Effects of EEG Neurofeedback Training on Visuospatial Working Memory Performance: A Comparison between Auditory Short-Term Deprived and Healthy Individuals

İdil Kuruöz - 21902009

Department of Psychology - Bilkent University

PSYC 506 & PSYC 406: Introduction to Electroencephalography (EEG)

Instructor: Asst. Prof. Burcu Ayşen Ürgen

June 4, 2023

Abstract

The present study aims to investigate the EEG neurofeedback training in working memory and compare healthy subjects and auditory short-term deprived subjects. As Vernon (2005) stated, EEG neurofeedback is a type of biofeedback that focuses on unique parts of cortical activity and demands the individual comprehend to adjust some elements of their cortical activity. EEG neurofeedback can be used for different aims in different settings. This study aims to use EEG neurofeedback not for clinical purposes but for neuroscience context experimental causes to investigate if EEG neurofeedback can enhance cognitive abilities. as mentioned in Geppert et al. (2017). Prior literature showed that subjects could benefit from EEG neurofeedback in different cognitive domains and tasks to increase their performance, as demonstrated by Gruzelier et al. (2014) and Vernon (2015). Among the cognitive domain, the most promising ones are attention and memory. As To et al. (2016) reviewed, EEG neurofeedback can enhance working memory performance. Prior literature generally focuses on healthy subjects, mainly when EEG neurofeedback is not used for clinical purposes. This particular study will focus on deprivation. As shown by Heled et al. (2022), blind and deaf people show enhanced working memory performance compared to control groups which can be explained by neuroplasticity. For short term-deprivation, enhanced performance for cognitive task results are not that clear, but some researches prove short-term deprivation can also result in enhanced performance. Adding the EEG neurofeedback's promising enhanced performance on cognitive tasks, this study will compare healthy subjects and an auditory short-term deprived group with the control group. A total of 30 subjects will participate in the study. Ten will be in the control group with no NF training. 20 will be the NF training group: ten deprived and ten non-deprived. All of them will be compared according to their Spatial Span Task performance. EEG neurofeedback technique can be compared to neuroplasticity in that neuroplasticity is the brain's ability to renew and modify itself. In contrast, EEG neurofeedback is the individual's ability to modify some cortical activity based on unique cortical activity patterns. In this context, it is hypothesized that both the healthy subjects and the auditory sensory deprived in the NF training group will benefit from EEG neurofeedback and show increased performance on visuospatial working memory tasks compared to their initial performance and compared to the control group. Moreover, it is expected that the short-term deprived group will deliver superior performance compared to the non-deprived group adding the benefit of neuroplasticity and EEG neurofeedback.

Introduction

As Vernon (2005) stated, EEG neurofeedback is a kind of biofeedback established on unique characteristics of cortical activity. EEG neurofeedback needs the individual to learn to adjust some parts of their cortical activity. This can contain comprehending to adjust the frequency, amplitude, or coherency of different electrophysiological features of an individual's brain. Neurofeedback training aims to guide the individual on what unique forms of cortical arousal sense like and how to trigger that condition willingly. EEG neurofeedback can be used in different settings for different purposes. As in Geppert et al. (2017), neurofeedback can be used for at least three objectives: as a therapeutic instrument, performance-enhancing training, and empirical approach.

This research aims to use EEG neurofeedback in the context of neuroscience for performance-enhancing. The literature has significant value in studies investigating the relationship between certain EEG frequency features and performance on some cognitive tasks. Existing literature provides a good enhancement in the performance of cognitive domains with EEG neurofeedback. EEG neurofeedback leads to increase performance, especially in memory and attention tasks, with the help of alpha, beta, theta, and gamma training as reviewed in Gruzelier (2014), Vernon (2005), To et al. (2016).

