NeuroRegulation

EEG Activation During a Mindfulness Session and Its Effects on Memory Encoding

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Abstract

This paper investigates the potential impact of a single mindfulness session on explicit memory recall, employing quantitative electroencephalography (qEEG) to compare a study group to a control group. Phase synchronization in alpha, theta, and gamma frequency bands across various brain regions involved in memory processes was analyzed. Twenty-eight adults, balanced in gender and age, participated in both groups. Memory encoding and retrieval were assessed using word lists presented over four successive sections, with EEG recordings taken before, during, and after mindfulness sessions. Results revealed increased theta and decreased gamma band activation in the right hemisphere during mindfulness, with synchronization between temporal and parietal cortices and frontal cortex during encoding. Higher gamma activation in specific brain regions correlated with better recall. While the study group showed no significant decline in posttest scores compared to controls, suggesting mindfulness may serve as a protective factor in free recall, further research with larger datasets is needed for validation.

Keywords: mindfulness; explicit mnesic enhancement; quantitative EEG (qEEG)

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Introduction

Memory is a process where learning is accumulated (Elsey et al., 2018; Ruiz Rodríguez, 2004). Traditionally, the memory neural bases research focused on the specific brain locations analyzes trying to discover where this information is stored. However, this localizationist trend has been replaced by a more current one seeking to understand the nervous system as a sequential and whole, encoding and retrieving this information, and considering the spatiotemporal synchronization or coherence in different wavebands between these neural areas (Elsey et al., 2018; Polanía et al., 2012).

In memory functioning, the working memory receives the information, and it is automatically transferred to the long-term memory. The latter functions as storage where learning is retained for an unlimited time, as long as it is used and considered helpful for survival or adaptation to the environment; otherwise, it is forgotten (Ruiz Rodríguez, 2004). This potentially permanent storage has been intensively studied in neuroscience. In explicit learning, the recording, processing of stimuli, information storage, and retrieval are associated with parahippocampal, perirhinal, entorhinal cortices, dentate circumvolution, hippocampus, amygdala, frontal, temporal, parietal lobes, and different cortical association areas (Buschke, 1984; León, 2008; Rodríguez-Ledo et al., 2018; Schoeberlein & Sheth, 2015; Sugiura, 2004; Zeidan et al., 2010). During an explicit learning process, such as retaining a word list or recalling it, the EEG activity studies have shown that phase synchronization for theta and gamma bands in frontal and temporoparietal structures seems crucial (Aftanas & Golocheikine, 2001; Field, 2013; Goleman, 2016; Homan et al., 1987; Horta-Barba et al., 2020; Labos et al., 2008; Neamțu et al., 2021; Pérez-Elvira, Oltra-Cucarella, Carrobles, Moltó, et al., 2021; Pérez-Elvira, Oltra-Cucarella, Carrobles, Teodoru, et al., 2021). More details related to different brain regions' connectivity for encoding and retrieving explicit information are presented in Appendix A.

On the other hand, the study of attentional mechanisms is of great interest since they are related to human memory and learning (Chica Martinez & Checa Hernández, 2013). Mindfulness is a type of attention that has been associated with better cognitive performance and better scores in working memory (Jha et al., 2010; Mrazek et al., 2013; Shapiro & Walsh, 2003; Yakobi et al., 2021). This type of sustained, open, and voluntary attention has been of interest to clinical neuropsychology. Mindfulness meditation could alleviate cognition. Mindfulness is related to the increase of power in the theta, alpha, and, perhaps, gamma bands in frontal areas of the cerebral cortex (Aftanas & Golosheykin, 2005; Andresen, 2000; Bennett & Trinder, 1977; Dunn, 1999; Ehrlichman & Wiener, 1980; Fell & Axmacher, 2011; Fenwick, 1987; Harne & Hiwale, 2020; Lutzenberger et al., 2002; Pagano & Warrenburg, 1983; Sarnthein et al., 1998; Serrien et al., 2003; Travis et al., 2002; West, 2016). Some reports have already shown that mindfulness improves different aspects of cognitive performance, or those related to it, such as academic performance (León, 2008; Schoeberlein & Sheth, 2015), learning, anxiety (Rodríguez-Ledo et al., 2018; Schoeberlein & Sheth, 2015; Sugiura, 2004), information processing speed (Zeidan et al., 2010), memory (Mrazek et al., 2013; Zeidan et al., 2010), attention, and impulse control (Mrazek et al., 2013; Zeidan et al., 2010). Moreover, mindfulness shows protective effects of memory decay and could be used as an effective technique to enhance cognitive performance in the learning process (Jha et al., 2010; Appendix A).

This research approach aimed to study the EEG activity during memorization or mnesic encoding and retrieval tasks. To this goal, we analyzed the behavior of alpha, theta, and gamma waveband amplitude and the coherence related to frontal, temporoparietal cortices, and medial temporal structures during a single mindfulness session to explore its role for a possible improvement or protection in the recall of the explicit mnesic material. To the best of our knowledge, current literature is scarce regarding the mindfulness role in this respect.

