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EFFECTIVENESS OF NEUROFEEDBACK-BASED COGNITIVE TRAINING IN OLDER ADULTS

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Abstract: *The increasing aging of the global population requires strategies that address age-related cognitive decline. This study investigated the impact of neurofeedback (NF) training on cognitive performance in healthy older adults, those with mild cognitive impairments (MCI), and those with mild dementia (MD). Participants engaged in bi-weekly NeuroPlay training over 4 weeks, targeting theta/alpha brainwave frequencies. The results revealed intriguing distinctions: ACE-III scores significantly improved in the MCI ($p < 0.001$) and MD ($p = 0.004$) groups, signifying robust enhancements in attention, memory, and language. MCI participants displayed notable gains in digit span tests ($p = 0.014$) and participants' Continuous Performance Task results indicated fewer errors ($p = 0.003$). Meanwhile, reaction times in the Simple Reaction Time task increased ($p = 0.047$) for healthy participants. These findings underscore NF's potential to enhance cognitive functions, particularly in attention-related tasks, suggesting its efficacy as an intervention tool for age-related cognitive decline.*

Keywords: *neurofeedback, mild cognitive impairment, mild dementia, cognitive training*.

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INTRODUCTION

The global population is aging at an alarming rate. The number of elderly people is expected to increase from 10% in 2022 to 16% in 2050. Furthermore, the number of people 65 years of age or older is forecast to be more than twice the number of children under 5 (United Nations Department of Economic and Social Affairs Population Division, 2022). With increased longevity and an aging population, the prevalence of age-related disorders, including cognitive and motor dysfunctions, is bound to rise (Podhorecka et al., 2021).

Deterioration of cognitive functioning is a natural age-related process that may contribute to several limitations. The most noticeable differences are observed in attention, memory, and executive functions, essential for independent living, communication, and sensory integration. This type of cognitive decline is most frequently associated with neuronal dysfunction or neuronal loss, which may also make it challenging to learn new abilities, impair short-term memory, working memory, decision-making, or multitasking (Murman, 2015; Wojciechowski et al., 2021).

Cognitive performance in older adults can be effectively stimulated by cognitive training that is increasingly becoming computerized (computerized cognitive training, CTT). CTT has gained considerable popularity as a safe, relatively affordable, and customizable intervention tool for maintaining cognitive functioning in older adults (Hill et al., 2017). Compared to traditional interventions, it allows for the use of single or multiple domains of cognitive functioning with flexible adaptation of exercises to the patient's performance and provides real-time performance feedback (Hill et al., 2017; Lampit et al., 2014). In addition, computerized training is characterized by situational accuracy as it refers to everyday life skills with multidimensional interfaces. Such visually appealing interfaces are well suited for the elderly and are intended to be enjoyable, exciting, and motivating for further training programs (Zając-Lamparska et al., 2019). Recent studies have demonstrated the effectiveness of CTT in healthy older adults and individuals with mild cognitive impairment (MCI) by stimulating neuroplasticity (Hill et al., 2017; Kueider et al., 2012; Lampit et al., 2014). However, such computer-based interventions have noted limitations, particularly in terms of modern technology accessibility among the elderly and the use of CTT in dementia patients. Therefore, there are a growing number of emerging trends in cognitive training, especially with the use of biometric sensors (Stavropoulos et al., 2020).

Neurofeedback (NF) is a method applicable to cognitive training. It is a non-invasive technique that promotes self-regulation of brain function by using real-time displays of neural activity, most frequently with electroencephalography (EEG). NF is a closed-loop application that can help control or modify cortical activity. Individuals are exposed to visual and/or auditory stimuli, representing various frequencies of bioelectrical brain activity that are recorded by sensors located on the scalp; thus, they can actively participate in the regulation of their brain activity with this type of training (Laborda-Sánchez & Cansino, 2021). The training aims to increase attention and memory and lower anxiety (Marlats et al., 2020). Recent studies have shown the effectiveness of NF in hyperactivity disorder, epilepsy, autism, depression, and anxiety.

