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Combining Interactive Technology and Visual Cognition—A Case Study on Preventing Dementia in Older Adults †

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Abstract: According to the World Health Organization, the global population is aging, with cognitive and memory functions declining from the age of 40–50. Individuals aged 65 and older are particularly prone to dementia. Therefore, we developed an interactive system for visual cognitive training to prevent dementia and delay the onset of memory loss. The system comprises three "three-dimensional objects" with printed 2D barcodes and near-field communication (NFC) tags and operating software processing text, images, and multimedia content. Electroencephalography (EEG) data from a brainwave sensor were used to interpret brain signals. The system operates through interactive games combined with real-time feedback from EEG data to reduce the likelihood of dementia. The system provides feedback based on textual, visual, and multimedia information and offers a new form of entertainment. Thirty participants were invited to participate in a pre-test questionnaire survey. Different tasks were assigned to randomly selected participants with three-dimensional objects. Sensing technologies such as quick-response (QR) codes and near-field communication (NFC) were used to display information on smartphones. Visual content included text-image narratives and media playback. EEG was used for visual recognition and perception responses. The system was evaluated using the system usability scale (SUS). Finally, the data obtained from participants using the system were analyzed. The system improved hand-eye coordination and brain memory using interactive games. After receiving visual information, brain function was stimulated through brain stimulation and focused reading, which prevents dementia. This system could be introduced into the healthcare industry to accumulate long-term cognitive function data for the brain and personal health data to prevent the occurrence of dementia.

Keywords: dementia; interactive technology; visual cognition; experiential design

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1. Introduction

With emerging technology and networks, the quality of medical care and medical research has been improved. The global birth rate is decreasing every year, and mortality rates are falling owing to the development of medical technology. Therefore, average life expectancy is prolonged, which is related to population aging. According to the United Nations, by 2050, more than 50% of countries will have entered the "aging society" stage [1].

The health of the elderly is the primary problem of an aging society. Elderly individuals face physical, mental, and emotional problems, and the need for prevention of dementia

in this population is emphasized [1,2]. In the age group of individuals aged 65 years old and above, the brain's ability begins to decline, especially in terms of cognition, memory, attention, and real-time response [3]. According to the World Health Organization (WHO), in 2021, 55 million elderly people had dementia worldwide. In 2015, the Alzheimer's Disease Association (ADI) pointed out that dementia affected one person in the world every three seconds [3]. The National Development Commission of the Executive Yuan of Taiwan estimated that Taiwan will become an ultra-aging society by 2026 [4]. According to the Ministry of Health and Welfare, there will be more than five Taiwanese people with dementia in 2061 for every 100 individuals [4]. Today, with the advancement of internet technology and interactive technology, new technologies are being used to prevent dementia, which is a common problem in an aging society. Therefore, we developed a new system with interactive games to improve the hand–eye coordination and brain memory of elderly individuals to prevent dementia and to improve their health.

2. Literature Review

2.1. Dementia

Dementia is a progressive brain disorder syndrome, characterized by the deterioration of cognitive function, memory function, and behavioral abilities, impacting daily life [5]. With advancements in medicine and declining birth rates, many countries are experiencing aging populations, increasing the issue of dementia in elderly societies. According to a study by ADI, the number of individuals with dementia will reach 74.7 million by 2030 [5]. As this population ages, brain function will gradually decline through cognitive impairment, spatial awareness decline, judgment decline, and other functional declines associated with the chronic deterioration of brain memory function [6]. Epidemiological studies indicate that the likelihood of dementia increases with age, particularly after the age of 65 [7]. According to the Ministry of the Interior of Taiwan in 2018, 18.23% of elderly people aged 65 and above experienced mild cognitive impairment, while 7.86% had dementia. Table 1 lists the different stages and symptoms of dementia [8,9]. Low educational attainment is also a risk for dementia, as education level affects lifestyle and environmental health factors that may contribute to dementia [9,10].

Table 1. Dementia classification and symptoms.

