

EEG-Based Brain-Computer Interfaces in Older Adults: Enhancing Memory, Function, and Quality of Life

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Key highlights:

- Neurofeedback improves cognitive function in older adults: Multiple studies, including meta-analyses and clinical trials, suggest that EEG neurofeedback can enhance memory, executive function, and overall cognitive performance in both healthy aging individuals and those with MCI or Alzheimer's disease.
- Neurophysiological evidence supports brain plasticity: Neurofeedback training has been shown to shift EEG activity toward healthier patterns (e.g., increased alpha power, decreased theta), and in some cases, induce functional reorganization of memory-related brain networks such as the parahippocampal region (Hohenfeld et al., 2017).
- Assistive Brain Computer Interfaces (BCIs) extend beyond cognitive training: BCIs are being developed for communication and mobility, offering support for individuals with advanced dementia through thought-controlled interfaces and smart devices, thereby enhancing autonomy and reducing isolation.

Introduction

As populations age, the incidence of cognitive decline, such as mild cognitive impairment (MCI), Alzheimer's disease (AD), and dementia, is rapidly increasing. Standard pharmacological treatments for these conditions have limited efficacy and fail to halt progression. In response, researchers have explored non-invasive interventions such as brain-computer interfaces (BCIs), particularly EEG-based neurofeedback (NFB), which enables individuals to modulate their brain activity using real-time visual or auditory feedback. Neurofeedback and BCIs sometimes are discussed together because both use real-time brain signals (e.g., typically EEG) to create a closed-loop system that supports cognitive functioning in aging populations. Neurofeedback represents a training-oriented form of BCI focused on self-regulation, while other BCIs translate neural activity into communication or assistive outputs. Their shared technological foundation and overlapping goals in

cognitive aging research make it appropriate to consider them within the same framework. These approaches aim to strengthen healthy neural patterns and support cognitive functioning in aging populations.

Beyond cognitive training, BCIs serve broader roles in assistive technology and clinical monitoring, offering new strategies to enhance quality of life for older adults with cognitive impairment.

Cognitive Training Outcomes

A growing body of research supports EEG neurofeedback's ability to improve memory and cognition. For instance, Laborda-Sánchez and Cansino (2021) reviewed 14 studies and found that EEG neurofeedback consistently improved memory in both healthy older adults and those with cognitive impairment, particularly when protocols targeted theta and sensorimotor rhythms. Tazaki (2024) similarly noted across 13 studies that NFB improved memory, attention, and other cognitive abilities in individuals with MCI and AD, despite variations in protocol and methodology.

Meta-analytic evidence reinforces these findings. Lin et al. (2024) analyzed 14 clinical trials involving 284 participants and reported moderate effect sizes for both working memory (Hedges' $g \approx 0.67$) and episodic memory ($g \approx 0.60$). Importantly, benefits extended to individuals with MCI, showing that neurofeedback is effective across varying degrees of cognitive decline. A critical insight was that more than 300 minutes of total training time was necessary to yield significant gains—highlighting the importance of intervention intensity.

Clinical trials also reported improvements in general cognitive functioning. Su et al. (2025) found that 92.9% of participants with amnesic MCI showed improved MoCA (Montreal Cognitive Assessment) scores following neurofeedback. However, not all individuals benefit equally. Paban et al. (2024) observed that one-third of older adults with subjective cognitive decline were “non-learners” who failed to master self-regulation of brain activity and did not improve cognitively. Their study further revealed that individualized neurofeedback protocols offered no significant advantage over standard ones, reinforcing the need to better understand individual variability in treatment responsiveness.

Despite this variability, the broader literature indicates meaningful improvements in memory and executive function for most older participants, making EEG neurofeedback a promising intervention.

Neurophysiological Mechanisms and Brain Plasticity

Neurofeedback targets specific neural oscillations to promote beneficial brain states. Aging and early-stage dementia are often characterized by increased slow-wave activity (theta and delta) and reduced alpha rhythms. Many neurofeedback protocols are therefore designed to downregulate excessive theta while upregulating alpha and beta waves associated with alertness and memory function. Several studies demonstrate that NFB can shift EEG profiles toward more youthful patterns. For example, increases in upper-alpha power and reductions in theta activity have been observed following training in older adults with MCI. These changes can persist beyond the training period, suggesting durable effects on brain function.