NF is also widely used in cognitive training with specific training protocols targeting frequency bands related to cognitive functioning. The first studies incorporating NF effects on memory were conducted with young adults (Lecomte & Juhel, 2011). The training condition was stimulation of alpha waves (8–12 Hz, related to the relaxation) (Bauer, 1976) or theta waves (4–7 Hz, connected to the working memory) with inhibition of delta waves (< 4 Hz, associated with sleep) (Vernon et al., 2003). Another protocol applied stimulation of sensorimotor rhythm (SMR) waves (12–15 Hz, related to attention) and inhibition of beta (18–22 Hz, associated with anxiety) (Vernon et al., 2003). Further studies showed that, generally, alpha/theta training can result in an improvement in cognitive performance in young adults (Hanslmayr et al., 2005).

NF has been widely used to improve cognitive function in various age groups. In children, NF is most commonly used to improve attention, impulsivity, and hyperactivity, with a series of studies providing evidence for the positive effects of NF in attention deficit hyperactivity disorder (ADHD). The most widespread protocol is theta/beta training where the goal is to decrease activity in the theta band and to increase the beta band in the frontal cortex. For this protocol, a decrease in behavioral problems and improved cognitive performance have been reported (Gevensleben et al., 2009; Heinrich et al., 2004; Strehl et al., 2017). In healthy adults, increasing the power of SMR brain waves has been reported to improve attention, memory, and executive function (Gruzelier, 2014). This protocol with 30 to 40 treatment sessions has also been reported to be effective in adults with ADHD (Arns et al., 2014). The latest findings have shown that NF is also useful to reduce reaction time and improve the cognitive performance of adult athletes. Nonetheless, no standard protocol has been found among the studies, as most of them used different frequency bands and different locations to measure the effect of NF (Brito et al., 2022).

Although the impact of NF on cognition has been established, only several studies have been conducted on the application of NF among older adults (Lecomte & Juhel, 2011). Comprehension of neural activity in the elderly is essential for the development of NF protocols. Peak alpha frequency (PAF) is known to be weaker in children, the elderly, and individuals with Alzheimer’s disease; thus, available protocols related to the PAF are on the rise.

Increases in PAF have been noticeable in frontal lobe brain areas after 30 NF sessions; this result was related to the enhancement of the speed of information processing, memory performance, and the resistance to interference (Angelakis et al., 2007). Alpha training lasting 10 days has also been confirmed to improve the flexibility of executive functions in patients after stroke (Reichert et al., 2016). In another study, a short and intensive alpha/theta NF protocol demonstrated that an intervention consisting of 30-minute sessions for 8 days improved cognition, especially short-term memory (Reis et al., 2016).

The role of the SMR/theta protocol was also investigated (Marlats et al., 2020). The average training period was 10 weeks, with two sessions each week. Results suggested that such training could be beneficial in reducing cognitive decline in the elderly.

SMR NF is suggested to facilitate thalamic inhibitory mechanisms and block motor activity that interferes with information processing; hence, it is claimed to improve working memory and attention in older adults (Kober et al., 2015). Working and short-term memory have also been enhanced by SMR training (Compos da Paz et al., 2018; Gomez-Pilar et al., 2016). Moreover, verbal ability increased during the protocol in Becerraa et al. (2011).

A systematic review of the effects of NF on memory in older people with cognitive decline observed that NF improved memory in both healthy and MCI people, particularly when the SMR/theta protocol was investigated (Laborda-Sánchez & Cansino, 2021). In general, there was no effect on the attention process. In contrast, another review revealed that NF can also increase attention functions in the elderly (Jiang et al., 2017), so its role in attentional capacity remains unclear.

NF protocols have been reported to improve cognition in older adults in at least one domain. The protocols distinguished between alpha/theta and SMR/theta protocols, with SMR waves obtaining more significant results (Laborda-Sánchez & Cansino, 2021). The current study aimed to investigate the role of NF training in cognitive performance in healthy older adults and those with MCI or mild dementia (MD).

METHODS

The study sample was recruited from various assisted living communities. The approval of a Bioethics Committee was obtained. The longitudinal design was evaluated. Participants were selected based on a medical diagnosis and Mini-Mental State Examination (MMSE) scores, with 27–30 points indicating normative cognitive function, 24–26 points indicating MCI, and 19–23 points indicating MD. Written consent was obtained from all qualified participants, and in the case of individuals with dementia, their caregivers also provided consent.