Dementia Level	Symptoms of Dementia
Level 1: Mild cognitive impairment	Extremely mild cognitive decline.
Level 2: Mild dementia	Slight loss of memory and slight impairment of judgment.
Level 3: Moderate dementia	Moderate memory loss, disorientation, and memory impairment regarding people, times, and places.

2.2. Impact of Visual Cognition on Dementia

The human brain is composed of nerve cells in four regions: the frontal lobe, parietal lobe, occipital lobe, and temporal lobe (Figure 1). The frontal lobe is responsible for cognitive functions, motor control, social interaction, and problem-solving [10,11].

The brain produces various brain waves that are closely related to cognitive, sensory, and motor functions. In the brain, alpha brain waves play an important role in visual information processing [11,12]. Many studies have shown the relationship between brainwave presentation and activity state responses to visual and cognitive functions and behaviors [12]. People use vision to enhance brain function. Card games, table games, puzzle solving, and mathematical logic games to activate brain functions and emotional feelings

and slow down cognitive decline in elderly individuals, thus preventing the occurrence of dementia [13]. Warren put forward the pyramid theory of the visual–perceptual hierarchy. He found that the visual–perceptual-related function is impaired in dementia, as shown in Table 2 [14,15].

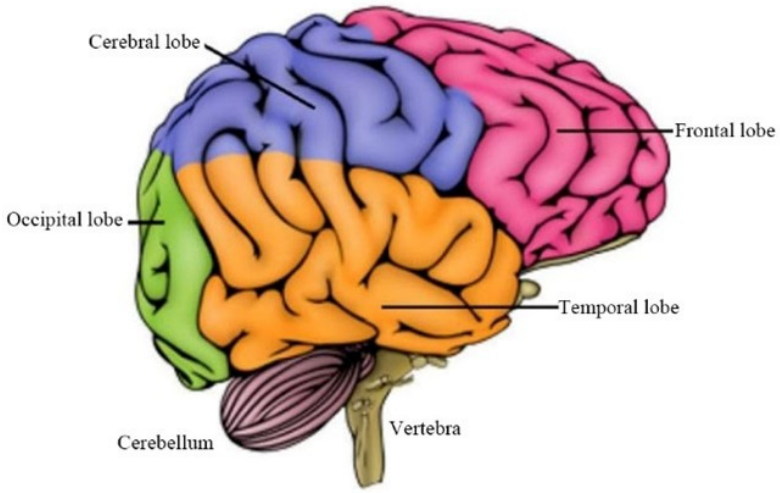


Figure 1. Brain structure [10].

Table 2. Dementia classification and symptoms visual symptoms of dementia [14].

Visual Transmission Paths	Visual Perception Problem	Visual Symptoms
Low-order transmission paths	Eye movement functions	Abnormal scanning and gazing
Low-order transmission paths	Basic visual functions	1. Contrast and visual field 2. Visually induced potentials
Higher-order transmission paths	Complex visual functions	1. Face and object recognition disorders 2. Spatial orientation disorder and dysarthria

Brain waves have different waveforms and frequency ranges, and each wavelength is distributed in the human brain and has biological significance [16]. The human brain has a frequency range of 1–50 Hz, and according to the International Brainwave Society (IBS), the frequency and amplitude of brainwave signals are classified as Delat (δ-wave), Theta (theta), Alpha (α), and Beta (β) wavelengths (Table 3) [17]. Different brainwaves affect the brain's awareness. For example, for the Alpha wave, the brain shows a relaxed and focused state and cognitive behavioral response, and brainwave activity state is shown by detecting the brainwaves using brainwave instrumentation [17]. The changes in brain waves can be used to understand the degree of cognitive ability, mental state, and brain deterioration in elderly dementia patients.

Table 3. Brainwave and characteristics.

