MSc INDIVIDUAL PROJECT

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Leap-piano, a tool to assess multisensory perception in patients with mild Alzheimer's disease.

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Abstract

Background： The prevalence of Alzheimer's disease is steadily increasing year after year, causing irreversible damage to the patient's brain. The most significant manifestation of this damage is the decline in the patient's memory capacity. Traditional medication methods and memory training techniques have proven to be only partially effective. Alzheimer's patients are in urgent need of a new, multi-modal memory training method that meets their behavioral and psychological characteristics.

Objective： The purpose of this study was to design and evaluate the feasibility of a multimodal approach for patients with Alzheimer's disease and older adults with the aim of assessing their multimodal perceptual abilities. This study aims to provide practical and theoretical support for the final study by testing their multimodal perceptual abilities.

Methods： Leap-Piano is a gesture-controlled piano playing game designed to assess multisensory (visual, auditory, and tactile) abilities in older adults or people with Alzheimer's disease. It reflects the level of coordination and response between the senses.

Results： The Leap-Piano can assess the multisensory abilities of people with Alzheimer's disease. Notably, some participants reported that the Leap-Piano had a certain amount of fun and brought a range of positive emotions such as joy.

Conclusion： The results of the study suggest that memory training using a multisensory approach is feasible. Older adults and people with Alzheimer's disease retain some perceptual abilities in certain senses.

Acknowledgements

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Introduction

Background- Alzheimer's disease

Dementia is a syndrome that can be caused by several diseases, with Alzheimer's disease (AD) being the main contributor (60%) to the development of dementia (R. Overshott & A. Burns, 2005). Currently, there are more than 50 million people living with dementia globally (Anders Gustavsson et al., 2022). in 2019, there are 14.1 million people living with the disease in Europe and 10.3 million in the Americas (World Health Organization Global Action Plan for the Public Health Response to Dementia 2017-2025 report).

Alzheimer's disease is the leading disease in the elderly population with a prevalence of 10-30% among people aged 65 and over. Alzheimer's disease is also one of the top four causes of disability-adjusted life years (DALYs) lost in people aged 75 and over (Anders Gustavsson et al., 2022).

According to the International Society for the Advancement of Alzheimer's Research and Treatment (ISTAART), Alzheimer's disease causes irreversible and fatal damage to a patient's neurobiology, leading to negative physical and psychological changes. This can lead to neurobehavioral and psychiatric symptoms (NPS) such as depression, apathy, aggression, and psychosis, as well as cognitive decline and memory deficits, which are core features of Alzheimer's disease (Xiao-Liang, 2014).

Notably, memory impairment is particularly prominent compared to other ADD symptoms. Although the degree of impairment varies from person to person, the impact on the patient is profound. In clinical practice, it is widely recognized that symptoms triggered by ADD begin with memory impairment. As the hippocampus, which is responsible for the integration of short-term and long-term memory, atrophies, patients with ADD progressively develop language deficits, intermittent feelings of hopelessness, cognitive decline, and eating disorders (Holger Jahn, 2013). Improving memory deficits in patients with ADD becomes particularly important.

1.1 Alzheimer's Disease Memory Loss Treatment Methods

There are two main approaches to treating memory impairment in elderly dementia:

1) Pharmacological Treatment: Acetylcholinesterase inhibitors (ChEIs) are drugs used in the treatment of central nervous system degenerative diseases and are currently the preferred medication for addressing memory loss associated with Alzheimer's disease (AD) (R. Overshott & A. Burns, 2005). ChEIs work by inhibiting the breakdown of acetylcholine in the brain, thereby increasing the levels of acetylcholine in nerve cells to enhance memory. However, their effects are limited to alleviating or slowing down symptoms and cannot completely cure the memory loss caused by Alzheimer's disease (Boustani MA, 2008). According to feedback from the National Health Service (NHS) in the United Kingdom in 2001, approximately 35% of Alzheimer's disease patients experienced drug side effects, such as nausea, diarrhea, muscle spasms, and intestinal ulceration, after using ChEIs. This has led to some patients developing resistance to the medication (R. Overshott & A. Burns, 2005).

2)Non-Pharmacological Interventions: Since pharmacological therapy is not effective in intervening in Alzheimer's disease and can lead to a range of drug side effects, researchers have been exploring non-pharmacological treatment methods for Alzheimer's disease patients since the early 21st century. Currently, non-pharmacological therapies primarily include two types: standard therapies and alternative therapies (Ballard et al., 2001).

1.2 Non-pharmacological interventions.

1.2.1 Standard therapies

Standard therapies are non-pharmacological treatments based on the principles of human conditioning, using methods designed to inhibit or direct negative behaviors triggered by illness (La Vigna & Donnellan, 1986). Standard therapies include Behavioral therapy, Reality orientation, Validation therapy and Reminiscence therapy. (Simon Douglas, Ian James, 2004).

1.2.2 Examples of typical standard therapies

Among the standard approaches is a therapy called Reality orientation, which was originally described as a technique used to improve the quality of life of older people (Taulbee & Folsom, 1966). This therapy is designed to help individuals who are cognitively impaired or suffer from cognitive disorders, such as older adults or those with Alzheimer's disease, by helping patients stimulate memories of time, place, and their own identities, and can help patients stay connected to the world around them by emphasizing reality and stimulating memories. (Cosin, Mort, Post, Westropp, and Williams 1958).