All participants underwent a neuropsychological assessment twice: a pretest conducted 3–7 days before training sessions using NeuroPlay, and a posttest conducted 3–7 days after the completion of the training. The NeuroPlay training sessions took place twice a week for 4 consecutive weeks. Each study session lasted approximately 45 min; the NF training itself lasted 21 min and consisted of six phases: alternate periods of eyes closed (2 min) and eyes open (5 min, active attention training). Thus, one training session comprised three 7-minute micro-cycles. The training protocol utilized a theta/alpha-based algorithm, promoting the increase of averaged theta [4–7] and alpha [8–12] frequency band values, as well as the theta/alpha ratio for the O1 and O2 areas (occipital leads), with the Fp1 and Fp2 areas (frontal leads) treated as control regions for the final comprehensive analysis. More specifically, Fast Fourier Transform (FFT) was used to algorithmically analyze the transmitted data. The algorithm consisted of key steps such as downloading data for selected channels, recalculating the data for each electrode using the FFT algorithm, calculating weighted averages from the given frequency ranges and then calculating their difference. In the next step, the data for each electrode were compared with the data calculated in the previous steps (shifting the reading frame), and then the data were summed and mapped, ultimately leading to a specific value of the fit factor parameter (ffx), which controls the animation and sound in the training games. NeuroPlay training used a headband fitted with ten EEG sensors placed around the circumference of the head, in a system corresponding to the standard electrode arrangement for EEG measurement in the 10-20 model. In practice, the headband was wirelessly connected to the tablet via a Bluetooth 5.0 connection and the NeuroPlay application installed on the tablet. In the Neuroplay solution, the headband is a measurement device, while the processing and decision algorithm is implemented in an application on the tablet. The main electronics of the headband (PCB with radio module, battery, USB-C input) were placed on the back of the head.

Study Methods

The study was performed using the following neuropsychological tools: (1) the MMSE to test time orientation, attention, verbal memory, language functions, and visual-spatial analysis; (2) Addenbrooke's Cognitive Examination III (ACE-III), a screening test composed of tests of attention, orientation, memory, language, visual perceptual, and visuospatial skills; (3) the Color Trail Test (CTT) to assess psychomotor speed, attention, spatial ability, and executive functions; (4) the forward and backward Digit Span Test (DST) from WAIS-R (PL) to assess attention and verbal short-term and working memory; (5) the Digit Symbol Coding (DSC) task from WAIS-R (PL) to examine learning abilities, attention, short-term memory, and visuospatial skills; (6) the Go/No-Go test to measure psychomotor speed, sustained attention, and response control; (7) the California Verbal Learning Test (CVLT) to measure the ability to learn and remember verbal material; (8) the Continuous Performance Task (CPT) to examine sustained and selective attention; and (9) the Simple Reaction Time (SRT) to assess the ability to sustain attention over a prolonged period of time.

Participants

A total of 190 participants comprised the sample. The individuals were divided into groups based on cognitive status and whether they participated in NF training (experimental group) or traditional paper-and-pencil cognitive training (active control group). Among people without cognitive impairments, the experimental group consisted of 53 participants (27 females; age: M =71.075, SD = 5.207; years of education: M = 14.430, SD = 4.591), while the active control group included 17 participants (14 females; age: M = 73.882, SD = 5.999; years of education: M = 13.647, SD = 3.570).

Among individuals with MCI (mild cognitive impairment), the experimental group included 52 participants (37 females; age: M = 74.442, SD = 6.014; years of education: M = 12.212, SD = 2.696), while the active control group consisted of 11 participants (six females; age: M = 73.091, SD = 5.029; years of education: M = 13.900, SD = 3.929).

Among individuals with MD (mild dementia), 48 participants were in the experimental group (30 females; age: M = 77.583, SD = 6.731; years of education: M = 12.177, SD = 2.790), while nine participants were in the active control group (eight females; age: M = 77.111, SD = 5.487; years of education: M = 12.556, SD = 2.455).