Brainwave Type	Frequency Range	Characteristics and Physiological Status
Delat wave (δ-wave)	0.1~3 Hz	1. Unconscious wavelengths 2. Deep sleep
Theta wave (θ-Wave)	4~7 Hz	1. Physical relaxation and meditative states 2. Deep memories and sensations
Alpha wave (α-Wave)	8~13 Hz	1. Brain waves observed in a normal, relaxed adult 2. The brain is in a relaxed and focused state
Beta wave (β-wave)	13~30 Hz	1. The brain is awake and alert 2. The brain makes analytical decisions and deals with the senses

2.3. Interactive Technology Experience

In recent years, network technology and generative graphic artificial intelligence (AI) have been used to study graphic audio–visual and interactive behaviors and stimulate the cognitive ability of elderly individuals. The dynamic interaction of real-time feedback helps to prevent the occurrence of dementia [18]. Ascott et al. stated "New media art creation is mainly divided into five stages, linking, integration, interaction, transformation, emergence and other five basic elements" [19]. Berkeley said "New media art creation is mainly divided into five stages, linking, integrating, interacting, transforming and appearing" [19]. Alvin proposed that music can enhance the cognitive ability, communication and interaction, and self-expression of elderly individuals and can soothe their emotional state and comfort them [20]. PicMemory is an application of mobile technology in the treatment of dementia patients, combining digital video technology with a personalized narrative platform to create opportunities for family members to share, communicate, and interact with each other and share nostalgic memories to prevent the possibility of dementia [21]. WhizTouch, a two-way interactive call bell, provides sound and light changes to allow seniors to interact and give feedback [22]. WhizToys includes software that provides colors, music, images, sounds, and other interactive products to prevent dementia [22] (Table 4). The use of technology in daily life is becoming increasingly important for people to participate in society. However, the changes in the overall technological environment are not applied to the life and daily living of people with age-related dementia [22]. In dementia research, it has been found that the use of artistic messaging reduces the risk of dementia and promotes prevention. In the literature, it has been found that an emphasis on art or esthetics, painting, music, graphics, and interactive technology can be combined to create technological art and new media interactive experiences, such as virtual reality (VR) [23].

Table 4. Analysis of installation works of interactive technologies.

Item	Directions	Photographs
PicMemory	A sound interface for seniors with dementia to express their emotions and facilitate interaction.	
WhizTouch	Make a sound and change the light to green for interactive feedback from seniors.	
WhizToys	Use the color band for motor and cognitive training.	

3. Methodology

In this study, we combined interactive technology and visual cognition to prevent dementia based on experimental methods and expert interviews. Using the framework of the interactive system, we designed an innovative interactive system. Meumann carried out an experiment that encompassed multiple empirical methods of conducting on-site systematic observation with oneself or others [24]. Through an expert interview, information on a two-way communication process was obtained [25]. Due to the rapid development of new technologies, interactive design has emphasized the integration of people, systems, and environments. Interactive systems are based on the concept of human-centered design, and the theoretical framework of interactive system design integrates people, activities, contexts, content, and technological components [26]. The structure of this study is shown in Figure 2.

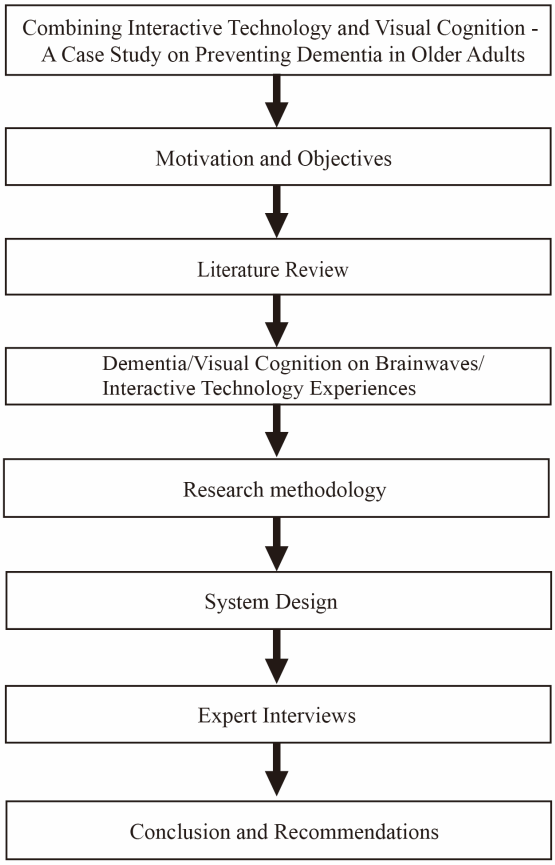


Figure 2. Research framework.