Materials and Methods

Subjects

This prospective study was conducted in NEPSA Rehabilitación Neurológica, a neurological rehabilitation clinic certified by the Government of Castilla y León (Spain), in collaboration with the Research and Telemedicine Center for Neurological Diseases in Children in Sibiu, Romania, for data analysis (Ethical Commitee: 5/2021).

The sample of this study consisted of 28 healthy adult participants aged between 24 and 35 years (mean age = 30.64, *SD* = 4.00), all of them medium–high cultural and socieconomic adult volunteers. The sample was collected at the neuropsychophysiology laboratory of NEPSA Rehabilitación Neurológica (Salamanca, Spain), and each participant was randomly assigned to the experimental or control group (by rolling dice). The participants in the experimental group totaled 14 people (7 men = 50%; mean age = 29.21, *SD* = 3.90). The participants in the control group accounted for a total of 14 people as well (8 men = 57.1%; mean age = 28.60, *SD* = 4.56). The inclusion criteria were: (a) no psychiatric or neurological pathology, and (b) no previous experience in meditation. The participants were informed in writing about the research design, and all of them gave their explicit written consent to carry out this study. The anonymity of the responses and scores of all participants was guaranteed and respected according to the Helsinki Declaration guidelines.

Instruments

Memory Test. The ad hoc list of words used in our study is presented in Appendix B (Buschke, 1984; Horta-Barba et al., 2020; Labos et al., 2008). The purpose of this list is to evaluate the memory encoding of the verbal material and its subsequent retrieval. Participants were given 20 s to try to memorize the six words that appeared on a computer screen. After these 20 s, a semantic cue was associated with each word to selectively ease the recall in later phases when they were asked to remember and name the words. Once these 20 s had passed, they were offered another six words, and once again the cue was selectively provided. This was done in repeated sections, four sections with 80 s of coding and 24 words to remember. After finishing these four sections, the participants were asked to try to remember and vocalize freely all the words they remembered in the desired order. This part is known as free recall. Once the subjects indicated they could not remember any more words, they were offered the cues and asked again to remember the word associated with the related cues, known as cued recall.

The word-list test was applied in the pre- and postmindfulness session, with two analogous versions of the same test where the words were changed but the same cues were maintained, with the idea that one version and the other were not significantly different in terms of difficulty of encoding and recall. Half of the participants received version A first and then received version B after the mindfulness session. The other half received version B first and then received version A after the mindfulness session (Table 1, Appendix B). For each trial, the participants were asked to freely recall as many items as possible, and the category cues were provided for items not retrieved by total free recall. The same procedure of recalling (freely and cued) was done after the mindfulness session. The subjects were required to freely remember the words, and the category cues were provided for items not retrieved freely. The measures evaluated here were total free recall (cumulative sum of free recall from the 4 sections of the test; range 0–24) and total recall (TR; cumulative sum of free recall + cued recall from the four sections of the test, range 0–24).

Electroencephalography Amplifier. Discovery 20-channel device (BrainMaster Technologies, Bedford OH) was used. It provides a 24-bit conversion with an internal sampling rate of 1024 samples/s and 256 samples/s data rate to the computer, providing 20 high-resolution and aliasing-free signals. A 50-Hz notch filter was used.

EEG Cap. Medium-size free-cap (Neurofeedback-Partner, Munich, Germany), which is an EEG electrode application technique with 19 channels located according to International System 10-20 (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, and O2; Homan et al., 1987) and using a Linked Ears montage. The electrodes on the standard caps were positioned according to the International 10-20 method of electrode placement. The spongy electrodes reservoir carried a sponge soaked with saline to record the EEG.

EEG Acquisition Software. BrainAvatar 4.6.4 software (BrainMaster Technologies, Bedford OH) recorded the EEG.

QEEG Analysis Software. NeuroGuide v. 2.9.1 (Applied Neuroscience, Inc., St. Petersburg FL) and BrainAvatar Analyzer (BrainMaster Technologies, Bedford OH) software were used for the EEG computation and analysis.

Mindfulness Session CD-ROM. Goleman (2016) recorded a brief mindfulness session of breathing meditation employed.

Procedure

Prior, during, and after the memory test, EEG data were collected to perform a descriptive study analyzing the brain activation in participants with no previous experience with this type of meditation.

Initially, an EEG baseline was recorded in eyes-closed and resting conditions for a period of time between 3 and 6 min (Pérez-Elvira, Oltra-Cucarella, Carrobles, Teodoru, et al., 2021). After this, the EEG activity was collected in the premnesic coding condition with eyes open and for a timeframe of about 80 s. Then, the EEG signals were collected during the guided mindfulness meditation session performed by the experimental group in the eyes-closed condition and for the duration of the session: 10 min and 27 s. During the same time, the subjects in the control group simply performed any activity they wished as long as it had nothing to do with the memory test, allowing them to check their cell phone, read, or chat with other people. Then, the EEG was recorded during the memory test performed postmindfulness procedure. As mentioned previously, to avoid the test–retest effect, the premindfulness test was designed in two versions (A and B). Hence the subjects receiving version A in the premindfulness test get version B in the postmindfulness test and vice versa. We also wanted to control the possible difference in the difficulty of versions A and B of the test, so the studied subjects and the control ones were balanced so that the potential differences between versions would not affect the results. The complete design of this study is shown in the following table (Table 1).

