Brain-Computer Interfaces Can Significantly Improve The Quality of Life for Aged People – A Review

Sanjay Kumar Mire [1], Deepak Kumar Sahu [1]

Abstract

As the global population ages, numerous programs have emerged to enhance the quality of life for seniors, addressing factors such as mental and physical well-being, mental illnesses, concurrent health issues, loneliness, and social interactions. Cognitive decline in aging poses a significant public health concern, impacting families and communities emotionally and financially. This review explores the effectiveness of healthcare surveillance combined with Brain-Computer Interfaces (BCIs) in improving memory and focus among a group of healthy seniors. Maintaining a high quality of life for the elderly is crucial, fostering resilience and perseverance. The review data suggests the potential of non-invasive BCIs, integrated with IoT-based Smart Home Technology (SHT), to enhance the Quality of Life (BCI-QOL) for seniors. The review focuses on advancing non-invasive BCI technology to support the health and well-being of older individuals, addressing dementia and physical impairments. It also discusses supportive BCI technologies for smart homes catering to seniors with motor control deficits. This comprehensive review aims to assess the immediate and long-term impact of regional features on the well-being and quality of life of seniors. The BCI-QOL-based system holds promise in enhancing cognition and focus, aiming for security, intuitiveness, and appropriateness for older users.

Keywords: Aging population, Quality of life, Brain-Computer Interfaces (BCIs), Smart Home Technology (SHT), Cognitive health

Significance | A non-invasive Brain-Computer Interfaces (BCIs) and IoT-based Smart Home Technology can enhance memory, focus, and aged people's quality of life.

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1. Introduction

The aging process often leads to a decline in intellectual abilities, which is associated with factors such as isolation, decreased independence, and a lower quality of life. Studies by economists reveal that individuals with cognitive impairment incur medical expenses approximately ten times higher than those without such impairment (Souza Júnior, E. V. D., 2021). There is a pressing need for scientifically validated strategies to preserve cognitive skills in the elderly (Kwon, M., 2020). Cognitive development has been shown to enhance awareness, accelerate thought processes, and improve mental agility in older individuals, leading to sustained improvements in quality of life even after the completion of training (Souza Júnior, E. V. D., 2021). Computer-based therapies offer a cost-effective and portable alternative to conventional psychological interventions, especially beneficial for elderly individuals facing mobility and financial challenges (Yuan, Y., 2020).

A brain-computer interface (BCI) serves as a system that collaborates with the brain to control external operations, such as

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cursor movement or the manipulation of artificial limbs, through brain signals (Xu, L., 2022). This interface establishes a communication channel between the human brain and the controlling device, detecting electrical impulses generated by brain activity on the head, cerebral surface, or deep within the brain (Amarilla-Donoso, F. J., 2020). BCIs convert these impulses into usable outputs, enabling independent interaction without reliance on external tissues and nerves. Our research aimed to gain insights directly from participants, exploring older individuals' perceptions of BCI technology, its potential use in Smart Homes, and their expectations regarding system features (Shrestha, K., 2020; Khanagar, S. B., 2020). Understanding user requirements is crucial for developing BCI-based Smart Home communication models (Zhao, X., 2020; Stanica, I. C., 2020).

Individuals with intellectual or neurological disorders increasingly benefit from BCI technologies, which have the potential to significantly enhance independence and movement, thereby improving their overall quality of life (Al-Taie, N., 2020; Belkacem, A. N., 2023). BCI applications extend to assistive, adaptive, and rehabilitative technology by monitoring brain activity and translating specific signal qualities into instructions for device control (Osawa, T., 2020). Daily tasks such as operating household appliances, social interaction, mitigating social isolation, and regulating prostheses to enhance joint strength can all be facilitated by BCI systems for senior citizens (Zhou, Y., 2020). This analysis explores various scenarios in healthcare and nonmedical contexts where BCIs can enhance the quality of life for both healthy and elderly individuals (de Oliveira Júnior, W. G., 2020).

This review mainly discusses the quality of life for elderly individuals, enabling them to age in place with dignity and independence. It proposes that designers of Brain-Computer Interface (BCI) technology should aim to contribute to a more enjoyable and, ideally, extended life for the elderly. The recommended BCI-QOL approach, particularly in a smart home environment, is put forth as a superior method for significantly improving the quality of life for the elderly.

