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# Intelligent Interaction Design of Environments for Early Symptoms of Alzheimer's Disease - A Case Study of Home Environments

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**Abstract.** Early symptoms in Alzheimer's disease (AD) patients are often subtle, and diagnosis typically occurs in the middle to late stages. Currently, there is a lack of effective targeted therapeutic drugs and treatments to halt the disease's progression, emphasizing the importance of early detection and intervention over treatment. This paper employs Ambient Intelligence (AMI) to monitor patients' daily behaviors and identify early symptoms in the home environment. This is achieved through the integration of intelligent sensors, interaction design, and artificial intelligence algorithms, leading to the formulation of personalized solutions based on patients' behaviors. Furthermore, the paper outlines the future research direction for AD, suggesting the incorporation of VR devices to allow users to experience the behaviors, emotions, and feelings of early-stage patients through visual and auditory immersion. This approach aims to provide a deeper understanding and foster empathy among non-patient individuals.

**Key words.** Alzheimer's Disease, Ambient Intelligence, VR Interaction

## 1. Introduction

Alzheimer's disease (AD), commonly known as dementia, constitutes about 60 to 70 percent of all dementia cases worldwide, as reported by Alzheimer's Disease International in the summary report "The Global Impact of Dementia 2013-2050." The policy report suggests that dementia has emerged as one of the world's most significant public health challenges. Globally, approximately 50 million people are living with dementia, and with nearly 10 million new cases each year, it is estimated that by 2050, this number could escalate to 130 million. Secondly, AD is a progressive neurodegenerative disease with inconspicuous symptoms in the early stages of development, particularly in the daily home environment, where symptoms may be more subtle and hidden. Simultaneously, AD has various causes, primarily degenerative diseases such as cerebrovascular disease leading to vascular dementia. This occurs due to long-term cerebral ischemia and hypoxia, resulting in malnutrition of brain cells and a decline in brain function, leading to memory and intelligence

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disorders. Some patients experience limb paralysis and speech disorders. Once the disease onset occurs, it cannot be cured; therefore, early treatment of AD patients is particularly crucial.

It is encouraging to note that the development of computer-aided and artificial intelligence technologies has opened up new avenues for neuropathological diagnosis and early prevention of conditions. In this context, this paper will employ an ambient intelligence system to utilize multiple sensors for real-time monitoring of patients' daily behaviors and activities. The system will collect data related to the user's mood management, memory, and cognitive abilities, aiding in the early detection of changes in patients' behaviors. Secondly, the analysis of patients' behaviors and needs through machine learning algorithms provides personalized support, such as reminding patients to take medication at specific moments, offering memory assistance, planning personalized daily activities, and adjusting the home environment in real time according to patients' behaviors and needs. For example, lighting and temperature are automatically adjusted to provide a more comfortable living environment. Finally, by integrating with VR devices, doctors and family members can experience the patient's environment and sense the patient's psychological changes, thereby offering more personalized and precise medical services[1].

## 2. Concept definition and literature review

### *2.1. Ambient Intelligence (AMI)*

Ambient Intelligent Systems (AMI) are sophisticated systems that integrate computation, communication, and perception technologies. Their primary objective is to offer intelligent and personalized services to users by perceiving and understanding the environment. The design aim of such a system is to enhance technology's sensorless, adaptive, and intelligent aspects, establishing a collaborative relationship where human-machine and environment coordination and unification occur. This system opens up the possibility for a new type of intelligent development, especially in the healthcare field. Unlike Artificial Intelligence, AIS places greater emphasis on the intelligent interaction between the environment and humans, utilizing non-contact sensors capable of sensing human behavior and transmitting information. The application areas of ambient intelligence systems are vast, spanning smart homes, healthcare, transport systems, retail, and more. In the medical field, AMI is dedicated to constructing intelligent, adaptive, and seamlessly integrated human-machine environment interaction systems through wireless technology and smart sensors. It utilizes radio as a new sensing method for wearable devices to recognize users' daily activities[2].Some of the key features and components of an ambient intelligence system include:

- Sensing Technologies: This involves the use of various sensors and sensing devices such as cameras, microphones, visual sensors, etc., to perceive the state of the surrounding environment.
- Intelligent Algorithms: These algorithms leverage artificial intelligence for analyzing and making sense of data acquired from sensors.