Statistical Analyses

ANOVA tests were used to assess cognitive functioning differences before and after training, considering NF or traditional cognitive training. Separate analyses were conducted based on cognitive status subgroups. A repeated measures ANOVA was used for single-indicator measurement tools, while a repeated measures MANOVA was used for multiple indicators. Univariate analyses were performed when a MANOVA showed significant differences, and post hoc tests were performed for specific pairwise differences.

RESULTS

In this section, only statistically significant differences between the cognitive performance prior to and after the test will be discussed. In all groups, no significant differences were observed in the following tests: CVLT, Go/No-Go task, DSC, and CTT. Additionally, within the healthy group, there were no significant differences in the forward and backward DST, MMSE, and ACE-III. In the group with MCI, there were no significant differences in the forward and backward DST after traditional cognitive training and the SRT independent of the type of training. For the MD group, no significant differences were found in the CPT and SRT, regardless of the training type.

Differences in the Pretest and Posttest Screening Scores (MMSE, ACE-III)

Significant differences in cognitive performance were observed between people with MCI ($F = 14.320$, $p < .001$, partial $\eta 2 = 0.19$) and MD ($F = 9.370$, $p =.003$, partial $\eta 2 = 0.15$), while no significant differences were found in those with normal cognitive functioning. These differences were independent of the type of training. However, for individuals with MCI, significant differences were found between pre-training and post-training ACE-III scores (Wilks' lambda = 0.763, $F = 3.538$, $p =.007$, partial $\eta 2 = 0.24$), indicating improvements, particularly in the attention domain ($F = 14.844$, $p < .001$), regardless of the training type. Similarly, among people with MD, significant differences were observed between the first and second measurements of ACE-III measurements (Wilks' lambda = 0.714, $F = 4.002$, $p =.004$, partial $\eta 2 = 0.29$), with significant improvements in memory ($F = 15.429$, $p < .001$) and language functions ($F = 7.491$, $p =.008$), regardless of the type of training. Table 1 refers to the significant results of the MMSE and ACE-III tests obtained among individuals differing in cognitive status before and after the training.

Table 1. Significant Differences in MMSE and ACE-III Scores Obtained Among Individuals Differing in Cognitive Status Before and After the Training, Accounting for the Type of Training Implemented.

Test/Group	**Neurofeedback training**		**Traditional cognitive training**	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)	Pretest *M* (*SD*)	Posttest *M* (*SD*)
MMSE				
MCI	25.404 (0.634)	26.558 (1.650)	24.909 (0.831)	25.727 (1.348)
MD	21.500 (1.305)	22.979 (2.893)	21.222 (1.093)	22.111 (1.167)
ACE-III Attention				
MCI	15.788 (1.073)	16.577 (1.391)	14.000 (2.191)	14.818 (2.040)
ACE-III Memory				
MD	12.438 (4.491)	14.213 (4.530)	13.556 (3.844)	15.667 (2.739)
ACE-III Language				
MD	20.917 (3.432)	21.660 (3.074)	20.889 (2.977)	21.778 (2.728)

Note. MCI – mild cognitive impairment, MD – mild dementia.

Differences in the Pretest and Posttest Digit Span Test (DST) Scores

No significant differences were found in the DST across all groups, irrespective of the training type. However, in the MCI group, a near-significant interaction effect between measurement and training groups prompted further univariate analyses. These analyses revealed significant differences in the forward DST between pre- and post-training measurements, depending on the type of training ($F = 6.498$, $p = .014$). However, post hoc analysis showed a statistically significant improvement in the NF training group ($p = .008$), while the decrease in the active control group was not statistically significant ($p = .633$). Table 2 refers to the significant results obtained in the DST.

Table 2. Significant Differences in WAIS-R Scores Obtained Between MCI-Positive Individuals Before and After Training, Accounting for the Type of Training Carried Out

Test/Group	**Neurofeedback training**	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)
Forward Digit Span Test		
MCI	4.904 (1.176)	5.327 (1.410)

Note. MCI – mild cognitive impairment.