2. Literature Review

Several research studies address various aspects of the quality of life (QoL) for elderly individuals. The study conducted by Ooi, P. B. (2021) employed the Partial Least Squares-Structural Equation Modeling (PLS-SEM) technique to investigate perceptions of physically active elderly individuals during the era of Motion Regulation Rules. The findings underscored the significant impact of psychological health on Quality of Life (QoL), ranking it highest, followed by social connections, regular routines, and strategic resource utilization. In another study by Afifi, T. (2022), the use of virtual reality (VR) with distant family members was explored for older individuals with Mild Cognitive Impairment (MCI) or mild to moderate dementia, revealing potential benefits for both parties' quality of life. Preliminary observations suggested that VR might be particularly advantageous for individuals with dementia and their families compared to those with MCI and their families. Moghadam, K. (2020), in a descriptive-correlational research paper, focused on dynamic aging and emphasized the importance of comprehensive social support and timely identification of needs to enhance the quality of life for the elderly. Adami, I. (2021) detailed the methodology of creating an adaptive system to monitor the well-being of the senior population, emphasizing the strict adherence to human-centered design principles and ongoing consultation with actual users throughout the development process. In the study by AlAbedi, G. A. H. (2020), the correlation between the quality of life of the senior population and socio-demographic factors was examined using a quasi-experimental approach. The results indicated poor exercise and quality of life levels in both groups of seniors before the implementation of the program. Lastly, the cross-sectional study presented by Nugraha, S. (2020) aimed to compare the quality of life of elderly individuals in institutional settings with those in neighborhoods. The study revealed substantial variations in different age groups, educational levels, dependence on others for Activities of Daily Living (ADLs) and Instrumental Activities of Daily Living (IADLs), and the overall quality of life scores.

3. Enhancing Quality of Life for the Aging Population through Innovative Approaches

The societal shift towards higher expectations for a decent life has prompted a renewed focus on the quality of life (QoL), aging, and independence among the elderly. Optimistic perspectives on aging are emerging due to medical advances, leading to policies like "Enhancing Possibilities for Aged Persons" and "Lifetime Communities." These initiatives aim to empower the elderly to maintain movement, gain independence, and participate socially while addressing the challenges of aging.

Recognizing the enduring impact of the physical environment on both quality of life and societal well-being, the article underscores the influence of individuals' social ideals, education, economic aspirations, and spiritual values—elements molded by their upbringing. The ongoing evolution of structures to align with social progress and the transformation of older buildings disrupts the delicate balance between architecture and society.

As the significance of quality of life concerns for the elderly intensifies, urgent attention is required to implement protocols, processes, and surroundings conducive to enhancing their well-being (Lee, T. S., 2013). While recent years have seen increased focus on improving the external private environments for the aged, it is emphasized that meticulous consideration must be given to the design of artificial structures where most people spend their

time. This careful design is crucial to promote healthy aging and ensure a high quality of life for all occupants.

In this study, Figure 1 illustrates the quality of life for older individuals based on a developed model. The theoretical framework encompasses six elements—health, safety, the built environment, individual growth, material abundance, and social capital—making it versatile and suitable for a broad range of research participants, including the elderly. Modifications were made to adapt it for use in rural areas of emerging nations, similar to adjustments made for the older population. Various factors, such as health (both mental and physical), the environment, natural resources, commodities and services, community growth, and individual improvement, were examined in different regions (Collinger, J. L., 2013).

Unexpected declines in cognitive and functional abilities are common among older individuals with minor mental and physical challenges who live independently. These individuals often rely heavily on informal caregivers, such as friends, family, and neighbors, for support. The assistance provided typically involves tailored aid to help them carry out daily responsibilities. Adequate healthcare for the elderly requires age-friendly surroundings, personalized treatment, suitable medical equipment, and access to relevant information and resources. The proposed solutions aim to enhance the health of the aging population through increased social interaction, enhanced physical activity, and early detection of cognitive decline.

Key determinants of an older individual's quality of life include satisfaction, self-esteem, social bonds, and social participation (Fry, A., 2022). Seniors who are physically and mentally robust tend to report higher levels of happiness compared to their less healthy counterparts. Those who heavily depend on others in their later years often express lower levels of happiness.

Retirees who actively participate in society tend to experience higher levels of happiness compared to those who choose withdrawal. Older couples, benefiting from shared social support and companionship, report higher life satisfaction than singles or non-married individuals. Adult day activities significantly enhance the well-being of older individuals, particularly those facing impairments. The rapid pace of technological and social change may create challenges for the elderly in feeling valued by modern society. However, well-designed healthcare products can assist older individuals in maintaining mental and emotional engagement within their communities.