Neuroplasticity is defined as the brain's capability to modify and adjust in reaction to learning and external triggers. Neuroplasticity targets different groups to investigate the underlying mechanisms and brain change. Neuroplasticity studies can include healthy individuals, individuals with a brain injury like stroke or TBI, individuals with developmental disorders like ADHD, individuals with a neurological disease like Parkinson's disease, or individuals with sensory deprivation. Neuroplasticity research can focus on sensory, cognitive psychological, or other domains. The primary focus of this study is on neuroplasticity and sensory-deprived individuals, particularly auditory-deprived individuals, focusing on the cognitive domain, particularly visuospatial working memory.

Existing literature showed that sensory-deprived individuals could show enhanced activity in cognitive domains compared to healthy individuals. As demonstrated by Heled et al. (2022), blind and deaf people show improved working memory performance corresponded to healthy subjects. This enhanced performance can be explained by neuroplasticity in that the brain modifies itself to adapt to its present condition. When one sensory modality is damaged or fails, the brain rearranges itself and redeploys its resources to repay for the sensory deficiency. In the context of the cognitive domain, individuals lean better on mental operations, such as memory, to counterbalance the sensory lack. The brain assigns additional neural resources to these cognitive operations, directing to their improved performance.

There are different suggested underlying mechanisms for neuroplasticity. As Leone et al. (2005) stated, quick modifications during blindfolding show the power of the plastic brain to adjust in reaction to environmental transformations and support practical behavior. Similar findings in the literature suggest that brain plasticity is fast, functional, and responsive to environmental conditions. By this underlying mechanism of neuroplasticity, it is offered that the influence of neuroplasticity can also be seen in short-term sensory deprivation. It is observed that for neuroplasticity to take place, no long time is needed. The brain can adjust to adapt to the current situation within minutes. This leads the existing literature to focus on short-term sensory deprivation and its influence. As Weisser et al. (2005) concluded, individuals in the short-term deprivation group generated meaningful differences in the neural processing of tactile tasks. Existing literature has many studies on short-term deprivation (visual and auditory) and its effect on sensory and perceptual tasks. Still, it is limited and unclear on short-term sensory deprivation and its influence on cognitive domains and the performance of cognitive tasks.

Current studies focus on the influence of neuroplasticity and EEG neurofeedback because the two concepts can be considered interrelated. EEG neurofeedback technique can be likened to neuroplasticity in that neuroplasticity is the brain's capability to modify itself. In difference, EEG neurofeedback is the individual's capability to adjust some cortical activity based on special cortical activity patterns. The two concepts are both studied for enhancement in different domains, especially in the cognitive domain. Also, the two concepts have supporting literature on the enhancement of performance.

The specific research question of the study is if the EEG neurofeedback can lead to enhanced performance in visuospatial working memory tasks and if this enhancement will be more for the short-term auditory-deprived group than the healthy subject group. This question is especially significant for several reasons. First, EEG neurofeedback is generally used to search for cognitive performance enhancement in healthy subjects but not in deprived individuals. Second, the literature on short-term sensory deprivation and its effect on the cognitive domain is limited.

EEG neurofeedback can be beneficial for seeing more significant enhancement in this group. Lastly, if more performance enhancement can be seen in the short-term deprived group, this study can be repeated on the sensory-deprived people (blind, deaf). EEG neurofeedback can be used for further clinical interventions, which are not considered or searched before on sensory-deprived people.

EEG neurofeedback is used to examine this research question for several reasons. First, It instantly targets brain activity: EEG neurofeedback delivers in-time data about the electrical activity, permitting participants to understand to self-arrange their brainwave routines. Secondly, it provides unique training for each participant: EEG neurofeedback can be adjusted by an individual's characteristic brainwave patterns and purposes. The training method can be individualized to manage particular circumstances or optimize specific brain states. Lastly, it proved its reliability and validity: EEG neurofeedback is used for different situations and aims, including treating some medical conditions like ADHD or migraines and performance enhancement.