Table 1
Study Design

	Stage 1	Stage 2	Stage 3	Stage 4
Experimental type 1 ($N = 8$)	Baseline ***(EEG)***	Pretest (test version A), ***EEG***	Meditation *Mindfulness* (***EEG***)	Posttest (test version B), ***EEG***
Experimental type 2 ($N = 6$)	Baseline (***EEG)***	Pretest (test version B), ***EEG***	Meditation *Mindfulness* (***EEG***)	Posttest (test version A), ***EEG***
Control type 1 ($N = 7$)	Baseline (***EEG)***	Pretest (test version A), ***EEG***	Pause (***EEG***)	Posttest (test version B), ***EEG***
Control type 1 ($N = 7$)	Baseline ***(EEG)***	Pretest (test version B), ***EEG***	Pause (***EEG***)	Posttest (test version A), ***EEG***

The EEG records were imported into NeuroGuide version 2.9.1 (Applied Neuroscience, Inc., St. Petersburg, FL) software for editing and removing artifacts. The artifacts removal was done manually. Then, the files were further imported to the Brain Analyzer of BrainAvatar (BrainMaster Technologies, Bedford, OH). Brain electrical activity was reconstructed by combining the sLORETA localization algorithm with a real-time reference database and creating accurate 3D images of brain activation in the EEG component bands of interest. All 6,239 voxels of brain activity were computed in real-time (8 images per second) in eight frequency bands and converted into amplitude. Using the analysis in the qEEG option from BrainAvatar software, we selected EEG segments of 1-s epochs and performed the statistical analysis providing sLORETA 3D images. We used the summary values for amplitude and connectivity metrics for every frequency in each channel (Pérez-Elvira, Oltra-Cucarella, Carrobles, Moltó, et al., 2021).

Data Analysis

Analyses of the gathered EEG recordings were made using a general linear model analysis in the form of a repeated-measures study (MANOVA performed in SPSS version 25; α level of 0.05; Neamțu et al., 2021). The first objective was to study the EEG changes considering the dependent variable, the mean amplitude of each frequency range or, more simply put, activation in the meditation phase, while the independent variable was the same measure in its basal form (baseline EEG). Then, a similar analysis was carried out with repeated measures to test whether there was an improvement in memory performance after the mindfulness session. Specifically for this objective, the dependent variable was the score in the free recall part of the ad hoc list of word test (postmindfulness test), while the independent variable was the fact of having performed a mindfulness meditation in the case of the experimental group, or not (in the case of the control group; the categorical variable). The scores of the postmindfulness test were compared with those obtained before meditating or resting to evaluate the change produced. For both analyses (the EEG metrics pre-, during, and postmindfulness, and memory test scores pre- and postmindfulness), the Pillai trace (F) and Eta partial square (η_p^2) were employed to measure the effect size, being $\eta_p^2 < 0.06$ small, $0.06 < \eta_p^2 < 0.14$ medium, and $\eta_p^2 > 0.14$ large (Field, 2013).

The data on the synchrony between frontal, temporal, and parietal cortices during mnestic encoding were analyzed by the bivariate correlation between the regions of interest. This type of statistical analysis allowed us to know the degree to which two variables vary jointly so that we could study the synchrony or coherent joint activation of two cortical areas. The Pearson's correlation coefficient (r) and the strength of the correlation was interpreted as low $0 < r < 0.3$, medium $0.3 < r < 0.6$, and high $0.6 < r < 0.9$ (Field, 2013).

Results

We separately present the results with a focus on three dependent variables: (a) alpha, theta, and gamma waveband amplitude and coherence related to frontal, temporoparietal cortices, and temporoparietal structures during a single mindfulness session; (b) the study of the EEG activity during memorization or mnesic encoding tasks; and (c) exploring the role of the mindfulness session for a possible improvement in the recall of the explicit mnesic material.

Mindfulness Meditation Session Waves Versus Basal Condition

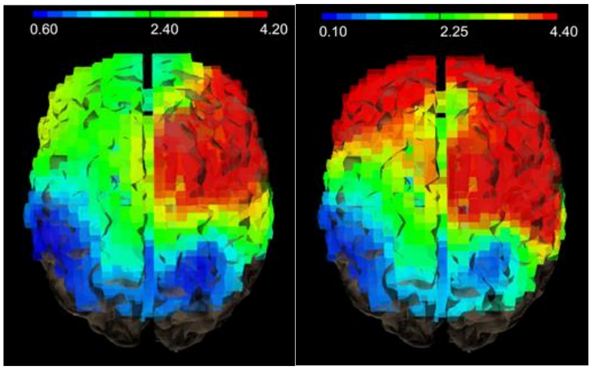
The results of the repeated measures analysis comparing basal and meditation activation levels in terms of the mean amplitude of each of the frequency bands in the zones of interest based on previous literature are presented in Table 2.