- Communication Technologies: Devices within an ambient intelligence system can communicate with each other and connect with cloud servers or external resources, enabling different devices to collaborate.
- Adaptive Capabilities: These systems can adapt to user behaviors and preferences automatically, providing personalized services and recommendations.
- Security and Privacy Measures: This includes implementing security measures such as encryption, access control, and data anonymization.

Overall, Ambient Intelligent Systems represent a fusion of IoT and Artificial Intelligence, with the goal of enhancing the user's living environment by delivering intelligent, transparent, and personalized experiences.

### *2.2. Literature review*

Research based on machine learning for predicting Alzheimer's disease and its early stages of mild cognitive impairment (MCI) is advancing. In the literature, the study titled "Improving Alzheimer's Disease Diagnosis with Machine Learning Techniques" utilized Support Vector Machines (SVMs), a machine learning technique designed to differentiate between patients with Alzheimer's disease and healthy individuals. This approach introduces a novel method for accurate diagnosis. Another study, "Forecasting the Progression of Alzheimer's Disease using Neural Networks and A Novel Preprocessing Algorithm," developed a neural network model with a focus on diagnosing MCI patients, aiming for early intervention in Alzheimer's disease and thereby enhancing the cure rate. In "Personalised Predictive Modeling for Patients with Alzheimer's Disease using An Extension of Sullivan's Life Table Model," researchers employed a convolutional neural network and LeNet-5 architecture for feature extraction and diagnosis of Alzheimer's disease stages in patients, utilizing a deep learning approach. Furthermore, the study titled "A Bayesian Network Decision Model for Supporting the Diagnosis of Dementia, Alzheimer's Disease, and Mild Cognitive Impairment" utilized a probabilistic graphical modeling approach, drawing on expert knowledge to construct a Bayesian network structure. They employed a parametric learning approach to train the model for predicting Alzheimer's disease. These studies collectively illustrate the efficacy of various machine learning algorithms in predicting Alzheimer's Disease and MCI, offering a more intelligent and personalized approach to early diagnosis and treatment[3].

The academic community has undertaken numerous valuable initiatives to explore the adverse effects of Alzheimer's Disease (AD) on human functionality, employing deep learning techniques for assisted diagnosis and treatment of AD. In response to the memory decline associated with AD, Lussier et al. conducted a study comparing the daily activity behaviors of normal individuals with those of Alzheimer's patients. Their findings revealed that Alzheimer's patients frequently exhibited abnormal pauses in front of refrigerators and cupboards. In investigating the impact of AD on human mobility, Bringas et al. identified interruptions in movement during the daily activities of AD patients. To assess the cognitive status of AD patients, Negin et al. introduced a Praxis test, incorporating 29 medically specific gestures. They employed a deep learning framework to discern whether a user has developed Alzheimer's pathology by analyzing the distinctions between the gestures of the patient and those of a normal individual [4].In summary, recent years have witnessed a flourishing of machine learning-based research on the prediction of Alzheimer's disease and early cognitive impairment (MCI). These studies have introduced diverse methods and techniques that successfully enable the early prediction of AD patients. However, a notable gap exists in terms of personalized interventions, and theoretical studies have yet to integrate ambient intelligence systems into the early treatment of AD patients, presenting a challenge for the application of ambient intelligence systems. Moreover, a more profound understanding of patients' memory, motor, and cognitive abilities offers valuable insights for designing ambient intelligence systems that are better aligned with patients' needs. Through meticulous monitoring and intelligent interaction, Ambient Intelligence is anticipated to provide more personalized and comprehensive support. This not only assists patients in better coping with the challenges of daily life but also equips families and healthcare professionals with more timely and accurate information to enhance the management and care of Alzheimer's disease.