EEG neurofeedback is also helpful for studying short-term auditory-deprived individuals for several reasons. Firstly, short-term auditory deprivation lead to shifts in brain activity and neural processing. Utilizing EEG neurofeedback and examining oscillatory ways can shed light on how the brain adjusts and reimburses for the absence of auditory information. Secondly, auditory information is essential for various cognitive processes, including working memory. EEG neurofeedback and oscillation investigation can reveal how the brain changes its action and connectivity routines to reimburse for deficient auditory input.

EEG neurofeedback and oscillations are also helpful in studying working memory. Various oscillatory patterns are linked with unique cognitive processes. For instance, specific frequency bands, such as the alpha (8-12 Hz) and beta (12-30 Hz), are connected to working memory. The fundamental neural mechanisms influencing cognitive performance can be better understood by analyzing the oscillatory patterns throughout the visuospatial working memory task.

Overall, EEG is the best-suited technique for this question because EEG is a direct measure of electrical activity and has a high temporal resolution. Using EEG, neural activity routines linked with visuospatial working memory performance in both auditory short-term deprived and healthy individuals can be better investigated. Also, EEG delivers helpful knowledge about the active shifts in brain activity during cognitive tasks. Secondly, because this is a comparison study, EEG has an advantage for a straightforward comparison of the brain activity and oscillatory ways between the groups throughout the working memory task. EEG can show possible distinctions in neural activity and oscillatory dynamics connected with working memory performance and deliver an understanding of the influences of short-term auditory deprivation on cognitive functioning.

Existing literature supports that EEG neurofeedback training can enhance cognitive task performance. Escolano et al. (2001) showed that the NF training group displayed a noteworthy increase of upper alpha and performed remarkably more satisfactorily in the working memory test, offering a cognitive advancement because of the NF training course. Also, as described in Hanslmayr et al. (2005), neurofeedback training achievement in upper alpha NFT and progress in cognitive performance behind upper alpha NFT associated exceptionally and meaningful relations between training success in NFT and advanced connection power located at right parietooccipital electrode areas. In Gruzelier (2014), different studies supported the advantage of neurofeedback on improving cognitive performance in various domains, with other protocols and feedback guides reported. Heled et al. (2022) demonstrated that the deaf subjects performed better than the control group on the visuospatial memory task.

In the light of existing literature review above, it is hypothesized that both the healthy subjects and the auditory sensory deprived group in the neurofeedback training group will profit from EEG neurofeedback and deliver improved performance on visuospatial working memory tasks corresponding to their early performance and compared to the control group, which didn't receive any training. Furthermore, it is anticipated that the short-term deprived group will provide outstanding performance corresponding to the healthy subject neurofeedback training group counting the advantage of neuroplasticity with EEG neurofeedback.

Methods

Participants

Thirty subjects participated in the study. Ten subjects were assigned to the control group (6 female, 4 male, mean age=27.34). Twenty subjects were assigned to the NF training group. Among these 20 subjects, 10 were assigned to the short-term auditory deprived group (5 female and 5 male, mean age=24.06), and 10 were assigned to the non-deprived group (7 male and 3 female, mean age= 29.12). They had no history of any neuropsychological disorders, not participated in other NF studies before. They had normal or corrected to normal vision. Participants were randomly assigned to the groups. All of them were informed about the entire protocol related to their group before signing the consent form. Short-term auditory deprived informed that they would go under a 30-minute deprivation period, and throughout the study, they will be auditory deprived.

Special Information Regarding the Study

The control and NF training groups were informed about the Spatial Span Task in general and what to do during the task. They were also informed that their brainwaves would be recorded with EEG for the study.

Both NF training groups were informed about the training session. Participants are notified about the general purpose of the neurofeedback training. They are informed with a description of enhancing the visuospatial working memory performance by increasing the upper alpha brain activity. Participants are notified concerning the feedback signal utilized throughout the training. They are clarified on how their brainwave activity will be observed and decoded into visual feedback alerts.