Professor Kiran Ijaz of Macquarie University, Australia, has combined reality orientation and reminiscence therapy and utilized virtual reality (VR) to train spatial navigation memory in AD patients. The design trains short-term memory skills in older adults to help them enhance their perception of place and space. In his design, the user is asked to follow a navigation starting position and is asked to recognize six landmarks distributed along a specified navigation path. Recall training in the form of VR navigation will be performed during the user test, and the results of the completed test can also be used to assess the prevalence of dementia, and the biosignal data generated during the test will be collected for clinical medical use through the Google BioBracelet (Kiran Ijaz et al, 2019). This is a classic case on reality orientation, in this project Prof. Kiran Ijaz has enabled older adults to strengthen memory of real locations to aid wayfinding in AD patients by training them to use a head-mounted virtual reality device through a reality-orientated design.

Figure 1: From left to right, The detail of the non-pharmacological therapies, Kiran Ijaz‘s work （reality orientation）

1.2.3 Alternative therapies

Alternative therapies are non-pharmacological treatments aimed at intervening and treating emotional disorders or negative behaviors triggered by illnesses by means of external stimuli or guidance. (La Vigna & Donnellan, 1986) Alternative therapies include art therapy, music therapy, activity therapy, complementary therapy, aroma therapy, and bright light therapy. Complementary therapy, Aroma therapy, Bright-light therapy, and Multisensory approaches. (Simon Douglas & Ian James, 2004).

1.2.4 Examples of typical alternative therapies

Typical alternative therapies in a more typical approach are music therapy, which is a professional therapy that uses music and musical activities to promote healing and mental health on physical, emotional, cognitive and social levels. Music therapies are typically offered by professionally trained and certified music therapists who use music as a tool to meet the specific needs and therapeutic goals of their patients. (Felicity Baker, 2004) Music therapy enables people with AD to improve emotional expression problems and mood management, enhance cognitive functioning of the brain, and promote physical rehabilitation and motor coordination. A music therapy video game designed by Prof. Mélodie Boulay of the University Descartes in France, which uses a Wiimote Pistol to aim and shoot at a virtual keyboard, is typical of this therapeutic approach. This program engages AD patients in music composition and music therapy by using a toy pistol to shoot at a virtual target, and it also allows AD patients to play the game enough to rapidly improve their own cognitive-motor skills and short-term quick memory (Mélodie Boulay, 2017).

However, while the design elements proposed by the above scholars can have a positive effect on older adults with Alzheimer's disease in both the level of wayfinding and cognitive enhancement, how can we better slow down the memory loss of Alzheimer's patients, even more than just starting with the functional loss of Alzheimer's patients, but rather the progression of Alzheimer's disease by slowing down the loss of functioning of the patients? But Alzheimer's is a very complex disease, and in order to better mitigate memory loss in AD patients I hope to use Multisensory to design and provide multidimensional (multisensory) intervention therapies for AD patients that are more in line with their physical and psychological characteristics.

1.3 Multi-sensory design

Multi-sensory experience design is a design approach that considers the different human senses and their interrelationships when designing an experience. (Marianna Obrist, 2017) is defined as "the impression formed on a particular thing that is artificially created by using sensory elements" (Velasco , 2020) For example, in order to create a person's impression of a sunflower, the taste, texture and color can be designed in a way that, from the sunflower's unique attributes that reinforce the impression of itself. (e.g., an art exhibition, Vi et al., 2017) Multi-sensory experience mainly involves the synergistic action of multiple sensory channels to enhance the perceptual experience from multiple dimensions (touch, hearing, sight, smell and taste). (Marianna Obrist et al, 2017)

1.3.1 Classification of multisensory perception

Multimodal experience classifies human sensory perception into two categories, physical perception (visual, tactile and auditory) and chemical perception (olfactory and gustatory). (Emanuela Maggioni, 2016)

(1) Physical sense: perceiving and interpreting external stimuli and information from the physical world through the sense organs (eyes, ears, skin, etc.). Physical sense includes touch, sight, and hearing.

Sense of Touch: Through different sensory cells in the skin, it allows people to perceive temperature, pain, and stimuli, and can help people better perceive and understand the texture and temperature of objects.
Sense of Visual: Visual perception is the ability to perceive information through the eyes. Through the retinal photoreceptor cells in the eye, a person can convert sensory fibers into visual images, enabling them to see objects, colors, and shapes.
Sense of Voice: Hearing is the ability to perceive sound through the ears. The cochlea in the ear has auditory receptors that convert sound waves and air vibrations into neural signals, allowing people to hear the different characteristics of sound.

(2) Chemical sense: An organism perceives and interprets external stimuli and information from chemical substances through its sense organs. Chemical sense includes taste and smell.

Sense of Smell: The olfactory receptors inside the nose recognize chemicals that are not used to emanate from substances, which in turn enables a person to sense and identify different odors.
Sense of Taste: Taste is the ability to perceive flavors through the mouth. Taste buds in the mouth allow the person to perceive chemicals in food, which in turn allows the person to perceive different flavors such as sour, sweet, bitter, spicy, and salty.

The behavioral characteristics of people with dementia (impaired brain structure and function, cognitive decline, impaired perception, etc.) can lead to impaired chemoreception with age and dementia's destruction of the nerves in the brain (trigeminal system), resulting in symptoms such as reduced sensitivity to odors and anorexia. (Claire Murphy, 2009) Thus a design using chemical perception may not be effective in assessing the extent of memory intervention for people with AD. Interventions designed for the psychological characteristics of people with dementia (depression, irritability, agitation, fantasy etc.) need to be low stimulus. Whereas interventions for dementia using physical perception (passive perception) may achieve better results, research has demonstrated that although people with AD have reduced perceptual abilities, they still talk about retaining a greater ability to perceive and understand tangible objects (objects, images, colors, and sounds). (Marshall & Line, 2014).