The comparative analysis of activation levels in the alpha, theta, and gamma bands in the frontal cortex and in the sum of all locations offered different significant results. The first result is related to the increase of the theta wave in the right frontal cortex (η_p^2 = 0.297 and p < .05) during meditation compared to the basal activation of the participants. This effect is illustrated for better understanding in Figure 1.

Table 2
Mean Amplitude by Frequency Band and Zone of Interest

	Basal	Meditation	Effect size	Sigma
	M (*SD*)	*M* (*SD*)	η_p^2	*p*
	Amplitude (uV)			
Left frontal cortex				
Alpha (α)	1.39 (0.43)	1.36 (0.39)	0.008	.747
Theta (Θ)	1.29 (0.35)	1.37 (0.19)	0.112	.223
Gamma (γ)	0.13 (0.33)	0.12 (0.28)	0.234	.067
Right frontal cortex				
Alpha (α)	1.57 (0.49)	1.48 (0.39)	0.128	.191
Theta (Θ)	**1.41 (0.41)**	**1.58 (0.24)**	**0.297**	**.036**
Gamma (γ)	0.14 (0.41)	0.12 (0.24)	0.257	.054
All left cortices				
Alpha (α)	1.85 (0.77)	1.96 (0.79)	0.037	.489
Theta (Θ)	0.92 (0.27)	0.96 (1.18)	0.033	.518
Gamma (γ)	0.91 (0.32)	0.76 (0.17)	0.265	.050
All right cortices				
Alpha (α)	1.39 (0.39)	1.34 (0.39)	0.028	.549
Theta (Θ)	**1.02 (0.30)**	**1.18 (0.18)**	**0.369**	**.016**
Gamma (γ)	**0.12 (0.27)**	**0.10 (0.19)**	**0.335**	**.024**

Figure 1. *Amplitude in the Theta Range During Mindfulness Meditation of Two Types of Participants—(A) Basal Activation and (B) During Meditation (the Color-Coded Scale Represents Microvolts)*.



This increase is also in the sum of all locations (η_p^2 = 0.369 and p < .05), with a large effect size in both cases. Similarly, we noticed a large effect size but related to a decrease in the level of gamma activation in the sum of all locations, again in the right hemisphere (η_p^2 = 0.335 and p < .05). Table 3 presents the relationship between frontal cortex activation and its synchrony with the temporal and parietal ones, based on the alpha, theta, and gamma frequency bands (preferentially related to each other in these regions). We highlighted the bivariate correlations between these key cortical regions and the alpha, theta, and gamma bands.

Table 3
Synchrony in Codification (Bivariate Correlations)

	Left Frontal Θ	Right Frontal Θ	Left Frontal α	Right Frontal α	Left Frontal γ	Right Frontal γ
Left Temporal Θ	**.823****	**.536***	.291	.128	.378	.350
Right Temporal Θ	**.605***	**.729****	**.761****	**.662****	.523	**.563***
Left Temporal α	.133	.491	**.576***	**.624***	.460	.333
Right Temporal α	.128	.376	**.726****	**.780****	.344	.300
Left Temporal γ	.474	.126	.050	−.156	**.747****	.518
Left Temporal γ	**.749****	**.596***	.232	.090	.529	**.596***
Left Parietal Θ	**.708****	**.691****	**.740****	**.644***	.443	**.679****
Right Parietal Θ	.507	**.600***	**.750****	**.656***	.481	**.624***
Left Parietal α	−.055	.328	**.732****	**.823****	.216	.267
Right Parietal α	−.064	.243	**.667****	**.781****	.077	.138
Left Parietal γ	**.786****	.405	.276	.081	.471	.458
Right Parietal γ	**.814****	**.712****	.423	.285	.335	.507

Note. *N* = 14 for all results; * = significative correlation at level .05; ** = significative correlation at level .01 (2 tails).

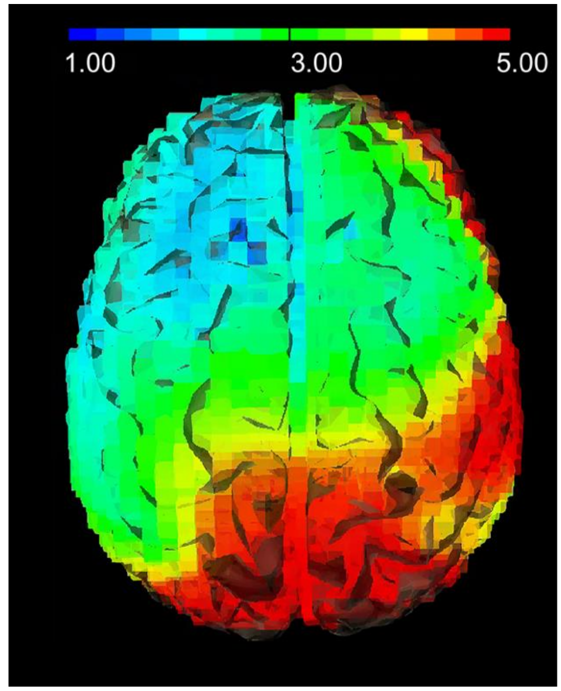
Our results pointed to clear synchrony between the frontal cortex and the temporal and parietal cortex during the encoding of verbal material. There was a marked tendency for the temporal and parietal cortices to synchronize with the frontal cortex, responding in the same frequency range: (a) when the frontal cortices of the left and right hemispheres showed activity in the theta rhythm (Θ), the temporal and parietal cortices were synchronized in the same frequency range with an exception, the lack of coherence between the left frontal and contralateral parietal (Figure 1); (b) When the left and right hemisphere frontal cortices showed activity in the alpha (α) rhythm, the temporal and parietal cortices were synchronized in the same frequency range without exception; and (c) When the frontal cortices of the left and right hemisphere showed a gamma (γ) rhythm synchronization, this coherence occurred only in the same frequency range in the ipsilateral temporal cortex, but not in the contralateral or parietal cortex.