They are informed that a smiling avatar means positive feedback showing a wanted brainwave pattern, and a crying avatar is negative feedback showing an unwanted brainwave pattern. If the feedback is positive, participants are motivated to support and preserve those patterns by demanding to calm, keep their attention, or encounter mental imagery. If the feedback is negative, participants are told to relax and redirect their attention and thoughts. The NF training group, which will be deprived, was informed that they would be under a short-term auditory deprivation period before this process started. The deprivation period will be in a controlled environment with minimal auditory stimuli and earplugs for 30 minutes. The deprivation group also informed that this kind of environment would be preserved, and they would be with earplugs from the beginning and through the end of the study. They will tell that if any additional information is needed during the study, they will receive it in a written form but not orally.

Signal Recording and Processing

Along with the 10/10 system, the EEG signal was recorded from 12 active electrodes, which are C3, Cz, C4, F3, Fz, F4, O1, Oz, O2, P3, Pz, and P4. A neutral side is selected and placed on FPz for the ground electrode. With the help of existing literature, Escolano et al. (2011) a reference electrode placed on the left earlobe. To catch eye artifacts, EOG was recorded from 4 electrodes: one above the left eye, one below the left eye, and two on both eyes' lateral sides. Artifact detection was conducted online in the EOG with a threshold of 50µV. Artifact rejection is done online with the help of ICA. gTec system was used to amplify the signal recordings. The sampling rate was chosen to be 256 HZ filtered at 50 Hz and bandpass-filtered among 0.5 and 60 Hz.

Signal acquisition, feedback, and processing representation develop utilizing self-made software. EEG power in P3, Pz, P4, O1, and O2 locations, known as feedback locations, averaged, and feedback was revised each 30 ms accordingly.

Material

The spatial Span task, the computerized version of the Corsi Block Tapping task, was used to measure visuospatial working memory. In the task, a grid of squares is shown to the subjects. A particular series of squares in a standard order is highlighted. The subject's task is to produce the same series by clicking on the squares in the proper order. The series begins with a brief length and slowly advances in difficulty as subjects make the sequence successfully. Performance in the task is calculated by the most extended right series length the subject can produce accurately.

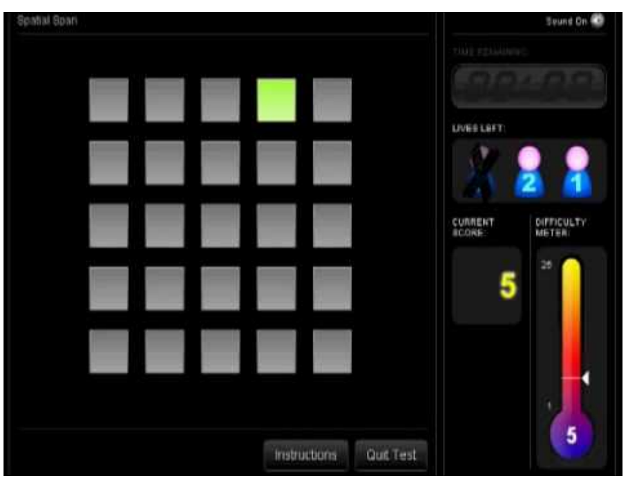

Figure 1: *The Spatial Span Task*

Experimental Procedure

Figure 2: *The Experimental Protocol*

For the NF training groups, the session comprised five blocks for each subject. There were three types of blocks: passive assessment, NF training, and active assessment. Both passive assessment and active assessment were presented twice pre to NF training and post-NF training. The whole session lasted 45 minutes. The short-term auditory-deprived group goes under 30 minute deprivation period before a 45-minute session.

Passive assessment consists of open- eyes resting-state recording for 5 minutes. During this assessment period, participants were asked to stay comfortable and concentrate on a sign shown in the interface. This assessment aims to make participants knowledgeable about the feedback triggers and the connection between their brainwave ways and the feedback signals, to enhance the participants' understanding of their brainwave, and allow them to identify the feedback cues connected to their particular brain conditions.