Therefore, I would like to incorporate visual, auditory, and tactile senses into multisensory therapy to provide a non-pharmacological intervention method of memory training for people with AD through visual art therapy (visual), music therapy (auditory), and tangible interaction (tactile).

2 Literature review

2.1 Psychological and Physical Characteristics of Alzheimer's Disease

Alzheimer's disease is different from other diseases of the elderly, it will have an impact on the psychological and physiological characteristics of the patient, in order to better study the multimodal interaction and apply it in the Alzheimer's disease to give rational intervention, the first thing we need to do is to study the psychological and physiological characteristics of Alzheimer's disease patients.

2.1.1 Psychological Characteristics of AD

The psychological characteristics of Alzheimer's disease affecting patients mainly include four factors, namely, personality, behavior, spirituality, and emotion, which lead to changes in the personality and psychological state of dementia patients. (A,Mirakhur & D.Craig, 2004)

1. personality factors: these include depression, anxiety, irritability, irritability, emotional instability, irritability, and aggression.
2. behavioral factors: these include apathy, abnormal motor behavior, sleep disturbances, and eating disorders.
3. psychotic factors: including delusions and the presence of hallucinations.
4. Emotional factors: bipolar disorder is present. Bipolar disorder, also known as manic-depressive disorder, can cause extreme mood swings, including high (mania or mild mania) and low (depression) moods. (Reilly-Harrington NA et al, 2016)

2.1.2 Physiological features of AD

Dementia leads to a range of changes in the physiological characteristics of the patient, which are mainly produced by damage to the brain structure, and these damages also progressively worsen as the disease progresses. (Tom Kitwood, 2008) These physiological changes include:

1) Memory loss due to impaired brain function: dementia causes irreversible structural damage to the brain, including degeneration of neurons, disruption of neuronal connections, and impaired function of different brain regions. For example, the hippocampus, which is

associated with memory, usually shows significant atrophy in dementia patients, leading to severe impairment of memory function. (Hanna Rosenmann, BioMed Research International, 2014)

2) Communication Disorders and Behavioral Problems: dementia can lead to negative changes in mood and behavior, and according to the International Society for the Advancement of Stimulation of Alzheimer's Disease Research and Treatment (ISTAART), Neuropsychiatric Symptoms (NPS) such as depression, apathy, aggression, and psychosis, which are now considered to be the core features of Alzheimer's Disease (AD), can block an AD sufferer's interaction with others, and cut off the person's access to society. and cuts off the person with AD from society. The severity of social impairment symptoms and loss of independent personality are positively correlated with the rate of progression of Alzheimer's disease. (Xiao-Liang, 2014,)

2.2 Multi-sensory intervention methods

Multi-sensory interaction can cope with different physical and psychological symptoms of Alzheimer's disease, for the psychological characteristics of AD patients can use multi-modal interaction (haptic) to provide them with emotional support, for the behavioral characteristics of AD patients multi-modal interaction (visual and auditory) can provide them with effective memory training methods.

2.2.1 Memory training method with multimodal interaction (visual) - image mnemonics

Visual short-term memory is defined as the ability to retain a small amount of visual information (letters, shapes, colors, etc.) over a short period of time. This type of memory is part of short-term memory (STM). (Duncan E. Astle, 2010) For people with AD, Alzheimer's disease can cause damage to visual short-term memory, which is rapid and the most severe of the many types of memory impairments, which can lead to behavioral symptoms such as dyslexia, indirect amnesia, dyscalculia, face blindness, and language deficits, and can greatly affect a person with AD's daily life. (Mario Parra, 2016) Therefore, it is particularly important to train patients' visual short-term memory through image mnemonics.

Image mnemonics is a kind of eye-brain combination memory, and its core method lies in mobilizing the brain for memory through visual stimulation. It was first used in early childhood education and is the simplest and most effective way to aid memory. 2020, Seo Jung Yun, a researcher at the School of Rehabilitation Medicine at Seoul National University Hospital in South Korea, developed a virtual crop harvesting and cooking memory training game using virtual reality (VR) technology in order to improve short-term memory in AD patients through gaming. Seo Jung Yun invited physical therapists, patients with mild cognitive impairment, and patients with mild dementia to test and experience the program to evaluate its feasibility and usability for memory training. In Seo's program, patients interact with the environment and objects from a self-centered perspective (i.e., the "first-person perspective"), and they can choose different levels of difficulty for memory training in a game that has three levels of difficulty (difficulty increases with each step): nori rolls (11 steps), omelette (12 steps), and bolognese stew (14 steps). (14 steps). In the game, the patient needs to get the ingredients from the farm and cook the dish according to the recipe in the game, which means that the participant needs to memorize the images of the ingredients in the recipe (image memory) and recall the characteristics of the ingredients (color, shape) in the farm and select the correct ingredients. During the cooking process the patient needs to recall the preparation steps in the recipe (step memory) and needs to follow the correct steps to cook it out (process memory).The game process designed by Seo focuses on training the patient's visual short-term memory, working memory capacity, spatial memory capacity, and process memory capacity. (Seo Jung Yun1, MS & Min-Gu Kang1,2020) validated the feasibility and usability of the method based on evaluations and reports from physical therapists, patients with mild cognitive impairment, and patients with mild dementia.