Social networks, support systems, and integration form the foundation of social relationships for older individuals, with most having circles comprising relatives, friends, and acquaintances. Those with extensive social connections tend to live longer, receive better community support, and actively participate in civic life. Social engagement for seniors involves activities such as socializing, collaborating on tasks, assisting others, and contributing to society. Protecting older individuals from the negative impacts of social isolation involves providing psychological comfort, opportunities for self-actualization, and information on healthy living.

The interface mechanism involves electrodes capturing brain impulses, processed by a Brain-Computer Interface (BCI) microcontroller to eliminate environmental or hardware-induced artifacts. Artificial neural networks, known for their robust data processing capabilities, are often employed for analysis. While specialized computers can independently perform this task, the detected command is typically sent to an external device for further processing based on a pre-programmed algorithm. The controlled device then interprets the incoming instruction using unique features (see Figure 2). EEG sensors, consisting of electrodes on the scalp or other body regions, measure electrical activity generated by neurons in the brain. Continuous monitoring of this activity allows clinicians to observe shifts in mental states, such as sleepiness or alertness, and identify abnormal brain activity related to conditions like epilepsy or stroke. Cognitive skills, including attention span and memory recall speed, can also be evaluated through EEG data.

Effective signal processing in Brain-Computer Interface (BCI) technology relies on synchronization and asynchronization, enabling seamless communication between the user's brain impulses and the computer. Synchronization ensures precise timing alignment between two signals, while asynchronization allows for some flexibility. Achieving synchronization is crucial when a precise temporal link between events or signals is necessary, ensuring reliable communication between devices at the exact moment data is obtained from its source.

Maintaining accurate time control over both devices is imperative to keep them synchronized during data transmission. This precision demands robust hardware components like clocks that can uphold accuracy over extended periods, enduring external variables such as temperature fluctuations and electrical interference. Research indicates that synchronized data collection surpasses non-synchronized methods in signal identification, as any timing variations can be compensated for during analysis.

EEG metrics, such as coherence values or event-related potentials (ERPs), can be recorded from distinct electrode locations in each channel through the synchronization of multiple channels. Individuals with cognitive impairment, especially the elderly, may find benefit in using BCI technology to rehabilitate learning and enhance memory, attention, and awareness. Non-invasive BCIs have been employed in rehabilitation centers, utilizing acoustic stimulus and biofeedback to restore memory and planning abilities by altering brain activity. Theta and alpha channel brain waves have also been utilized to predict the effectiveness of

memory encoding in improving short-term recall among human volunteers.

Furthermore, BCI holds promise as a powerful strategy for mental prostheses, offering potential enhancements in memory and cognition for individuals with cognitive disabilities. This potential underscores the need for a comprehensive understanding of the brain systems supporting such intellectual functions.

Smart homes offer promising outcomes in the management of chronic diseases by prioritizing exacerbation control and enhancing patient safety, particularly for cognitively challenged older individuals. The implementation of home visits has demonstrated an increase in the happiness of both homebound seniors and their caregivers. Previous research suggests that preventative home visits can contribute to an improved quality of life for the elderly. These visits have been associated with the absence of physical suffering (e.g., pain, dyspnea, nausea) and a state of emotional well-being, characterized by contentment and reduced worry. The ability to perform routine and more complex tasks, engaging in pleasurable activities both physically and mentally, is also enhanced.

A high quality of life becomes a motivating factor for the elderly to persist and avoid resignation, prompting loved ones to exert efforts in enhancing the living standards of their aging relatives. Smart homes play a crucial role in supporting individuals with disabilities to live independently. They provide safety measures such as fall prevention equipment, automatic timers, warnings, and remote monitoring capabilities through the internet. Integration with Brain-Computer Interface (BCI) technology further elevates the standard of living by addressing challenges associated with aging, such as restricted mobility, alongside other non-fatal health declines that accompany an extended lifespan.

The predictive model, BCI-QOL with the SHT, is designed to monitor and assist the elderly in smart home environments. This intelligent system is programmed to perform tasks such as turning off unnecessary lights, watering houseplants, detecting gas leaks, monitoring for strangers, and triggering alarms in emergencies. Sensor devices connected through Wi-Fi and command interfaces carry out these functions, providing a seamless experience for the elderly through a user-friendly control system interface.