Active assessment consists of open-eyes active recording for 5 minutes. The pre-NF training active assessment was utilized to compute individual alpha frequency and the baseline for NF training. Individual alpha frequency is the peak frequency in the frequency scope of 7.5-12.5 Hz, the standard range. Upper alpha is the (individual peak alpha + 2) Hz. For both pre-post NF training, active assessment participants encountered the Spatial Span Task, which permits a baseline comparison and the NF training.

NF training consisted of 5 trials, which lasted 5 min each. In the NF training sessions, the Spatial Span task, was used to measure visuospatial working memory. In the trial, subjects encountered either a smiling or a crying avatar when the recent average upper alpha powers in the feedback places were higher or lower than the baseline. When an artifact is detected, the avatar winked for 2 seconds. The test was done on the NF training group (both sensory-deprived and non-sensory-deprived). The same tests were also done on the control group at exact intervals of the period to assess the influence of the training effect. The control group didn't go under training sessions or receive feedback. The EEG recording for the control group was only for observation and validity.

Data Analysis

Participants were assessed by corresponding their Spatial Span task performance before and after the training session (pre-active and post-active assessments). The most extended series length was accurately produced were investigated. NF training groups will be compared according to their pre and post-training results. Also, the NF group will be compared to the control group, and the non-deprived NF group and deprived NF group will be compared between them. Paired t-tests were used to compare the performance differences among the prior and post-training active assessments. This analysis revealed the effect of the EEG neurofeedback training session. Independent t-tests were used to display if there are considerable distinctions in task performance between the controlled group and the NF training groups. An Independent t-test was used to investigate the differences in task performance between deprived and non-deprived groups which received NF training. Also a paired, one-tailed t-test was used for independent samples.

Results

In all the subject training sessions, the upper alpha power was significantly higher than before the active training assessment. No subject was determined as non-responders, so no subject was excluded from the results.

Paired t-test results for the prior and post-training active assessments showed that both NF training enhanced their performance on Spatial Span Task in the post-assessment compared to their initial performance. While the averaged extended series length for 20 subjects of the NF training group was 6 in the initial assessment, the post-assessment average length was calculated as 16. There is a significant increase between the initial and last performance of the participants, for the paired t-test results for the control group showed no significant increase in performance.

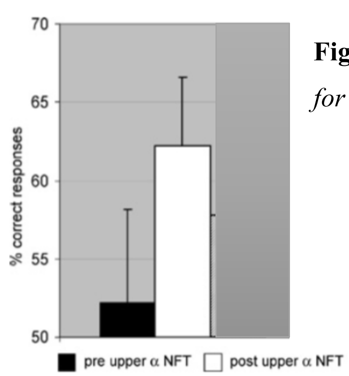

Figure 3: *The performance change between pre NF training and post NF training for NF groups.*

Independent t-test results for comparing the performance of the control group and the NF training group revealed a significant difference. The averaged Spatial Span Task extended series length was 7 for the control group and stayed at 7. In contrast, the performance of the NF training group increased by ten levels (initial 6, last 16), showing a significant performance difference between the control and NF training groups.

Figure 4: *The comparison of performance increase for control and NF group*

The NF training group was also compared within the group. The independent t-test results for comparing performance between deprived and non-deprived groups revealed a significant performance difference between deprived and non-deprived groups. While the initial average of extended series length for the Spatial Span task for ten subjects in the deprived group was 6 after the NF training, it averaged 22. The non-deprived group averaged performance was 6, and after the NF training, the average was 10. The deprived group showed superior enhanced performance compared to the non-deprived group.

As hypothesized, the NF training group showed significantly higher performance on visuospatial working memory tasks than the control group. Within the NF training group, the deprived group performed considerably more than the non-deprived group.

A paired, one-tailed t-test for independent samples was employed to evaluate effectiveness, receiving substantial growth for the NF group. NF training group demonstrated a substantial enhancement of upper alpha and performed remarkably more satisfactorily in the visuospatial working memory test. Also, an accumulation concerning upper alpha power was discovered during the memory task performance.