2.2.2 Multimodal Interactive (Auditory) Emotional Support - Music Therapy

The World Federation for Music Therapy (WFMT) defines music therapy as "a professional therapeutic approach to the use of music and its elements for healing in medical, educational and everyday settings for people seeking to optimize their quality of life and to improve their communication, emotional and spiritual well-being. "

Essentially, listening to music reduces stress hormones, such as cortisol, which can help people cope with, for example, pre-operative stress, and bring emotional relaxation to patients. For people with AD, having music therapy can be soothing and have a positive impact on emotional well-being (Brotons, 2000). In terms of memory, music therapy can bring back memories of life experiences and emotional experiences. (Jenny T van,2018) In the case of people with severe dementia (loss of speech function and language recognition), familiar music will provide them with a sense of security and well-being as musical memories are stored longer than memories without musical accompaniment during the same period of time (Baird, 2009 & Broersen 1995) conversely familiar musical rhythms will help dementia patients to organize time and space. Music-based interventions may positively affect dementia patients to varying degrees.

Prof. Maarten Houben of the University of Eindhoven in the Netherlands presented a music therapy product that provides emotional support for people with AD. (Enriching Everyday Lived Experiences in Dementia Care, Maarten Houben et,al, 2022) A textile cushion called VITA, which the designers equipped with conductive sensors inside, plays audio content based on touch-based inputs, and AD patients can Play meaningful (e.g., barking enough, calming ambient sounds) audio content with their relatives or caregivers to calm the AD patient's agitation. Caregivers are also able to personalize and control the experience for the patient through an online interface (recordings of family members, familiar songs.) Maarten wants to stimulate positive emotions and stimulate the exploration and expression of the identity and self of the person with dementia through music and sound and to apply these beneficial sound effects to the care environment of the person with dementia. (Maarten Houben & Rens Brankaert et,al, 2020).

2.2.3 Emotional guidance of multimodal interactions (haptics) - tangible interactions

Prof. Maarten Houben also mentioned an emotionally designed smart product that enhances the social connection of people with dementia during social events in nursing homes. The SAM Interaction Buddy, a product that enhances the social connection of people with dementia during social events in nursing homes, is designed as a semi-transparent sphere and can be touched according to the way the user touches it (holds, taps, clicks or shakes) changes color, vibration and sound. When two SAM devices are linked together, they respond together to user input and provide a sense of connection between the users of the SAM. When the SAM responds to user input, it sends a signal to the other SAM device, which responds or interactively translates it to the user (e.g., when one SAM is touched and the other is not, the other SAM emits a frustrated face or a lost voice to stimulate the user to engage in interactive behavior).SAM can provide social support for older adults living in nursing homes and can encourage and motivate older adults to engage in social activities.(Maarten Houben & Rens Brankaert et,al, 2020)

In addition to providing memory training, emotional support, and emotional guidance for people with AD from a multisensory interaction perspective, it is particularly important to consider stakeholder design, and it is worth noting that the majority of people with AD have one or more family caregivers who spend a great deal of time and energy caring for them, leading to the development of psychological disorders and poor health outcomes. While designing for people with AD I also hope to help the stakeholders of people with AD through stakeholder design.

2.3 Stakeholder design (Stakeholder design)

Stakeholders of Alzheimer's disease include individuals, organizations, and entities that have a direct or indirect connection to the disease, which can specifically be patients, family members and caregivers, medical personnel and health care providers, and social and community organizations. Alzheimer's disease, while devastating for people with AD, also negatively impacts these stakeholders, with family members and caregivers being the most impacted.Data from a 2019 Alzheimer's Association (USA) survey suggests that globally there are 230 million people with AD family members and caregivers provide approximately 1.86 billion hours of unpaid care for people with AD (caregiving is valued at approximately $234 billion), and that 34% of caregivers experience emotional stress, anxiety, and depression while performing caregiving tasks, and 22% of caregivers' health is negatively impacted. (Alzheimer's Association, 2019) In the social context of the increasing severity of Alzheimer's disease, people with AD and their stakeholders are suffering immensely, thus applying stakeholder design in the design process is necessary.

2.3.1 Definition of stakeholder design

Stakeholder design is a multi-faceted design approach that serves the needs and expectations of stakeholders in design, reducing potential conflicts and improving project success by proactively meeting stakeholder needs.

A prime example of the use of stakeholder design in AD is the Wearable Lullaby designed by scholar Elizabeth H. Ehleringer. Elizabeth's research introduces a wearable Lullaby she designed to improve the lives of people with AD and their caregivers. quality of sleep for people with AD and their caregivers. It's worth noting that according to Elizabeth's research 70% of caregivers said that sleep deprivation was a major factor in the decision to place a loved one in a nursing home. This is because people with dementia are more awake at night than during the day (day-night reversal syndrome.) Elizabeth uses Simulated Presence Therapy (SPT) and Human-Computer Interaction to allow caregivers to create personalized audio (a recording of a family member or caregiver, such as soothing words) for the person with dementia that can be used to " replicate the caregiver's presence," which Elizabeth plays on an MP3 player for the patient, and which can calm agitated dementia patients at night and put them back to sleep to reduce disruptive behaviors during the night. The Wearable Lullaby has been shown to be effective in reducing sleep disturbances and caregiver burden for people with dementia who wake up frequently during the night and keep their caregivers awake, and Elizabeth's use of stakeholder design to provide a solution to the symptoms of insomnia in people with AD has resulted in a benefit to the stakeholders of people with AD. And that's what I'm hoping for.