Differences in the Pretest and Posttest Continuous Performance Test Scores

Analyses with CPT scores were conducted with smaller sample sizes due to incomplete data. The analysis included 36 healthy individuals (25 neurofeedback, 11 active control), 42 individuals with MCI (36 neurofeedback, six active control), and 38 individuals with MD (35 neurofeedback, three active control). Among healthy individuals, an interactive effect of measurement time and training type was observed in the total number of errors ($F = 9.963$, $p = .003$). A post hoc analysis revealed a significant increase in errors after NF training ($p = .044$), while traditional training did not yield a statistically significant change. In the MCI group, significant differences were found between pre- and post-NF training measurements. Univariate analyses showed that the total number of errors was the only performance indicator affected by this interaction ($F = 9.963$, $p = .003$), with better results after the training. In the MD group, there were no statistically significant differences between the results of the pre-and posttest. Table 3 refers to the significant results obtained in the CPT.

Table 3. Results from the CPT Obtained Among Individuals With Varying Cognitive States in the Measurement Before and After Training, Considering the Type of Training Conducted.

Test/Group	**Neurofeedback training**	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)
Error numbers		
CN	0.960 (1.513)	1.640 (1.469)
MCI	1.972 (3.009)	1.083 (1.052)

Note. CN – cognitive norm, MCI – mild cognitive impairment.

Differences in the Pretest and Posttest Sustained Response Task (SRT) Scores

Analyses of SRT scores were carried out with smaller sample sizes due to incomplete data. The analysis included 35 healthy individuals (24 neurofeedback, 11 active control), 40 individuals with MCI (35 neurofeedback, five active control), and 36 individuals with MD (33 neurofeedback, three active control). In healthy individuals, a significant change was observed in the second measurement compared to the first (*Wilks' lambda* = 0.826, F = 3.374, p =.047, partial $\eta 2$ = 0.17), specifically an increase in the average reaction time (F = 6.253, p =.018) regardless of the training type. No significant changes were observed in individuals with MCI or MD due to NF training. See Table 4 for detailed results.

Table 4. Significant Results from the SRT Obtained Among Individuals in Healthy Adults in the Pre-Training and Post-Training Measurements, Accounting for the Type of Training Performed

Test/Group	**Neurofeedback training**		**Traditional cognitive training**	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)	Pretest *M* (*SD*)	Posttest *M* (*SD*)
	Average reaction time (in ms)			
CN	1460.785 (763.387)	1557.394 (702.305)	1392.709 (771.427)	1833.441 (589.416)

Note. CN – cognitive norm.

DISCUSSION

The present study aimed to investigate the effects of NF (neurofeedback) training on cognitive performance in older adults with different cognitive performances. The results obtained indicate that NF training may have selective effects on specific cognitive domains and may not improve performance on all cognitive tasks (see Table 5).

Table 5. Summary of the Results Obtained.

	Neurofeedback training			**Traditional cognitive training**		
	CN	MCI	MD	CN	MCI	MD
MMSE	-	+ ↑	+ ↑	-	+ ↑	+ ↑
ACE-III	-	+ ↑	+ ↑	-	+ ↑	+ ↑
CTT	-	-	-	-	-	-
DST	-	+ ↑	-	-	-	-
DSC	-	-	-	-	-	-
Go/No-Go	-	-	-	-	-	-
CVLT	-	-	-	-	-	-
CPT	+ ↓	+ ↑	-	-	-	-
SRT	+ ↓	-	-	+ ↓	-	-

Note. CN – cognitive norm, MCI – mild cognitive impairment, MD – mild dementia, (+) – significant difference between pre- and posttest, (-) – no significant difference between pre-and posttest, (↑) – better obtained results within the difference, (↓) – worse obtained results within the difference.

Interesting results were obtained with the MMSE and ACE-III screening tests, which showed significant differences between pretest and posttest scores in individuals with MCI and MD, regardless of the type of training. These screening tools are considered sensitive to cognitive changes in individuals with cognitive decline (Kourtesis et al., 2020), thus no differences in scores in healthy subjects seem reasonable. In the ACE-III, the MCI group improved in attention, while those with MD achieved progress in both memory and language function. Such enhancement was acquired both in NF and traditional cognitive training, which indicates that any brain stimulation—understood as cognitive activity—may stimulate overall cognitive ability measured by screening tools (Liu et al., 2016). Furthermore, the social aspect may also have influenced the results in the experimental and active control groups, as both groups had direct contact with the researcher. Phenomenologically, MCI and MD appear to bring a lower quality of life, more frequent depressive symptoms, and avoidant coping strategies compared to healthy older adults (Bárrios et al., 2013). Researchers indicate that loneliness predicts cognitive decline and the risk of developing dementia (e.g., Freak-Poli et al., 2021), therefore social interactions are perceived as a promising intervention for improving cognitive function, especially for language functions (Dodge et al., 2015).