## 3.Holistic Construction of Environmentally Intelligent Systems

The overall architecture of the Ambient Intelligence System comprises a sensor data acquisition module, a data processing and analysis module, an interface interaction module, and a data storage and transmission module (as depicted in Figure 1 on the left). Firstly, to collect the patient's daily behavioral data, wireless communication technologies such as Radio Frequency Identification (RFID), a technology enabling automatic identification of items and data collection, and advanced mobile communication will be employed with the sensor components [5]. Data about the patient's daily behavior is obtained through visual sensors, and information about daily mood changes is captured by sound sensors. This data can be stored and processed in internal servers or cloud databases, which can be built around technologies like Hadoop (known for its open-source nature, low cost, and high efficiency) or Spark (noted for its fast computation speed and simple operation). This allows for the storage and analysis of the extensive data collected, breaking it down into segments, reducing the time for data aggregation, and enabling effective processing.Simultaneously, based on GPRS/4G, NB-IOT, and other data transmission communication methods, support is provided for various ways of accessing the collected data in real-time transmission to smart devices (such as smartphones, watches, or VR devices). The data is then processed using the system's built-in APP to create data charts and visual graphs [6].

Secondly, the collected patient data are integrated into a virtual environment to visualize the real situation of family members' patients. A virtual reality (VR) environment is established to recreate the real-life scenes of patients in the virtual realm, allowing users to more realistically experience the patient's daily life (e.g., the right side of Fig. 1). Users wear VR helmets, handles, and other equipment interfaces to enter the virtual environment, achieve user interaction through gestures, and utilize voice recognition technology for communication with the virtual environment through voice.

Finally, the scene is uploaded to corresponding VR platforms such as SteamVR, Oculus Store, etc., enabling educational and promotional activities for non-patients. This facilitates a broader understanding of Alzheimer's disease, and continuous feedback collection helps identify scene shortcomings and areas for improvement. Families and healthcare professionals can leverage this hands-on experience to better comprehend each patient's symptoms and needs, leading to personalized means of treatment [7].

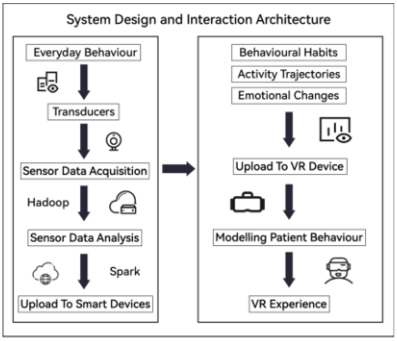


**Figure 1.** System Design and Interaction Architecture.

## 4.Experiments and analyses

### *4.1 Experimental process*

The purpose of this experiment was to assess the effectiveness of an ambient intelligence system in monitoring the behavior of patients with early Alzheimer's disease and enhancing awareness of Alzheimer's disease in non-patients through virtual reality (VR) technology. Experimental subjects included fifty individuals in the early stages of Alzheimer's and fifty healthy older adults. Healthy older adults were selected based on self-reported absence of cognitive impairment and neurodegenerative diseases. Both high-resolution vision sensors and sound sensors were employed, with sensors strategically placed in the kitchen and daily living areas of each subject. These sensors possess the ability to promptly respond to changes in the environment and capture subtle behaviors exhibited by the subjects in their daily lives[8].

Before commencing the experiment, the visual sensor undergoes calibration to ensure accurate capturing of the patient's movements. This calibration process includes adjusting the camera angle, determining the capture area, and ensuring accurate scene perception by the sensor. Computer vision techniques, including writing or using existing algorithms such as Convolutional Neural Networks (CNNs), are employed to learn and recognize specific patient movements during salt spreading. The network is trained on a large dataset to capture subtle movement patterns.Algorithms like Recurrent Neural Networks (RNN) or Long Short-Term Memory Networks (LSTM) are utilized to capture the time-series patterns of a patient's salt spreading. Key point detection algorithms, facilitated by open-source libraries like OpenPose, track the movement of a patient's hand by detecting key points in the body and monitoring their movement. The recorded data includes the number and frequency of times each patient sprinkled salt while cooking. The large dataset collected is stored and analyzed using techniques based on Hadoop or Spark, comparing the number of times patients and normal elderly people sprinkled salt, as well as behaviors like rummaging through boxes in daily life to find things.This includes searching for keys, glasses, the remote control, documents, and the mobile phone. The experimental data is used to generate visualization graphs (e.g., Figure 2)[1]. The sound sensor records data on changes in crying, laughing, and normal states in daily life. The most frequent mood changes throughout the day for each experimental subject are recorded and visually represented (as in Table 3 and Fig. 3). The collected data undergo preprocessing, including noise removal, data alignment, and standardization, to ensure accuracy and consistency.