The capabilities of this smart home extend to daily tasks, including house cleaning, identifying propane leaks in the kitchen, setting alerts and reminders for essential activities, and more, enhancing the overall quality of life for seniors. The BCI-QOL system incorporates a specialized electrical sensor called a Passive Infrared Sensor (PIR) for security warnings and hands-free control of lights and fans. The ZIGBEE communication protocol determines the presence of a person in a room, while an LPG sensor issues a warning signal upon detecting a gas leak.

In the smart home environment, a Terminator machine navigates through the space using a follower method during tasks like vacuuming. An alarm system, triggered by an infrared (IR) sensor detecting obstacles in its path, enhances safety. A real-time clock (RTC) is utilized to set alarms and generate reminder messages for medication and activity scheduling on the LCD panel.

The conceptual framework of the BCI-QOL-based smart home assistance system for the elderly is illustrated in Figure 3. Through a combination of cloud computing and control system interfaces, the smart home assistance control depicted in Figure 1 manages electronic appliances, sensor devices, electronic home appliances, and control system modules. The BCI-QOL system comprises modules for the home environment, user interface, sensor-based electronic appliances, and a cloud-based computing platform. Users can interact with their home's Wi-Fi network through mobile or internet-based applications, utilizing sensors and communication modules throughout the house to connect electrical products. The backend of the BCI-QOL system stores received sensor signals and their information in a cloud storage platform.

Features of the Predictive Model

Control System Interface:

User interaction with the BCI-QOL paradigm occurs through the control system interface, accessible via Wi-Fi and a mobile or web-based application. The smart home's environment is monitored through live CCTV camera feeds, allowing users to check various aspects such as humidity, temperature, status of electronic appliances (fans, lights), and presence of intruders using a specialized Android app. The outputs from different sensors are sent to a cloud database for future reference. The smart home's control app is compatible with Android, enabling real-time surveillance on desktop PCs, laptops, or mobile devices.

Intelligent Home Setting

The BCI-QOL smart home ecosystem consists of three components: the external communication interface, electrical appliances, and sensors. Connected through a microcontroller, sensor devices in the IoT-based electrical equipment of the smart home exchange data with the external world. The microcontroller communicates via Wi-Fi and an ESP8266 module using HTTPS/IP and TCP/IP. It requires a power source and the ESP32 camera module on an Arduino board for operation. The Wi-Fi chip incorporates a built-in ESP32 camera board with a wireless connection, utilizing the ESP8266 and ESP32 for wireless transmission.

Cloud Computing System

This component communicates with the system to perform tasks for the elderly. It features a cloud-based storage system that archives sensor data for later use. The BCI-QOL algorithm