4. System Design

The participants were senior citizens. The experimental equipment included a MindWave Mobile 2 brainwave meter, three-dimensional objects, and visual interface design. When the participants carried out tasks, they wore the Cerebral Wave Meter on their heads and used their hands to grasp the "three-dimensional objects" and sense the information on the surface of the "three-dimensional objects" using the mobile phone. After receiving the information, the brain wave data were recorded using the Cerebral Wave Meter to show the concentration and relaxation of the brain, the cognitive ability for the images, and the emotional feelings, as shown in Figure 3.

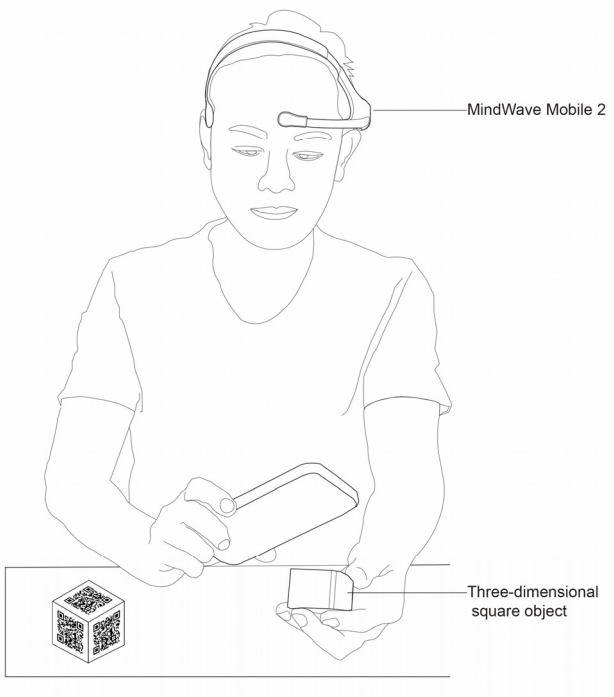


Figure 3. System design.

4.1. Interactive Interface

The interactive system consisted of a three-dimensional square object and software on an interactive interface. The cube-shaped object has a 2D barcode and wireless communication function. The software on the visual interface was used to prevent dementia based on thinking and cognitive recognition. Thinking and cognitive recognition were displayed to show the brain's wavelength response. Increased brain stimulation for elderly individuals can delay the onset of dementia by training thinking, reading books, practicing regular exercise, and community interaction and communication.

The system was designed to include three different units of color, direction, and memory for the visual interface with different brain stimulation functions. The design elements of the visual interface were based on images, geometric shapes, and three-dimensional shapes, as shown in Table 5. The system can improve the hand–eye coordination and memory of middle-aged and senior citizens through the interactive process of games. After receiving the information content visually, an elderly individual can use their brain to read the information and stimulate brain function and activation for the prevention of dementia.

Table 5. Interactive interface design.

Item	Interface Visual Design
Color module	
Functional description	Using color recognition to detect and prevent one of the first signs of dementia.

Table 5. *Cont.*

Item	Interface Visual Design
Memory module	
Functional description	Using three-dimensional modeling pictures to promote memory function and logical thinking, improve memory, and concentration.

4.2. System Architecture

Images, colors, and three-dimensional shapes from the obtained data were stored on a hard disk, as shown in Figure 4. The system was evaluated by middle-aged and elderly individuals using a pre-test questionnaire. In the second step, the tasks were selected for the participants to execute. Using sensing technology (QR-code and NFC), the information was displayed on a smartphone. The information was presented using two different interface presentation modes, namely, text–image narration and media–video playback. The brainwave meter was used to identify visual recognition and perceptual responses. In the third step, after the tasks, the system was evaluated for ease of use using SUS. Finally, the data were compiled and analyzed. SUS was assessed using a Likert scale consisting of ten sets of questions.