Finally, the data collected by the visual and sound sensors in the home environment is transmitted in real-time to the server or cloud database of the environmental intelligence system. In the server or cloud database, the collected data undergoes analysis and processing. Leveraging artificial intelligence algorithms and machine learning techniques, patients' behavioral patterns can be identified and analyzed to detect changes in early Alzheimer's symptoms[9].

**Table 1.** Data collected by visual sensors (patients)

| Number of times salt is sprinkled during cooking | Finding the key | Finding the Eyes | Finding the remote control | Finding Documents | Find a mobile phone |
|---|---|---|---|---|---|
| 3 | 4 | 3 | 1 | 1 | 2 |
| 4 | 6 | 1 | 2 | 4 | 1 |
| 2 | 4 | 4 | 1 | 6 | 3 |
| 5 | 5 | 3 | 4 | 2 | 4 |
| 3 | 2 | 2 | 2 | 4 | 5 |
| 6 | 7 | 3 | 1 | 4 | 3 |
| 2 | 6 | 4 | 2 | 3 | 3 |
| 4 | 6 | 3 | 3 | 4 | 3 |
| 3 | 7 | 5 | 2 | 3 | 2 |
| 5 | 3 | 2 | 2 | 5 | 4 |
| ... | ... | ... | ... | ... | ... |

**Table 2.** Data collected by visual sensors (normal elderly)

| Number of times salt is sprinkled during cooking | Finding the key | Finding the Eyes | Finding the remote control | Finding Documents | Find a mobile phone |
|---|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 | 2 |
| 2 | 2 | 0 | 1 | 1 | 0 |
| 2 | 2 | 0 | 1 | 2 | 1 |
| 1 | 3 | 1 | 2 | 2 | 2 |
| 2 | 2 | 2 | 1 | 4 | 1 |
| 1 | 1 | 3 | 0 | 2 | 1 |
| 1 | 2 | 1 | 1 | 3 | 1 |
| 2 | 3 | 0 | 2 | 0 | 0 |
| 1 | 1 | 1 | 1 | 2 | 1 |
| 2 | 4 | 1 | 1 | 4 | 1 |
| ... | ... | ... | ... | ... | ... |

### *4.2 Experimental results and personalised analysis of vision sensors*

By analyzing the experimental data collected from visual sensors and employing machine learning or pattern recognition algorithms to study patients' behavioral patterns, we observed a significant increase in the number of times early Alzheimer's patients sprinkled salt while cooking (e.g., Figure 2). Additionally, these patients exhibited higher uncertainty and frequent rummaging behavior (e.g., Figure 3).Taking the results in Figure 1 as an illustration, based on the 20-day average of the specific data regarding the number of times salt was sprinkled, AI algorithms demonstrated a gradual cognitive decline in early-stage patients. This decline may manifest in their inability to accurately judge the amount of salt needed for cooking. Memory problems may contribute to patients forgetting whether they have added salt or recalling the appropriate quantity during the cooking process. Emotional changes, such as anxiety due to confusion and upset feelings, can lead to over-salting. Furthermore, a decline in executive functioning may result in difficulties completing complex tasks like cooking. Lastly, patients may struggle to concentrate during cooking, affecting their ability to judge the amount of salt accurately.These findings align with the cognitive decline and loss of behavioral control characteristic of early Alzheimer's symptoms, presenting a significant distinction when compared to healthy older adults.

Concerning personalized smart reminders, the system and family members establish appropriate thresholds to determine when a patient's salt usage behavior is deemed abnormal or excessive. This determination is based on the results of data analysis and insights from hospitals regarding early symptoms in patients with AD. A device, connected to a mobile app or smart home system, is then employed. This device can alert patients through sound, light, and vibration if they exceed the set threshold for salt use. The system can monitor how often patients use salt while cooking in real-time and provide immediate feedback if an abnormality is detected. This real-time monitoring aids patients in adjusting their behavior promptly.

• Intelligent Reminder and Assistance: Utilizing visual sensor data, during the process of adding salt, the system can issue a sound reminder, stating, "Salt has been added."

• Memory Assistance Function: In cases where a patient faces memory problems while cooking, the system displays the current steps or ingredients that have been added. This aids the patient in better completing the cooking task.