Discussion

As hypothesized, EEG neurofeedback training has an advantage over non-training, as results show that those in the EEG neurofeedback training group can enhance their upper alpha and deliver significantly better performance than the control group. Also, the EEG neurofeedback group's memory task performance was considerably better than their initial performance before the training. The EEG neurofeedback group generally exhibits more extended series length with better accuracy than the control group. This study is different from those others that it compares the visuospatial working memory. Most existing literature focuses on attention or memory rather than visuospatial working memory. Also, this study differs from others in that it uses EEG neurofeedback in a neuroscience context for performance enhancement. In contrast, although there is literature on performance enhancement, the dominance belongs to EEG neurofeedback and clinical purposes and treatments. These findings suggest that with EEG neurofeedback training, individuals can enhance their cognitive task performance, specifically for visuospatial working memory performance.

Also, as expected, when the two neurofeedback training groups were investigated, the deprived group showed better visuospatial memory performance than the non-deprived group. This finding supports adding the benefit of neuroplasticity. This study is different from those others in that it compares the deprived individuals with the non-deprived individuals in the context of performance enhancement; this is the first comparison done in the literature. The deprived group redirects their limiter resources to a cognitive domain which can explain the superior performance on the task even compared to other neurofeedback training groups. The deprived group formed a more extended series length with better accuracy than the non-deprived group.

References

Alkoby, O., Abu-Rmileh, A., Shriki, O., & Todder, D. (2018). Can we predict who will respond to neurofeedback? A review of the inefficacy problem and existing predictors for successful EEG Neurofeedback Learning. *Neuroscience*, *378*, 155–164. https://doi.org/10.1016/j.neuroscience.2016.12.050

Enriquez-Geppert S, Huster RJ and Herrmann CS (2017) EEG-Neurofeedback as a Tool to Modulate Cognition and Behavior: A Review Tutorial. Front. Hum. Neurosci. 11:51. doi: 10.3389/fnhum.2017.00051

Eric YuLeung To, Kathy Abbott, Dale S. Foster & D'Arcy Helmer (2016) Working Memory and Neurofeedback, Applied Neuropsychology: Child, 5:3, 214-222, DOI: 10.1080/21622965.2016.1167500

Escolano, C., Aguilar, M., & Minguez, J. (2011). EEG-based Upper Alpha Neurofeedback Training Improves Working Memory Performance. *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. https://doi.org/10.1109/iembs.2011.6090651

Gruzelier, J. H. (2014). EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants. *Neuroscience & Biobehavioral Reviews*, *44*, 124–141. https://doi.org/10.1016/j.neubiorev.2013.09.015

Hanslmayr, S., Sauseng, P., Doppelmayr, M., Schabus, M., & Klimesch, W. (2005). Increasing individual upper alpha power by neurofeedback improves cognitive performance in human subjects. *Applied Psychophysiology and Biofeedback*, *30*(1), 1–10. https://doi.org/10.1007/s10484-005-2169-8

Heled, E., Ohayon, M., & Oshri, O. (2022). Working memory in intact modalities among individuals with sensory deprivation. *Heliyon*, *8*(6). https://doi.org/10.1016/j.heliyon.2022.e09558

Pascual-Leone, A., Amedi, A., Fregni, F., & Merabet, L. B. (2005). The Plastic Human Brain Cortex. *Annual Review of Neuroscience*, *28*(1), 377–401. https://doi.org/10.1146/annurev.neuro.27.070203.144216

Vernon, D. J. (2005). Can neurofeedback training enhance performance? an evaluation of the evidence with implications for future research. *Applied Psychophysiology and Biofeedback*, *30*(4), 347–364. https://doi.org/10.1007/s10484-005-8421-4

Weisser, V., Stilla, R., Peltier, S., Hu, X., & Sathian, K. (2005). Short-term visual deprivation alters neural processing of tactile form. *Experimental Brain Research*, *166*(3–4), 572–582. https://doi.org/10.1007/s00221-005-2397-4