Moreover, neurofeedback may promote reorganization of functional brain networks. Su et al. (2025) showed that neurofeedback enhanced connectivity strength and global efficiency in delta-band networks while reducing maladaptive connectivity in higher frequency bands. Other studies have reported similar increases in EEG coherence and synchronization between key brain regions involved in memory processing.

Hohenfeld et al. (2017) found that individuals with prodromal AD showed activation of parahippocampal regions—critical for memory—after neurofeedback training. Even healthy older adults displayed similar neural responses, while placebo controls did not, indicating that neurofeedback likely facilitates genuine neuroplastic changes.

At its core, EEG neurofeedback leverages operant conditioning and Hebbian learning. By rewarding desired brain states in real time, it reinforces optimal neural activity and strengthens the synaptic pathways responsible for those patterns. Over time, this repeated training can recalibrate dysfunctional neural circuits and enhance cognitive performance, particularly memory and executive functions.

Assistive Applications and Quality of Life

BCIs are not limited to training; they also support communication, mobility, and independent living in individuals with cognitive and motor impairments. As verbal and motor functions decline in dementia, BCI-based systems can help users communicate through thought-controlled text or yes/no interfaces. These technologies can reduce isolation and preserve autonomy.

For example, EEG-controlled spellers or smart-home devices allow individuals with late-stage dementia to interact with their environment despite profound communication or mobility limitations. BCIs are also being integrated into wheelchairs, prosthetics, and environmental controls, offering enhanced independence for users with impaired motor skills.

In clinical settings, BCIs hold potential for early detection of neurodegenerative diseases. EEG can reveal subtle markers of cognitive decline, such as decreased alpha power or slowed dominant rhythms, long before symptoms become clinically apparent. Combined with machine learning and neuroimaging, BCIs can stratify AD severity or monitor disease progression in real time.

Although many assistive BCI technologies are in the prototype phase, they illustrate the broad potential of EEG-based systems to not only restore function but also maintain quality of life for individuals with aging-related cognitive decline.

Challenges and Future Directions

Despite promising results, several challenges remain. Many early studies had small sample sizes, lacked blinding, or used diverse protocols, limiting generalizability. Standardized training protocols, larger clinical trials, and robust placebo controls are essential for validating findings.

Another challenge is variability in outcomes due to differences in EEG signal quality, learning ability, and motivation—especially in older populations with comorbid conditions. Older adults tend to produce noisier EEG signals and may experience cognitive fatigue more quickly. As a result, algorithms must be adapted to age-related neural variability, and interfaces must be user-friendly to ensure sustained engagement.

Technological limitations also pose barriers. Most EEG neurofeedback systems are not yet optimized for home use. Portable, wearable, and wireless EEG devices are needed to scale interventions beyond clinical settings. Integration with artificial intelligence can enhance adaptability, personalizing training to individual performance in real time.

Hybrid BCIs that incorporate additional modalities such as fNIRS, eye tracking, or biosensors, could further improve signal quality and feedback precision. Advances in wireless connectivity, electrode comfort, and interface design will be key to broader adoption.

Looking ahead, the most promising approaches will combine EEG neurofeedback with other non-pharmacological therapies, such as cognitive games, physical exercise, or non-invasive brain stimulation (e.g., tDCS or TMS). Multimodal strategies that address multiple mechanisms of decline may offer synergistic benefits.

Critically, future research must move beyond short-term cognitive gains to assess whether BCI interventions delay dementia onset, improve functional independence, or enhance overall well-being in older adults. Longitudinal studies, real-world outcome measures, and patient-centered design will be essential to establish the lasting value of these technologies.

Conclusion

BCIs and EEG neurofeedback offer a novel and potentially transformative approach to cognitive aging. By promoting neuroplasticity and improving memory and executive function, these tools could help older adults maintain autonomy, communication, and quality of life. As research progresses, the refinement of protocols, technology, and accessibility will determine the extent to which these interventions become integrated into future dementia care.

For further reading:

Hohenfeld, C., Nellessen, N., Dogan, I., Kuhn, H., Müller, C., Papa, F., ... & Reetz, K. (2017). Cognitive improvement and brain changes after real-time functional MRI neurofeedback training in healthy elderly and prodromal Alzheimer's disease. *Frontiers in neurology*, *8*, 384.

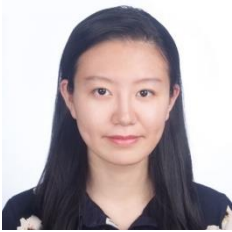
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