• Distraction Management: The system analyzes the patient's distraction during cooking based on visual sensor data. Through sound prompts and visual guidance, the system helps the patient concentrate better, reducing misoperation and judgment errors.

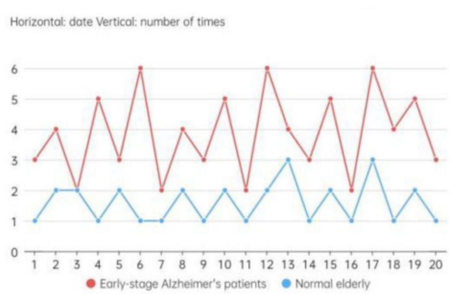


**Figure 2.** Number of Times Salt Is Used in Cooking

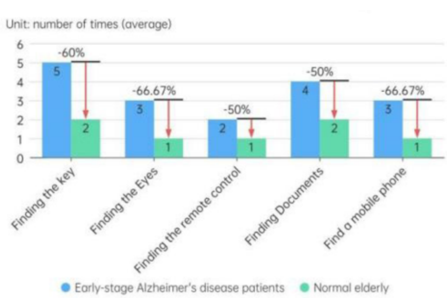


**Figure 3.** Make a Thorough Search for Something

*4.3 Experimental results and personalised analysis of sound sensors*

By analyzing the sound data and employing emotion recognition algorithms to distinguish between different emotional states, such as crying, laughing, and normal expressions, we discovered that the frequency of laughter and crying in the daily lives of early Alzheimer's patients was considerably higher than that of normal older adults (e.g., Fig. 5). This suggests, firstly, that patients' laughter and crying reflect emotional instability due to impaired cognitive functioning, reducing their emotional processing ability and making them more prone to emotional volatility. Secondly, due to increased social impairment, patients might exhibit inappropriate emotional responses in social interactions, impacting communication; additionally, strong emotional responses may be triggered by emotional recollections. Lastly, early-stage impairment in memory and cognitive functions may cause confusion about the environment, leading to inappropriate expressions of emotional responses.

Concerning the personalized smart reminder device, the patient's family is notified through a device connected to the mobile app and home system if a set sound pattern threshold has been exceeded. This device transmits data and reminder feedback to the patient's family member's electronics, enabling family members to monitor the patient's condition and take action if necessary.

• Using sound sensor data, the Ambient Intelligence System can monitor the frequency of patients' laughter and crying in their daily lives. When the system detects mood swings, it can automatically initiate emotional interventions, such as playing calming music and providing tips, to help patients manage their emotions better.

• In response to the patient's social impairment, the system can encourage normal social interactions by reminding the patient to control their emotional responses through voice prompts, preventing abnormal laughter or crying.

• Considering patients' potential feelings of depression and confusion due to impaired memory and cognitive functions, the system can mitigate abnormal emotional responses by adjusting the environment. For instance, by modifying lighting and acoustic conditions, the system can create a more calming and quieter environment, helping to reduce emotional swings.

| Laughing (patient) | wee ping | norm alcy | Laughing (normal) | weep ing | norm alcy |
|---|---|---|---|---|---|
| | √ | | | | √ |
| √ | | | | | √ |
| | √ | | | √ | |
| | √ | | | | √ |
| | | √ | | | √ |
| | √ | | √ | | |
| | | √ | | | √ |
| √ | | | | | √ |
| | √ | | √ | | |
| | | √ | | | √ |
| ... | ... | ... | ... | ... | ... |

**Figure 4.** Data Collected By Auditory Sensors.

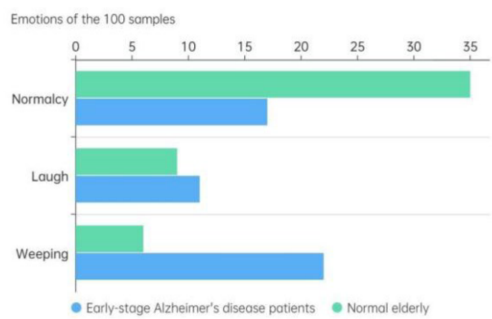


**Figure 5.** Daily Emotional Management Skills

In summary, the ambient intelligence system can capture patients' daily behaviors and activities, aiding in the identification of early-stage Alzheimer's patients. Additionally, it facilitates family members in gaining a profound understanding of the patient's lifestyle and behavioral habits. This understanding helps in developing personalized treatment plans and undertaking early interventions to alleviate symptoms and decelerate the progression of the disease. Simultaneously, the Ambient Intelligence System can offer personalized solutions for cognitive abilities and training for emotional management tailored to the patient's individual characteristics and situation.