2.3.2 Reasons for using stakeholder design.

There are three reasons why I expect to apply stakeholder design on Alzheimer's intervention:

(1) Stakeholder design can take into account the needs of different stakeholders, and I expect to use stakeholder design for the well-being of multifaceted Alzheimer's stakeholders (patients, family members, and caregivers).

(2) Stakeholder design can provide me with valuable feedback because family members and caregivers, as the group of stakeholders who have been in contact with people with AD for the longest period of time, are familiar with the behavioral patterns and psychological characteristics of people with AD, and it is necessary to take into account their voices (feedback) and opinions, and the feedback they give may result in a more appropriate intervention therapy for people with AD.

(3) The use of stakeholder design can enhance the connection between different stakeholders. Stakeholder design can facilitate communication and understanding between different stakeholders and enhance understanding of people with AD from different identity perspectives in order to resolve potential conflicts between people with AD and stakeholders.

2.3.3 Summary of Literature Review

As the global trend of aging is on the rise, over 50 million elderly individuals suffer from Alzheimer's disease. Among them, 26% exhibit symptoms of memory loss (Holger Jahn, 2013). I aim to address the issue of impaired memory through Human-Computer Interaction (HCI). While many scholars have used designs focusing on a single sense to help Alzheimer's patients regain their memory, the use of multiple senses proves to be a more effective approach. In future research, I aspire to design a multimodal memory training smart toy to enhance the memory capabilities of Alzheimer's patients. In the multimodal domain, I incorporate visual, auditory, and tactile elements, integrating therapeutic approaches corresponding to each sense.

(1) Through visual—graphic memory training, I aim to enhance the short-term memory of Alzheimer's disease (AD) patients and impact overall memory abilities.
(2) Through auditory—music therapy, I intend to involve AD patients in music creation activities to alleviate emotional issues associated with AD.
(3) Through tactile—tangible interaction, I aim to promote social interaction among elderly AD patients and reduce digital aversion.

However, at the current stage, I must conduct empirical research on the use of multimodal interventions for Alzheimer's patients and assess the three perceptual abilities of Alzheimer's patients. To achieve this, I have designed a gesture-controlled music game called Leap-Piano. This game serves to test the three perceptual abilities of Alzheimer's patients and explore the feasibility of applying multimodal approaches to memory training and virtual keyboard tactile interaction.

3.Design

3.1 Design Purpose

Utilizing Leap Motion gesture control technology and the Unity game engine, I want to create a gesture-controlled music game to test the multimodal perceptual abilities (visual, auditory, and tactile) of Alzheimer's disease patients. Additional evaluations will be conducted based on subjects' performance (engagement, test data feedback) to further assess the feasibility of virtual keyboard tactile interaction for individuals with Alzheimer's disease.

3.2 Gesture Control

The Leap Motion Controller (LMC) is an interaction technology that tracks and identifies gestures using an infrared camera and infrared LEDs. It captures movements of hands and fingers (such as fist, gestures, palm, hand direction, and position), enabling users to control computer applications through gestures.

3.2.1 Technical Limitations of Leap Motion Controller

However, the LMC exhibits a certain degree of latency. Silva et al. addressed this issue by designing a Digital Musical Instrument (DMI) using LMC and measuring its latency with scripts written in Java. In Silva's study, all digital instruments designed using LMC had latency (20 milliseconds in high-precision mode, 10 milliseconds in balanced tracking mode, and 5 milliseconds in high-speed mode). The study also mentioned that, in music games, the minimum acceptable latency for players should be less than 20 milliseconds, making it necessary to choose slow-paced music. To reduce latency, the manufacturer's blog suggests that switching from a USB 2.0 port to a USB 3.0 port can increase the frame rate by 1.5 times per second, significantly reducing real-time latency. Therefore, when designing digital instruments using LMC, it is advisable to choose music with a slow rhythm and use a USB 3.0 port.

3.2.2 Leap Motion Controller Project Design

I conducted two rounds of project design:

In the initial design iteration, I aimed to complete my project by integrating Leap Motion Controller (LMC) with TouchDesigner (TD). I created two art projects related to gesture control, importing the root directory of LMC into TD and establishing LMC nodes in the CHOP (Channel Operator) network. I utilized LMC to detect the tx, tz, and ry values of hand movements, converting them into digital signals transmitted to the Geo node. This implementation enabled visual image zooming, shrinking, and rotation based on the tx, tz, and ry values. Additionally, I used AudioAnalysis to import and process music, converting high and low amplitude information into digital signals for basic music control.

However, after communication with stakeholders, I found that the output of this assessment resembled more of a digital art piece and did not fully meet my design objectives. Consequently, I further planned the assessment output and requested that the new design output should incorporate data collection functionality to assess the multimodal perceptual abilities of Alzheimer's disease patients. Moreover, I need to consider the project's entertainment value and user-friendliness to address the concerns of care for Alzheimer's patients.

3.2.3 Design References and Second Design Output

In the second design iteration, I drew inspiration from various similar designs, with a notable reference being the rhythm-based music game. In playing such games, players must engage three senses simultaneously. Rhythm-based music games aim to stimulate brain control over hand movements through simultaneous feedback from visual imagery and music rhythm. These games assess players based on completion, error rate, and precision (Perfect Combo), criteria that can also demonstrate the players' three perceptual abilities.

