO: Margaret Rys
Industrial & Manufact Sys Engg
Manhattan, KS 66506

FROM: Lisa Rubin, Chair
Committee on Research Involving Human Subjects

DATE: 08/22/2022

RE: Proposal #IRB-11107, entitled "Effects of Learning Techniques on Virtual Reality's Usability."

MODIFICATION OF IRB PROTOCOL #IRB-11107, ENTITLED, "Effects of Learning Techniques on Virtual Reality's Usability"

EXPIRATION DATE: 04/06/2025

The Committee on Research Involving Human Subjects (IRB) has reviewed and approved the request identified above as a modification of a previously approved protocol. **Please note that the original expiration remains the same.**

All approved IRB protocols are subject to continuing review at least annually, which may include the examination of records connected with the project. Announced in-progress reviews may also be performed during the course of this approval period by a member of the University Research Compliance Office staff. Unanticipated adverse events involving risk to subjects or to others must be reported immediately to the Chair of the IRB, and / or the URCO

It is important that your human subjects activity is consistent with submissions to funding / contract entities. It is your responsibility to initiate notification procedures to any funding / contract entity of any changes in your activity that affects the use of human subjects.

Electronically signed by Phill Vardiman on 08/23/2022 11:37 AM ET