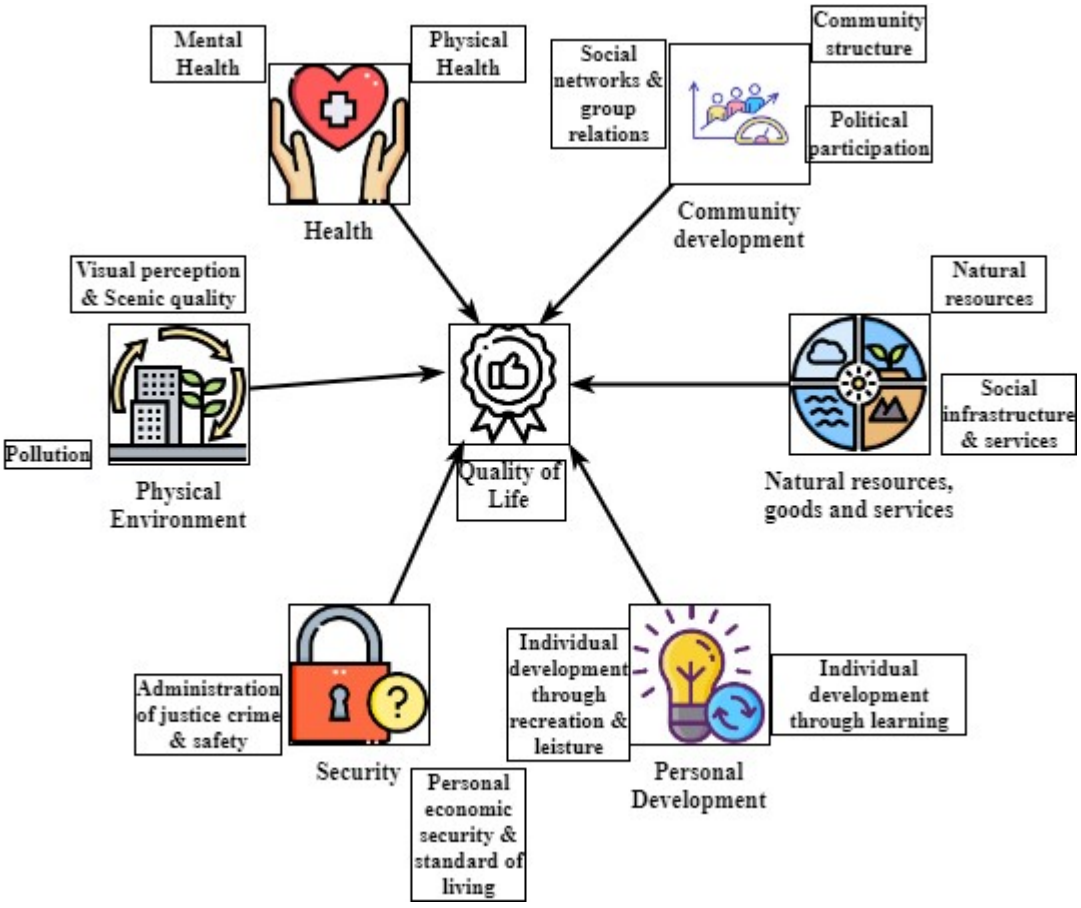

Figure 1. Quality of Life of Aged people Persons

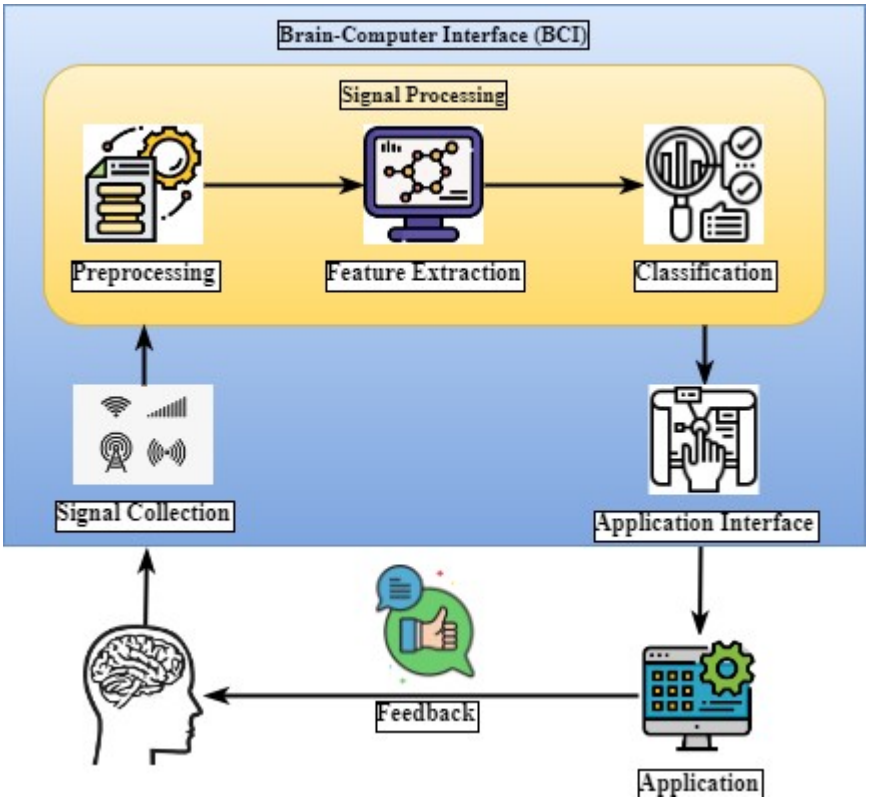

Figure 2. Brain-Computer Interface for aged people monitoring

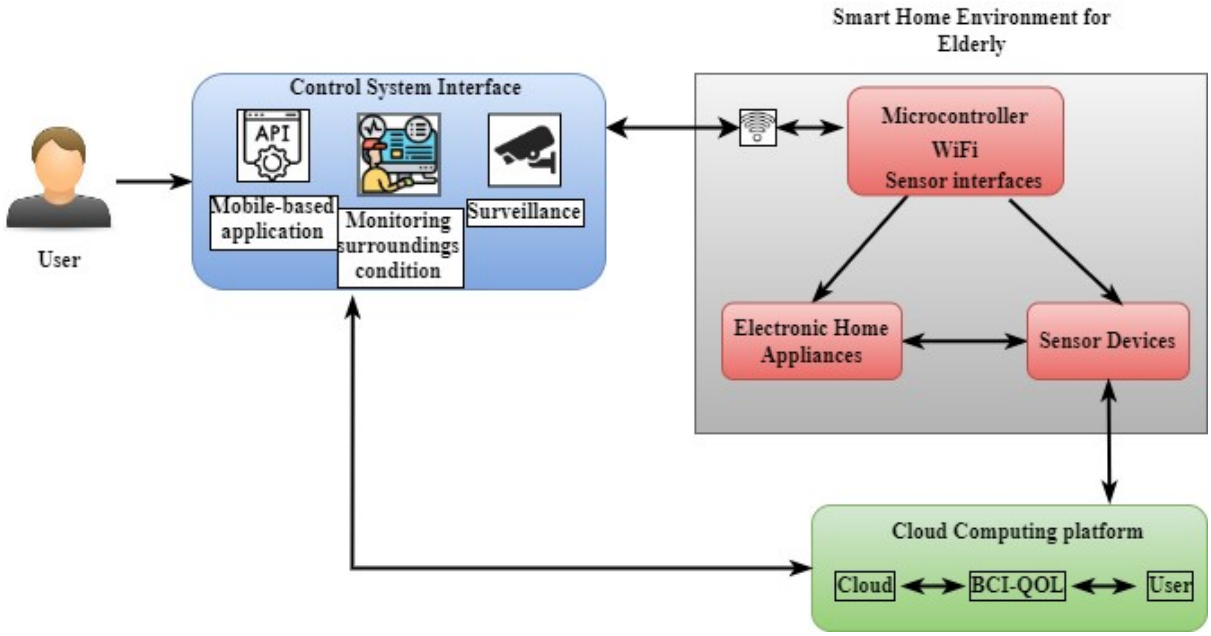

Figure 3. BCI-QOL in smart home environment for elders

enhances the smart home assistance system for the elderly, enabling functions like neighborhood monitoring, security camera checks, automatic control of electronics, medication reminders, and alerts for suspicious activities. The integration of brain signals and abnormalities aims to combine individual elements vertically, with minimal transmission delay between the brain and sensors. The total quantity of distinct elements aligns with the count of sensors capturing EEG signals. In theory, BCI seeks an exponential projection optimizing bilateral isolation as described in Box 1, Equation 1.

BCI functions as a translator of human brain activity into external actions by conveying neural commands to external devices. While commonly employed to assist individuals with motor system impairments, brain-computer interfaces can also significantly enhance the lives of healthy individuals, particularly the elderly. There is a demand for adaptive and rehabilitative BCI applications tailored to older individuals and aging patients, aiding them in daily tasks, strengthening interpersonal connections, and sharpening cognitive and physical faculties.

Various health concerns associated with aging, such as cognitive deficiencies, sluggish processing speed, reduced memory, and diminished movement capacity, can be addressed by BCI technology. With applications spanning clinical and non-clinical domains in medicine, entertainment, education, and psychology, BCI becomes a versatile tool. The mental health of the elderly, along with their overall quality of life, can be negatively impacted by these age-related challenges.

Over the past decade, numerous BCI applications have been developed to empower seniors in maintaining a high quality of life and fulfillment. In the mental health realm, BCI plays a crucial role in evaluating cognitive processes like attention and memory, identifying shifts in emotional states, monitoring therapeutic progress, measuring stress and relaxation, providing feedback during biofeedback exercises, diagnosing neurological disorders like Alzheimer's or Parkinson's disease, rehabilitating motor skills post-stroke or traumatic brain injury, and facilitating self-management of depressive symptoms.

BCIs based on EEG have proven valuable in the early detection of psychological problems, enabling timely intervention before they escalate. Some studies suggest that EEG-based BCIs can identify indicators of depressive distress that might elude traditional evaluation methods like questionnaires or interviews. The portability of EEG equipment in real-time situations outside clinical contexts provides essential information to doctors, even when patients are not physically present.