Previously, I had experience in music game development, albeit in a different context. In a previous project, I used VR devices for physical therapy with patients suffering from shoulder periarthritis. However, after reviewing Kiran Ijaz's assessment of VR usability for the elderly, I rejected the idea of using VR for this design. VR interaction for Alzheimer's patients may be overly sophisticated, and considering cognitive impairment is a common symptom of Alzheimer's, the design and testing evaluation for Alzheimer's patients must "de-intellectualize." Additionally, VR usage may lead to issues like dizziness and photosensitive epilepsy, which are factors I needed to consider.

While seeking design inspiration, I found an open-source project related to Leap Motion MDI (Musical Instrument Digital Interface) piano in the open-source community. I aimed to combine the MDI keyboard with a rhythm-based music game to create a Leap Motion music game that could assess participants' multimodal perceptual abilities. I integrated Leap Motion with Unity, ensuring that it not only met my assessment requirements but also provided a certain level of game enjoyment.

3.3 Unity Game Design

I imported Unity Assets from the Leap Motion Controller (LMC) Software Development Kit (SDK) into the Unity project and added a Leap Motion Rig object to the scene to enable control of game actions using LMC. To simplify game interaction, I reduced the number of interactive cases from the original open-source files to 10, corresponding to the 10 fingers of a person, thereby easing the interaction difficulty for participants. Additionally, I created a few motion effects, lowered the scene's brightness, and reduced neon lighting to minimize the likelihood of photosensitive epilepsy seizures triggered by the game.

The production process involved three steps:

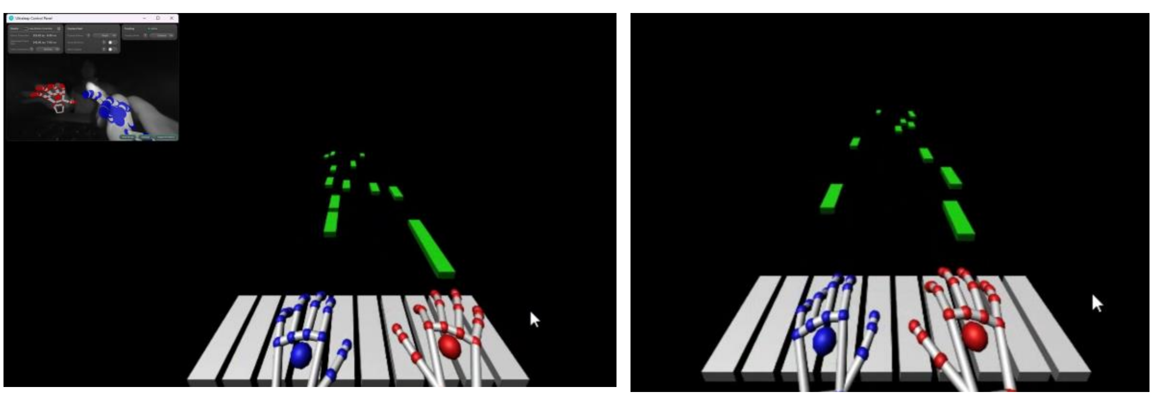
1）Basic Functionality Implementation:
In the open-source project files, basic code files were available, requiring slight modifications to be applied and meet the game's basic requirements. To align the game with the physiological characteristics of Alzheimer's patients, I configured the Leap Motion Rig to increase hand tracking range and reduce triggering conditions, thus lowering the operational cost for Alzheimer's patients.

2）Generation of Objects According to the Musical Rhythm:
Using the Koreographer plugin from the Unity store, I edited the music and generated beats. In Koreographer's audio editor, I added object generation events at each beat. Notably, as this is a rhythm-based

music game with a discrepancy between object generation time and player interaction timing, players must interact with objects at the rhythm points in the music. Koreographer cannot achieve this automatically, so I had to manually calculate and set the generation time and interaction time.

3） Creation of Motion Effects:
The creation of motion effects served two main purposes: firstly, to enhance the sense of interaction for virtual keyboard controls, addressing the issue of delayed interaction feedback inherent in virtual keyboard controls. Secondly, to increase the game's entertainment value. However, considering the potential for photosensitive epilepsy, it was necessary to reduce the overall scene brightness and set intervals for the light flickering in motion effects.

Design Summary: Through self-evaluation, I rejected my initial design output and thoroughly reconsidered the design requirements. In the second design iteration, I drew inspiration from rhythm-based music games and created a virtual piano rhythm game (Leap-Piano) （TableA） through the connection of Leap Motion and Unity. With Leap-Piano, I aim to assess the multimodal perceptual abilities of Alzheimer's patients.



TableA： Leap-Piano Photo Demo

4.Methodology

4.1 Participant Recruitment

For participant recruitment, I considered two approaches, Plan A and Plan B. Due to the constraints of this assessment test—lack of sponsorship, limited time, and conditions—Plan A might encounter obstacles during implementation. Therefore, after careful consideration, I opted for Plan B for practical testing. In my subsequent academic career, I plan to refine this study according to the original Plan A.

Plan A:

Participant Selection: Choosing individuals diagnosed with mild Alzheimer's disease from nursing homes or healthcare hospitals as research subjects.

Recruitment Channels: Randomly selecting participants from three nursing homes or healthcare institutions, controlling variables such as age, dementia severity, and cognitive level using a controlled variable method to maintain consistency in specific variables and the randomness of participant recruitment.