The results obtained also suggest that NeuroPlay training may have beneficial effects on the ability to maintain and manipulate information in short-term and working memory in individuals with MCI. Specifically, MCI individuals showed improvement in the DST (Digit Span Task) after NF training. These findings are partially in line with previous studies that indicate older individuals with MCI can improve specific aspects of EEG activity, leading to improvements in working memory and processing speed (Lavy et al., 2019). Studies focusing on training the alpha brainwave frequency showed significant improvements in short-term memory and working memory tasks, including the DST (Digit Span Test), highlighting the potential role of alpha training in cognitive performance (Hsueh et al., 2016).

Furthermore, the MCI individuals improved in the CPT (Continuous Performance Task), which is sensitive to sustained and selective attention. Subjects made fewer errors after NF training, implying that they paid more attention to the tasks, indicating that NF is also helpful for attention enhancement (Cho et al., 2004).

Notably, no differences were observed in the Go/No-Go test across all groups, regardless of the type of training. Although both tasks are designed to assess complex attentional functions, the CPT is more sensitive to response inhibition, which is thought to be better evaluated by the theta components that were targeted in the NF protocol employed in this study (Kirmizi-Alsan et al., 2006). Moreover, the findings hold particular relevance as research suggests that deficits in attentional processes may underlie the development of episodic memory loss—a hallmark of dementia in Alzheimer's disease. Therefore, the observed protective role of NF training in mitigating further cognitive decline in people with MCI is noteworthy (Malhotra, 2019).

In the analyses of the healthy subjects' group, the reaction time in the SRT (Simple Reaction Time) task increased significantly regardless of the type of training. Furthermore, the number of errors in the CPT (Continuous Performance Test) increased in the NF group. It should be noted that both tasks are designed to assess sustained attention. Previous research suggested that older individuals exhibit slower responses to stimuli compared to younger individuals, a phenomenon that has been attributed to a reduction in alpha wave power in EEG tests (Gajewski & Falkenstein, 2014; Porciatti et al., 1999). Nevertheless, researchers have indicated that increasing the alpha wave power in NF does not decrease participants' reaction time (Woodruff, 1975). Conversely, augmenting the power or amplitude of faster brain frequencies, such as the SMR (sensorimotor rhythm, 12–15 Hz), and increasing beta waves in the 13–30 Hz range, may lead to faster reaction times (Egner & Gruzelier, 2004). From a neurophysiological standpoint, it is known that shorter response times are associated with heightened EEG oscillatory activity and increased arousal levels, although this association does not necessarily lead to more accurate responses. Enhancements in alpha wave power can improve accuracy on the CPT, as evidenced by a reduction in errors. However, these enhancements tend to slow down reaction times, particularly in the SRT task, due to a decrease in arousal (Mirifar et al., 2022), although this hypothesis was not confirmed in the present study.

Among normal-aging subjects, there was a significant increase in the number of errors after NF training, as well as a substantial increase in reaction time during the second measurement of the SRT task. It can be hypothesized that motivation plays a significant role in explaining this phenomenon. In the context of cognitive tasks, older adults frequently exhibit a heightened sensitivity to motivational factors in comparison to their younger counterparts (Ennis et al., 2013; Hess, 2014). In the present study, participants underwent a repeated administration of tasks that were relatively straightforward and could have lacked engagement during the posttest session. This potential lack of engagement might have contributed to the observed decline in performance.

Recent studies indicate that theta and alpha bands serve as important indicators of cognitive abilities in older adults, suggesting that changes in these frequency bands are likely predictive of cognitive impairments (e.g., Trammell et al., 2017). Consequently, the theta/alpha NF protocol may be more beneficial for people with MCI (mild cognitive impairment) compared to healthy adults, which may explain the lack of general differences observed in the current study between the cognitively normal group. Furthermore, the MD (mild dementia) subjects demonstrated improvements only on our screening tools, including the MMSE and ACE-III. Dementia symptoms encompass a range of cognitive impairments including memory loss, language difficulties, anxiety, depression, and personality changes (Trambaiolli et al., 2021). The available studies that focus on the role of NF in MD implemented protocols that included 10 to 96 training sessions (Surmeli et al., 2016; Trambaiolli et al., 2021). It is plausible to hypothesize that a greater number of sessions may be necessary for MD patients to show improvements in more sensitive neuropsychological measures.