On the other hand, the analyzed data also informed us about the synchrony between frontal and temporal and parietal cortices in different frequency ranges. The ipsilateral parietal cortices and the contralateral temporal and parietal cortices responded synchronously in gamma rhythm when the left frontal cortex responded synchronously in the theta rhythm. The same effect was found for the right frontal cortex when it responded with increased activation in theta rhythm. However, only the ipsilateral temporal and parietal cortices were synchronized with it in the gamma rhythm. Synchronous activation in the alpha rhythm of frontal and temporal, and parietal cortices was also noticed in the theta frequency range. In this case, both right and left parietal cortices responded to such a pattern, while only the right temporal cortex was activated in the theta frequency range. Finally, it was shown how the activation in the gamma range of the right frontal cortex correlated in the theta range with the ipsilateral temporal and parietal cortices, and with the contralateral temporal cortex. Note that, in all cases, the strength of the correlation was medium or high, so the results obtained should be taken into consideration.

Memory Encoding Associated With Mindfulness

Regarding the encoding of verbal material, the analysis of the bivariate correlation between the different areas of the cortex studied, frontal, temporal, parietal, and the sum of all neocortices revealed a significant correlation between the score achieved in the free recall test and the increased activation in the γ range in (a) the right temporal cortex (r = 0.638 and p < .05), (b) the left and right parietal cortex (r = 0.544 and r = 0.596, p < .05), and (c) the sum of all neocortices of the left hemisphere (r = 0.605 and p < .05; Figure 2).

Figure 2. *Amplitude in the Gamma Range During Encoding of Verbal Material of a Subject (the Color-Coded Scale Represents Microvolts)*.



The results of the repeated measures analysis comparing the pre–post measure scores on the free recall test of verbal material showing the improvement in recall after the brief mindfulness meditation session are presented in Table 4.

Table 4
Effect of Mindfulness Meditation on Memory

	Free words recall Premindfulness $M(SD)$	Free words recall Postmindfulness $M(SD)$	Size effect η_p^2	Sigma p
Scores				
Experimental (N = 14)	12.64 (4.32)	12.29 (3.89)	0.006	.779
Control (N = 14)	**13.36 (4.05)**	**10.07 (4.75)**	**0.504**	**.003**

Note. Both experimental and healthy controls followed the same assessment.

Our results showed a predictable worsening in the free recall of the verbal material learned in the second part (post) compared to the first part (pre) in either the experimental or the control group, perhaps due to a primacy effect or due to the interference of the first items learned over the second ones. However, this pattern was significant in the control group (η_p^2 = 0.504 and p < .05) and not significant in the experimental group suggesting a protective role of the mindfulness session.

Discussion

In this study, we had the following objectives: to analyze the electroencephalographic activation during a brief session of mindfulness meditation carried out by participants with no previous experience with this type of meditation versus a control group, to study the synchrony between the frontal cortex and the temporal and parietal cortex during a memory task, and to explore the influence of mindfulness on the free recall of verbal material.

The results obtained during mindfulness meditation highlighted a specific activation pattern characterized by increased alpha, theta, and gamma frequency bands compared to the baseline activity of the subjects. The brief mindfulness meditation session participants did present an increased activation of the right frontal cortex in the theta wave range, which is consistent with previous studies (Aftanas & Golocheikine, 2001; Andresen, 2000; Dunn, 1999; Harne & Hiwale, 2020; Shapiro & Walsh, 2003; Travis et al., 2002). This suggests that when people with no previous experience follow the guided meditation instructions (Goleman, 2016), greater frontal activation in the theta frequency range is generated. Furthermore, the lateralization found towards the right hemisphere is in agreement with several authors' findings (Aftanas & Golosheykin, 2005; Ehrlichman & Wiener, 1980; Fenwick, 1987; West, 2016), and in opposition to other reports (Bennett & Trinder, 1977; Pagano & Warrenburg, 1983). With respect to previous literature, in our study we only found this significantly increased activation in the theta range, not occurring in the other two frequency bands shown in the literature (alpha and gamma). In fact, the gamma frequency showed a significant reduction when studied in all right hemisphere locations as a whole.