Plan B:

Participant Selection: Mild Alzheimer's patients and stakeholders for a small-scale test (3 elderly dementia patients with memory impairment, 1 caregiver, and 1 psychological counselor). Specifically recruiting caregivers and a psychological counselor.

Recruitment Channels: Three elderly dementia patients, average age 65 (Community Rehabilitation Service Center, Liangdao Street, Wuhan

City, Hubei Province, China). One caregiver (Liao.S, Community Rehabilitation Service Center, Liangdao Street, Wuhan City, Hubei Province, 48 years old, 8 years of caregiving experience). One psychological counselor (Winston.W, University of Sydney, Australia).

4.2 Design of Experiments

Experimental Method:

Caregiver Liao.S was responsible for conducting a 6-day assessment test offline for the three mild dementia patients. Each participant underwent visual, auditory, and tactile assessments using Leap-Piano at different time points to gather information on the perceptual abilities of the three senses within the same participant group.

Assessment Content:

Multisensory assessment using the Leap-Piano sensory assessment device:

1) Visual: Assessing visual sensory flexibility through Leap-Piano reaction speed.
2) Auditory: Evaluating keyboard accuracy (coordinated with the interaction timing of musical rhythms).
3) Tactile: Comprehensive assessment of reaction speed and accuracy. This assessment includes the synergy of visual and tactile senses.

Brain-Workshop Professional Program Assessment:
Visual: Using Brain-Workshop for visual ability assessment.
Auditory: Employing Brain-Workshop for auditory ability assessment.

Data Collection and Processing:

All participants followed a sequence: (1) Research introduction, (2) Pre-test questionnaire, (3) Medical history survey, (4) Leap-Piano test, (5) Brain-Workshop test, (6) Test feedback. Phases 4 and 5 spanned 6 days, with an average test duration of 10 to 15 minutes each.

Leap-Piano and Brain Workshop Tests:

Conducting two multimodal assessment tests on the same individuals, utilizing Leap-Piano for sensory assessment, and recording and processing data in SPSSPRO. Employing Brain-Workshop for professional program assessment and comparing the data collected by Leap-Piano to validate the accuracy of Leap-Piano assessment data.

After the conclusion of the assessment tests, conducting semi-structured interviews with a psychotherapist and caregiver through Tencent Meeting. These interviews aimed to explore the performance of the three perceptual abilities of the participants based on assessment data. Additionally, through interviews, gaining in-depth insights into the perspectives and needs of different stakeholders regarding Alzheimer's patients in nursing home environments.

4.3 Results

4.3.1Assessment Ability and Outcome

Leap—Piano Data Collection Results:

Participants were recruited from a community service center in Wuhan, China. They were patients diagnosed with mild Alzheimer's disease by medical institutions, with an average age of 65 years. All participants were informed about and consented to this study, and the study received approval from the author's university ethics committee. Participants underwent a six-day multisensory perceptual ability test using Leap-Piano. Three subjects used the same equipment and completed the tests within the specified time.

Table 1: The data results for the three participants using Leap-Piano for six days show that participants' visual perceptual abilities (reaction speed), auditory perceptual abilities (accuracy), and tactile abilities (comprehensive feedback) are proportional. The algorithm for comprehensive ability is 130 (number of interactive targets) * accuracy percentage / reaction speed. It is worth noting that Participant C, who has mild visual impairment (mild glaucoma), had a slight impact on the research data. However, the overall data indicates that even with partial impairment of perceptual abilities, participants still possess perceptual abilities in other sensory .modalities.

Table 2: Data Results for Three Participants Using Brain Workshop for Six Days. Brain Workshop records daily visual and auditory performances and processes the data into tables. Through the analysis and summary of data from Brain Workshop, I can directly assess visual ability (Position) and auditory ability (Sound).

Participant A	Visual (reaction speed)	Auditory (Accuracy)	Touch (Integrated assessment)
Day1	1567ms	0.43	3.567
Day2	1787ms	0.392	2.837
Day3	1531ms	0.523	4.44
Day4	1467ms	0.46	4.076
Day5	1252ms	0.57	5.918
Day6	1287ms	0.535	5.404
Participant B	**Visual (reaction speed)**	**Auditory (Accuracy)**	**Touch (Integrated assessment)**
Day1	1267ms	0.5521	5.643
Day2	1124ms	0.5741	2.837
Day3	1365ms	0.5277	5.025
Day4	1527ms	0.51	4.341
Day5	1721ms	0.3922	2.945
Day6	1387ms	0.515	4.826
ParticipantC	**Visual (reaction speed)**	**Auditory (Accuracy)**	**Touch (Integrated assessment)**
Day1	2267ms	0.2921	1.662
Day2	1923ms	0.3241	2.163
Day3	2329ms	0.1942	1.084
Day4	1743ms	0.228	1.715
Day5	1479ms	0.352	3.074
Day6	2188ms	0.3392	2.015