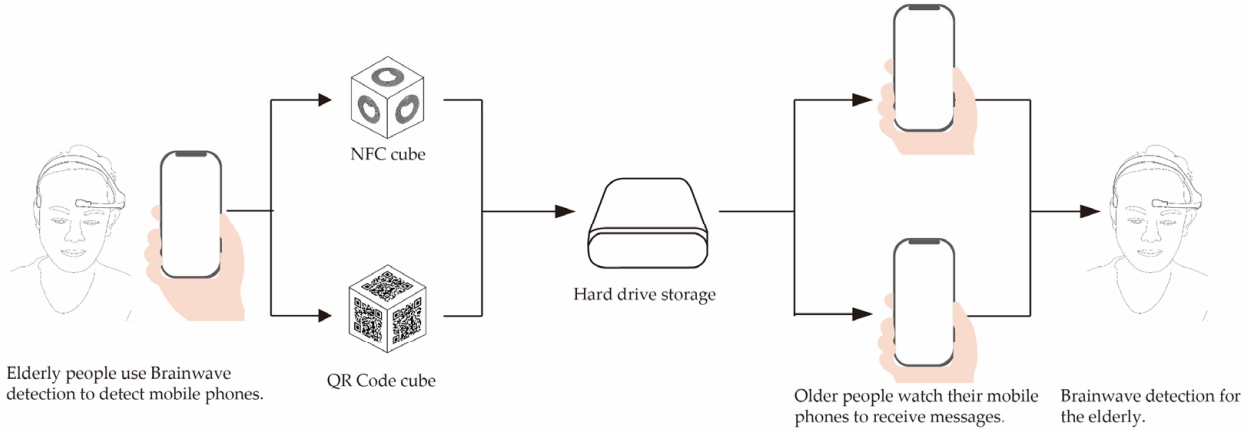


Figure 4. System architecture.

When the participants responded to the data through the brainwave meter, they could immediately understand the text and emotional responses. The system helped the participants prevent the occurrence of dementia.

5. Expert Interviews

Semi-structured interviews were conducted for invited experts in order to improve the interactive system. The interviewees included academic experts, scholars, professionals, or supervisors in related fields with experience and expertise, as shown in Table 6. Their

suggestions and opinions on the development of the system provided the basis for the revision and adjustment of the system.

Table 6. Basic Information sheet for respondents.

Interviewees	Occupational Nature	Areas of Expertise
Academic experts	Associate professor	Human machine interface Human factors design
Industrial supervisor	Design manager	Product design. Interactive interface design
Industrial supervisor	Senior designer	Visual communication design Multimedia design

They suggested effectiveness, simplicity, enjoyment, and visual graphic design for brain activation. The prevention of dementia needs to be carried out under the principles of universal design. Sharp edges must be omitted to reduce risks during use. When using three-dimensional square objects, a layer of icons or other single colors on the surface of the electronic sensor can enhance the integrity of human–machine interface operations. In the interactive visual design, the visual image design must include analog icons to effectively help brain activation. The use of brainwave equipment must be more reliable and objective. When elderly individuals operate using visual images, they have to spend more time searching for specific images. Therefore, simple and bright or contrasting colors in the design are more helpful for the brain activation of elderly individuals with dementia.

6. Conclusions

We collected examples of products with interactive technology for dementia prevention. Michael and Chen proposed that serious games include three key elements: technological media, entertainment, and experience. In this study, audio effects were provided in the interactive system and interactive feedback was given. In the case of interactive products that provide lighting or changes in light and shadow, visual feedback was used. In the expert interviews, the issues related to the design of the interactive system were discussed to make suggestions regarding human–computer interface operating behavior; the indicators of interactive design, including effectiveness, simplicity, and enjoyment; and visual graphic design to help brain activation. The graphic–analog design helps elderly individuals' visual experience.

The literature on dementia, visual cognition, and interactive technology were explored in this study. Interactive products and software interface designs for dementia prevention were investigated in order to generalize the design principles. A new dementia prevention interactive system was designed accordingly. In the future, a survey to understand user experience and satisfaction using SUS is necessary to evaluate ease of use. The interactive system requires more feedback and experience for effective dementia prevention.

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