We have found a particular pattern of wave synchrony that occurred when participants were trying to store or encode verbal material. The frontal cortex presented a high coherence with the temporal cortex in the theta and gamma frequency ranges and the parietal cortex in the gamma range. These results are in line with those found by other authors (Fell & Axmacher, 2011; Harne & Hiwale, 2020). These synchronizations in the theta and gamma range between the frontal cortex and temporal and parietal lobe have been previously related to the retention of information in the working memory (Sarnthein et al., 1998; Serrien et al., 2003) as well as with the workload and information retention in short-term memory (Babiloni et al., 2004; Lutzenberger et al., 2002), which predicts the individual working memory capacity (Kopp et al., 2006; Plaska et al., 2021). Furthermore, our approach has pointed out the importance of gamma in memory processes. According to our results, the higher activation of this frequency in the right temporal cortex and the left and right parietal cortex predicts a better result in the free recall test performed.

Finally, regarding the facilitation effect of the encoding and recall of explicit verbal material, our results showed a worsening in the performance but statistically significant only in the control group, not in the study group practicing mindfulness. This could be explained by the primacy effect or by the interference of the learned material in the first part of the test. The former refers to the possibility that the semantic relationship between the words in the list improves the recall of the initial words, but not latter items (Glanzer & Cunitz, 1966). On the other hand, the latter has to do with the retroactive inhibition it produces because when learning the two lists, each of them acts as a system of independent habits that compete at the time of retrieval (McGeoch, 1932). The greater the similarity between the lists, the greater the likelihood of these effects appearing, which is something that might have happened in this case, since the ad hoc design of both parts has been arranged so that both trials are analogous. However, the results also informed us of an effect that supports the usefulness of this type of mindfulness technique. In the control group, the worsening is evident in the posttest in relation to the pretest, however, this effect was not significantly observed in the group that meditated. The mindfulness technique has probably acted as a protective factor against this worsening, with a positive effect on the cognitive capacity, which is in line with the findings of relatively similar studies but on the working memory performance (Jha et al., 2010; Mrazek et al., 2013).

Future research to address the limitations in our study should envisage larger samples to explore further and strengthen our results regarding the mindfulness protective role in worsening in the posttest versus pretest scores due to primacy and or to the interference of the first presented items. Likewise, it would be very useful to use simultaneous EEG-fMRI or EEG-PET neuroimaging techniques with a higher spatial resolution to study activation in the cortical regions and the deeper regions of the brain. Using the brief guided mindfulness meditation approach, it would also be very interesting to study different brain regions' connectivity in encoding and retrieving explicit information in expert meditators versus beginner participants.

Conclusion

Mindfulness markedly synchronized temporal and parietal cortices with the left and right frontal cortex in the same frequency range when encoding the verbal material enhanced the studied group's cognitive performances. Mindfulness might be a protective factor in free recall in a series of multiple memory tests.

Author Disclosure

Authors have no grants, financial interests, or conflicts to disclose.

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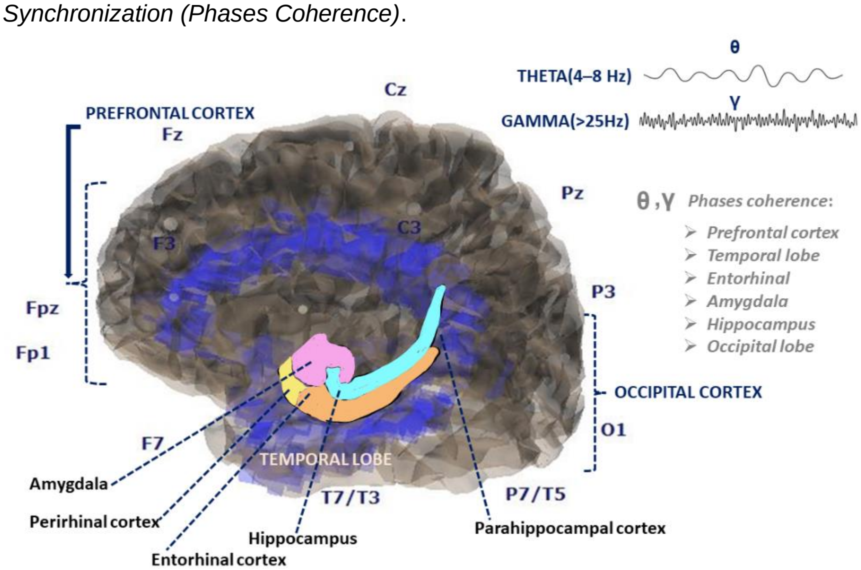
Appendix A

Memory, Mindfulness, and qEEG

Memory and qEEG. In explicit learning, the memory acquisition process begins with the recording and processing of stimuli arriving from outside in one or more heteromodal association cortices and sent further along to the parahippocampal and perirhinal cortices (Figure 1). Then, the information subsequently reaches the entorhinal cortex, which sends it to the dentate circumvolution through the perforant pathway to be finally transferred to the hippocampus (Androver-Roig et al., 2013). In addition, the hippocampus receives information from the amygdala, which has a modulatory role on learning by enhancing declarative learning of stimuli and emotionally charged situations (Redolar Ripoll, 2013). Once the encoding process carried out by the hippocampus ends, the information returns back to the cortex, reaching the medial structures that are basic for the definitive storage of information, according to Eichenbaum (2008; Figure A).