NF has been reported to improve cognition in older adults in at least one domain (Laborda-Sánchez & Cansino, 2021), typically focusing on improvement in a specific cognitive domain, as each brain wave is associated with different cognitive functions. Different protocols are employed for improving specific cognitive functions. For example, alpha waves are connected with relaxation and mental coordination, theta waves are linked to working memory, SMR waves to motor control and attention (De, Mondal, 2020).A significant body of work has linked alpha- and theta-band activity with attention (Foster et al., 2017; Guo et al., 2020). This supports the observation that only attention-related task performance improved in individuals with MCI (mild cognitive impairment).

In general, this study found that NF training had selective effects on cognitive performance in older adults, with improvements seen in specific cognitive domains. Aligning with previous studies, the theta/alpha protocol was related to improvements in attention domains. The findings highlight the potential of NF as an intervention to enhance cognitive function, especially in individuals with MCI. The social aspect of training and the role of brain wave frequencies in cognitive abilities were also discussed.

The study has several limitations. In our study, the active control groups were smaller than the experimental groups, which may affect the generalizability of the results, as unequal group sizes can increase the margin of error. in addition, as mentioned before, the weakening of some indicators (SRT and CPT) after neurofeedback therapy may be related to the lack of engagement with these particular tasks, which was another limitation of the study. It is possible that the repetitive nature of these tasks led to decreased motivation over time. Moreover, SRT and CPT are considered to be tedious and less attractive tasks, so the greater risk of loss of engagement is not necessarily due to neurofeedback itself. Despite these limitations, the present study provides valuable insights into the effects of NF training on cognitive performance in older adults with different cognitive abilities, suggesting the NF as an intervention for cognitive enhancement in aging populations. Further studies with larger groups are required to confirm and understand the full impact of NF training on cognitive achievement in older people with diverse cognitive functioning. It would also be valuable to investigate whether the observed improvements in cognitive performance are sustained over time. Future studies should also consider controlling for potential confounding variables that could influence the results, such as the use of medications by participants, comorbidities, or lifestyle factors.

CONCLUSIONS

The study revealed that NF training selectively improved certain cognitive domains in older adults, particularly those with MCI. Notably, improvements were observed in attention-related tasks for MCI individuals. Screening tools, such as the MMSE and ACE-III, showed significant differences in individuals with MCI and MD, suggesting improvements in attention, memory, and language function.

The theta/alpha NF protocol appeared more beneficial for those with MCI. To further understand NF's impact, future research with larger samples, long-term follow-ups, and control for confounding variables is recommended. Despite limitations, the study highlights NF's potential for enhancing cognitive function in older adults, especially those with cognitive impairments, through tailored protocols. Such tailored protocols are designed to meet the specific needs of each individual, rather than applying a generic treatment approach. It includes adjusting the neurofeedback training to target specific brainwave patterns that are linked to cognitive functions. For instance, increasing alpha wave activity can help improve relaxation for individuals who experience stress-related cognitive impairments or increasing theta wave activity can improve memory and attention.

IMPLICATIONS FOR THEORY

The research reveals that NF training has specific benefits on several cognitive domains. In an age where the world's population is getting older, training that is specifically targeted at particular cognitive domains, as this study has shown, has the potential to improve cognitive functioning and potentially slow down age-related cognitive decline.

The study also highlights the complex interactions between cognitive domains by revealing an intriguing idea: cognitive activity as a type of brain stimulation. This realization might completely change our knowledge of cognitive processes and how to use them to enhance cognitive function as a whole. The study also emphasizes how important motivation and engagement are for cognitive training, particularly for older persons. Understanding the importance of these variables might help develop more successful cognitive interventions that are suited to the particular requirements and traits of the elderly population, thereby promoting improved cognitive well-being as the population ages.

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