### *4.4 Interaction design solutions based on ambient intelligence*

A prospective solution for alleviating and preventing early-stage Alzheimer's patients involves creating a virtual reality scenario (e.g., Fig. 6) using a VR platform (e.g., Unity, Unreal Engine, etc.). This simulation mirrors the patient's daily life environment, paying special attention to various challenges encountered at home, such as cooking, searching for items, and communication. Virtual reality technology (VR) is utilized to simulate the patient's perceptions and behaviors, encompassing vision, hearing, and touch, along with cognitive impairments like memory loss and confusion. Users can immerse themselves in the virtual reality environment through a VR headset (e.g., the soon-to-be-released Apple Vision Pro), introducing a real-time feedback mechanism enabling family members to sense the patient's emotional changes—confusion, anxiety, frustration—in different contexts.For a visually impaired experience, tasks and challenges are developed to allow family members to encounter problems the patient might face in the virtual environment, such as searching for ingredients and cooking in the virtual kitchen or finding items in the virtual living room[10]. To simulate emotionally disturbed experiences, the patient's emotional expressions like crying and laughing are replicated through stereo sound technology. Visual effects, such as changing colors and blurring effects, convey the fluctuation of the patient's emotions (e.g., alterations in emotional state cause corresponding changes in the color and brightness of the VR environment to express emotional instability). Utilizing multi-sensory stimuli in virtual reality, including spatial sound effects, visual effects, and tactile feedback, enhances the realism of the experience. This, combined with relevant information and education, helps family members better understand the patient's predicament and needs, fostering improved care and support. The integration of actual patient data collected from the ambient intelligence system into the virtual environment visualizes the real situation of the family's patient, leading to a deeper understanding of the patient's dilemmas and challenges.

In this manner, family members can acquire a more comprehensive and profound understanding of the challenges faced by the patient in their daily life through virtual reality technology. This enables the provision of more targeted support and care. Not only does this aid families in better comprehending the patient's condition, but it also fosters the development of a closer family environment. Ultimately, by utilizing this VR experience program, educational and awareness campaigns can be conducted, targeting non-patients. This approach enables more individuals to learn about Alzheimer's disease, enhancing societal understanding and support for patients and thus positively impacting Alzheimer's patients and their families.Beyond education and awareness, this program holds potential for medical training and research purposes. Through hands-on experience, medical students and healthcare professionals can enhance their understanding of patients' symptoms and needs, thereby improving diagnosis and care. Innovative programs like this contribute to raising awareness and concern about Alzheimer's disease within the community, providing a positive impetus to enhance the quality of life for patients[11].

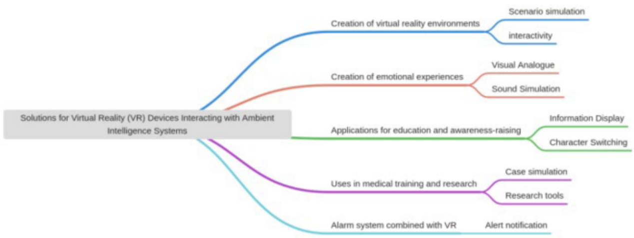


**Figure 6.** Solutions for Virtual Reality (VR) Devices Interacting

## 5. Summaries

This paper is anchored in Ambient Intelligence Systems, providing insights into the daily behavior and emotional responses of early-stage Alzheimer's patients through the utilization of visual and sound sensors. The integration of ambient intelligence systems into the daily lives of patients proves to be a highly effective method for early AD detection. This not only provides healthcare professionals with patient data but also empowers families and caregivers with personalized plans for prevention and treatment. Furthermore, the VR experience program proposed in this thesis, focusing on environmentally intelligent interaction design, introduces a novel approach to the early prevention and care of Alzheimer's patients. These methods and programs are expected to undergo further refinement and expansion in future research and practice, exerting a positive impact on the intervention and treatment of early Alzheimer's patients.

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