Figure A. *Explicit Learning Neural Substrate and the Wavebands Synchronization (Phases Coherence)*.



The neural substrate of explicit learning is mainly located in the medial temporal lobe, while the explicit memory is stored in the different cortical association areas (Eichenbaum, 2008). In the encoding and retrieval processes, the left prefrontal cortex seems to be more involved in the encoding process while the right prefrontal cortex in the information retrieval. For example, the semantic process in the explicit learning of the words seems to start with the occipital lobe and continues with the left temporal lobe. The inferior left frontal lobe is involved in word selection and retrieval, while the temporal lobe seems to have a crucial role in naming and reading words (Camina & Güell, 2017).

Hippocampus has a vital role in the transfer of information from immediate to long-term memory systems, initially consolidating the acquired information (Gilmore et al., 2021; Squire & Zola, 1996; Suzuki, 2005). Moreover, different wavebands synchronization (particularly in the theta and gamma range) seems to be crucial for the connectivity between the brain regions in the memory processes. According to Fell and Axmacher's (2011) meta-analysis, many studies support the correlation between the synchronization of anterior and posterior brain regions during encoding and retrieval of declarative information. The aforementioned authors pointed out that phase synchronization in medial temporal structures, specifically between the entorhinal cortex and the hippocampus, predicts subsequent word recall in humans.

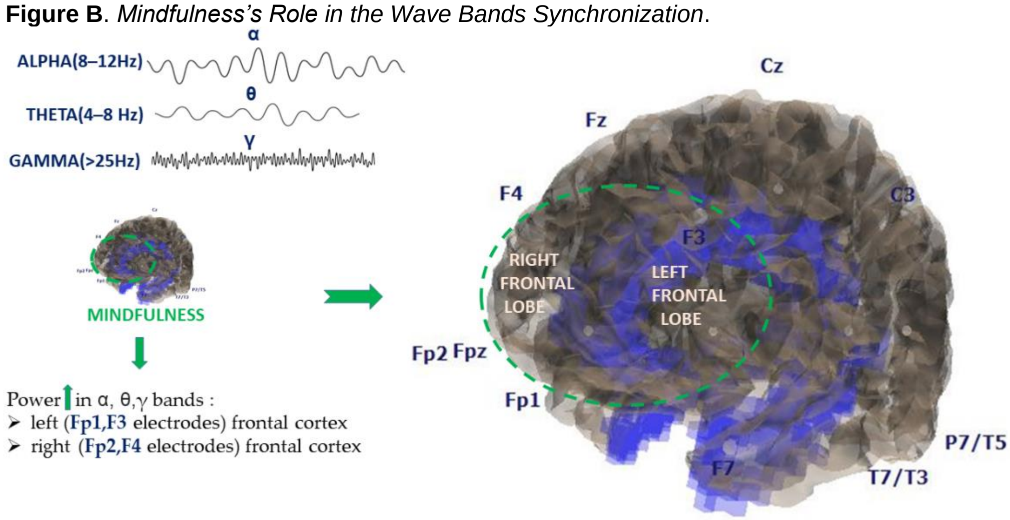
This phase synchronization was also reported in studies by Pavlides et al. (1988), showing how an increased theta and gamma coherence in the hippocampus, amygdala, and neocortex predicts the immediate recall in a verbal retrieval task. In these brainwaves frequency ranges, Fell and Axmacher (2011) indicated that the phase synchronization between frontal and temporal areas had a crucial importance for explicit memory. Moreover, theta synchronization between the prefrontal cortex and medial temporal lobe has been shown to occur during the maintenance of information in working memory (Sarnthein et al., 1998; Serrien et al., 2003). Furthermore, theta coherence between the frontal cortex and temporoparietal cortex regions increased workload and predicted individual working memory capacity (Kopp et al., 2006; Plaska et al., 2021). In short-term memory studies, this synchrony was noticed not only in theta but also in the gamma range between frontal areas during the retention of information (Babiloni et al., 2004; Lutzenberger et al., 2002; Plaska et al., 2021).

Mindfulness and qEEG

Grossman and colleagues (2004) comprehensively define mindfulness as maintaining a moment-by-moment awareness of our thoughts.

The EEG activation generated in people while performing mindfulness meditation has been studied. Increments in the power of the theta and alpha frequency bands in the frontal cortex have been found in addition to a decrease in the other frequency bands (Andresen, 2000; Shapiro & Walsh, 2003). This increase of alpha power in the frontal cortex is often observed when people are meditating, compared to control conditions (Aftanas & Golocheikine, 2001; Khare & Nigam, 2000; Lee et al., 2018; Figure B).

Figure B. *Mindfulness's Role in the Wave Bands Synchronization*.