Table 1: The data results for the three participants using Leap-Piano

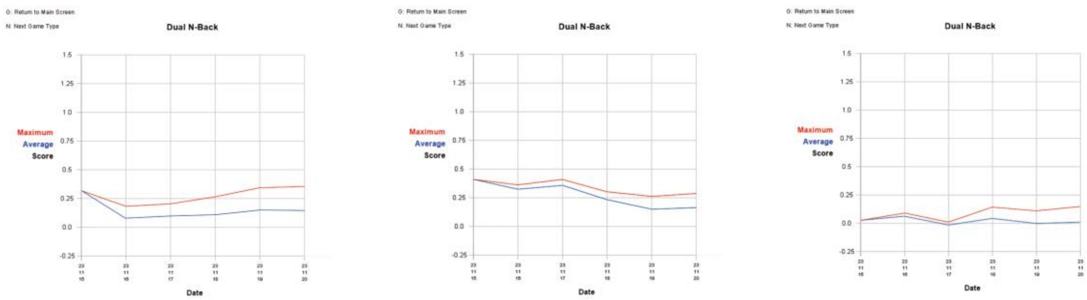


Table 2: Data Results for Three Participants Using Brain Workshop

4.3.2 Data Processing:

I compared the data collected from Leap-Piano and Brain Workshop. I utilized the SPSSPRO software for data processing (Table 3). Initially, I gathered the multisensory perceptual abilities demonstrated by three participants in the Leap-Piano project. Subsequently, a second collection was conducted using Brain Workshop. I encoded the data from both collections, processed the perceptual abilities displayed over the six days, and performed a normality test using the Shapiro-Wilk test on the information gathered by Leap-Piano and Brain Workshop.

The results indicate that for the variable analysis item Leap-Piano, employing the Shapiro-Wilk test, the significance (P) value is 0.930, showing no significance at the chosen level. Therefore, we cannot reject the null hypothesis, confirming that the data conforms to a normal distribution. Similarly, for the variable analysis item Brain Workshop, the Shapiro-Wilk test yielded a significance (P) value of 0.241, with no significance at the chosen level, indicating that the data also satisfies the criteria for normal distribution.

Due to the impact of Participant C's condition, the data exhibits some bias. Additionally, considering the limited sample size, it is essential to expand the scale and number of tests in future research to ensure the comprehensiveness and accuracy of the evaluation data.

A	Variable name	Sample size	median	average value	standard deviation	Skewness	kurtosis	S-W test	K-S test
	Leap-Piano	6	4.258	4.374	1.145	0.119	-1.022	0.976(0.930)	0.149(0.996)
	Brain Workshop	6	2.85	2.717	0.542	-0.634	-1.332	0.874(0.241)	0.26(0.727)
B	Variable name	Sample size	median	average value	standard deviation	Skewness	kurtosis	S-W test	K-S test
	Leap-Piano	6	4.583	4.269	1.147	-0.411	-1.693	0.898(0.364)	0.209(0.909)
	Brain Workshop	6	2.65	2.867	0.459	1.55	1.86	0.805(0.065*)	0.308(0.520)
C	Variable name	Sample size	median	average value	standard deviation	Skewness	kurtosis	S-W test	K-S test
	Leap-Piano	6	1.865	1.952	0.663	0.749	1.567	0.951(0.747)	0.209(0.911)
	Brain Workshop	6	1.255	1.563	1.022	0.455	0.002	0.928(0.562)	0.283(0.627)

Table 3： the data collected from Leap-Piano and Brain Workshop

4.4 Usability:

Through the testing and research with Leap-Piano and Brain Workshop, both contributed to data collection, and the data collected by both showed a positive distribution, confirming the accuracy of the data. In terms of multisensory perceptual abilities, Alzheimer's disease patients still retain some perceptual abilities. However, compared to adults, their multisensory perception is impaired. Among the three perceptual aspects, vision is least affected. The three participants were still able to control visual reaction times within 2000 milliseconds. However, auditory, and tactile (hand flexibility) aspects experienced some degree of impairment. Multimodal senses can be employed in memory training for patients with mild Alzheimer's disease, but considering the reinforcement of a single sensory modality, especially vision, may better align with the behavioral patterns of Alzheimer's patients.

4.5 Observation:

Observations during the study provided further insight into the participants' multisensory perceptual abilities, but at the same time, some additional issues emerged. Participants A and C initially seemed to encounter difficulties in control and only became proficient in the second session of testing. Participant A mentioned that due to the less sensitive hand motion detection of Leap Motion, there was a phenomenon of dual outputs when performing single-finger movements. Another participant expressed that this was not user-friendly, but consistently believed that, disregarding user experience, it could be an interesting and attractive project. This also indirectly indicates that older adults or Alzheimer's patients may lean towards tangible interaction for a more engaging experience.

5.Conclusion

Alzheimer's disease is a complex condition, and Human-Computer Interaction (HCI) methods can contribute to the well-being of individuals affected by it. In this paper, we introduced Leap-Piano, a music game designed to assess the multisensory perceptual abilities of individuals with mild Alzheimer's disease. The project was compared with traditional perceptual ability testing software, Brain Workshop. In addition to completing data collection and assessment tasks, Leap-Piano significantly engaged participants, with each eagerly inquiring about the next participation opportunity after each test session. This suggests that my research can serve as a tool for assessing multisensory perceptual abilities in the elderly.

On the other hand, participants expressed a retention of multisensory abilities during the tests, providing empirical support for my future research. In the future, I plan to further utilize multisensory approaches to bring well-being to individuals with mild Alzheimer's disease and memory impairments, building upon the foundation established by this study.

Appendix A

Links to Video Materials:

1) Leap-Piano prototype https://youtu.be/Xgem2JoYvnw
2) Leap-Piano prototype 2 https://youtu.be/RGjvV5i-gck
3) Touchdesigner works. https://youtu.be/ohoSLWaYVig

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