4. The Predictive Model effectiveness

Exploration of Brain-Computer Interfaces (BCIs) for restoring, repairing, or enhancing impaired cognitive or motor functions has gained significant attention, particularly with the growing elderly population. The selected research outlined in Table 1 sheds light on various ways BCIs contribute to improving the lives of the elderly, such as enhancing cognitive functions, managing smart homes, and providing limb support for mobility. Detailed information on participants, BCI paradigms, assigned tasks or goals, and experiment outcomes is provided to address the decline in memory and other cognitive capacities associated with aging.

a) Establishment of Efficacy in Enhancing Quality of Life (QOL)

While gauging the effectiveness of BCIs for computer control in diverse clinical trial cohorts can be challenging, this research emphasizes the potential of independent home BCI usage to offer quantifiable results. These results encompass occurrences of secondary medical complications, hospital stays, days spent out of the hospital, and changes in mortality rates. The study's longitudinal design suggests that clinical studies of new invasive BCIs face recruitment challenges but highlights the need for extended follow-up periods to consistently capture health indicators. Additionally, innovative patient-initiated communication channels are proposed to enhance health outcomes without the rigid requirements of a traditional "alarm" system.

b) Variables' Impact on Life Satisfaction

Four key factors significantly affect the quality of life, as explained in the study. Higher education levels correlate with increased happiness, exerting positive indirect effects on quality of life through general health and exercise. Urban living is associated with greater quality of life for the elderly, while neighborhood attractiveness and street security contribute positively to overall life satisfaction. Demographic factors like gender, age, physical restrictions, and the presence of grandkids show no statistically significant associations with life satisfaction. Physical restrictions modestly impact quality of life through general health, while social capital exerts a weak indirect impact through levels of physical activity and public health.

c) Enhancement of Elderly Quality of Life (QOL)

The study underscores the importance of convenience in the elderly's experience with a product or service over the benefits received. User-friendly systems, demonstrations, and training sessions are recommended for device makers and service providers to familiarize the elderly with smart home technology, encouraging wider adoption. To grasp the benefits of smart home services, the elderly need basic computer competence and BCI system familiarity, emphasizing the necessity of training programs that introduce and provide purpose.

d) Improvement in Elderly Care

Smart home technology can integrate diverse elderly-related devices into a comprehensive monitoring system, expanding the range of available information. Big data analytics, when

considering scaling and availability, can process vast amounts of diverse data to derive meaningful insights. The analysis incorporates sensory data, historical records (such as medical data), and supplementary information (maps, public transit data, shopping details, weather predictions) to offer more comprehensive services.

5. Conclusion

This groundbreaking research marks the first exploration into smart home adoption among the elderly, taking an innovative and exploratory approach. The proposed smart home environment control system, utilizing sensor modules, control modules, and human intervention, aims to automate the ON/OFF states of electronic appliances, detect intruders, and send timely alerts to users. Specifically designed to offer assistance to the aging population, the system has potential benefits for various patient categories, allowing them to independently operate computers using Brain-Computer Interfaces (BCIs). However, realizing these benefits requires expanding access to BCI technology beyond research contexts.

The study underscores the importance of addressing users' diverse needs and circumstances when designing general-purpose aging monitoring systems. The identified assumptions, while shaping system specifications, pose challenges for effective long-term monitoring of the elderly, emphasizing the critical need for methods that offer flexibility and individualization, ultimately ensuring personalization.

Before innovations in BCI technology can reach the market, demonstrating clinical and financial benefits to health insurance providers and regulatory agencies is essential. Developing reliable outcome metrics to substantiate the therapeutic use of BCIs becomes crucial for wider dissemination. Challenges arise in determining relevant metrics for clinical trials focused on BCIs for PC control, given the absence of a specific goal of recovering physical function. Further research is warranted to address these challenges and advance the field.

Ethical and privacy considerations must guide the appropriate use of BCI technology for individuals, emphasizing the need for a careful balance between technological advancements and safeguarding personal rights. The study highlights the necessity for additional research to fully harness the benefits of BCI technology for the dementia-affected population and underscores the ongoing exploration of BCIs for the elderly.

Author contribition

S.K.M. and D.K.M. conceptualized, wrote and reviewed on the BCIs for memory and non-invasive BCI for dementia.

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Competing financial interests

The authors have no conflict of interest.

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