Moreover, this frequency band acquires greater amplitude while people who meditate are resting than nonmeditating control groups (Aftanas & Golosheykin, 2005; Ehrlichman & Wiener, 1980; Harne & Hiwale, 2020; Travis et al., 2002), suggesting that both alpha activations are related to mindfulness meditation practice (Delmonte, 1984) both in their state or temporal form during meditation and in their trait. It seems to be sustained over time, even without meditation.

On the other hand, an increase in the theta frequency band has also been associated with state or temporary (Aftanas & Golosheykin, 2005; Aftanas & Golocheikine, 2001; Harne & Hiwale, 2020; Travis et al., 2002) and trait or permanent mindfulness, finding greater activity in this band in advanced meditators compared to beginners (Cahn & Polich, 2006). Expert meditators exhibit higher trait alpha and theta power compared to controls during meditation and baseline measurements (Aftanas & Golocheikine, 2001; Andresen, 2000; Delmonte, 1984).

In addition to the alpha and theta frequency ranges, the relationship between mindfulness meditation and the increase of frequency bands above 40Hz or gamma has also been documented. In this sense, increments in frontal activity are found to be greater in meditators during the mindfulness session compared to their resting state (Lutz et al., 2004). Also, Carter et al. (2005) found a higher mean gamma frequency activation during meditation while comparing expert and beginner meditators. Using low-resolution electromagnetic tomography analysis (LORETA; Pascual-Marqui et al., 1994), Lehmann et al. (2001) indicate that gamma is the only band that demonstrates differential spatial distributions in the frontal cortex comparing meditators and control EEG baseline. Mindfulness meditation could alleviate cognition. Mindfulness is related to the increase of power in the theta, alpha, and, perhaps, gamma bands in frontal areas of the cerebral cortex (Aftanas & Golosheykin, 2005; Andresen, 2000; Bennett & Trinder, 1977; Dunn, 1999; Ehrlichman & Wiener, 1980; Fell & Axmacher, 2011; Fenwick, 1987; Harne & Hiwale, 2020; Lutz et al., 2004; Pagano & Warrenburg, 1983; Sarnthein et al., 1998; Serrien et al., 2003; Travis et al., 2002; West, 2016). In fact, some reports have already shown that mindfulness improves different aspects of cognitive performance, or those related to it, such as academic performance (León, 2008; Schoeberlein & Sheth, 2015), learning, anxiety (Rodríguez-Ledo et al., 2018; Schoeberlein & Sheth, 2015; Sugiura, 2004), information processing speed (Zeidan et al., 2010), memory (Mrazek et al., 2013; Zeidan et al., 2010), attention and impulse control (Mrazek et al., 2013; Zeidan et al., 2010). Moreover, mindfulness shows protective effects of memory decay and could be used as an effective technique to enhance cognitive performance in the learning process (Jha et al., 2010)

Appendix B

Table 1

Category	Neutral (0) or emotional (1)	Item	RL1 (Free recall)	RF1 (Cued recall)
Reading Material	0	**Encyclopedia**		
Vegetable	0	**Bell pepper**		
Family	1	**Mother-in-law**		
Bird	0	**Canary**		
Dedication of time	1	**Job**		
When life does not go on	1	**Death**		
Reptile	0	**Crocodile**		
Physical sensation	1	**Pain**		
Tool	1	**Gun**		
Construction material	0	**Wood**		
Building	0	**Museum**		
Intense emotion	1	**Sadness**		
Economic status	1	**Poverty**		
Furniture	0	**Shelf**		
Verb tense	1	**Future**		
Musical instrument	0	**Harmonica**		
Event	1	**Accident**		
Vehicle	0	**Bus**		
Plant	0	**Margarita**		
Improvement	1	**Ascent**		
Family	1	**Son**		
Disease	1	**Cancer**		
Sports	0	**Basketball**		
Cooking utensil	0	**Strainer**		
		Sums	**0**	**0**
		Total Free Recall		
		Total Facilitated Recall		
		Deferred Recall Total		
		Total Recall		

Table 2

Category	Neutral (0) or emotional (1)	Item	RL1 (Free recall)	RF1 (Cued recall)
Game	0	**Ball**		
Electricity	0	**Plug**		
Show of happiness	1	**Laughter**		
Capturing reality and storing it	0	**Photography**		
Insect	1	**Spider**		
Element of terrorist aggression	1	**Pump**		
Body part	0	**Ear**		
Criminal act resulting in death	1	**Murder**		
Long-lasting interaction with a person	1	**Relation**		
To step on at home	0	**Carpet**		
For stargazing	0	**Telescope**		
Profession	1	**Police**		
Fluid inside the body	1	**Blood**		
To fly	0	**Balloon**		
When you have no stress	1	**Peace of mind**		
Viewing utensil	0	**Glasses**		
When someone does not tell the truth	1	**Liar**		
To drink	0	**Bottle**		
Electronic utensil	0	**Computer**		
When nails and slate or fork and plate	1	**Squeak**		
When you believe that good things are going to happen to you	1	**Hope**		
Family	1	**Primo**		
Space-Astronomy	0	**Moon**		
Eating utensil	0	**Spoon**		
		Sums	**0**	**0**
		Total Free Recall		
		Total Facilitated Recall		
		Deferred Recall Total		
		Total Recall		