v. 5, n. 30, 2025

International Journal of Health Science

EFFECTS OF MEDITATION AND MINDFULNESS PRACTICE ON THE MODULATION OF NEUROPLASTICITY AND COGNITIVE ABILITY

Acceptance date: 29/09/2025

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Abstract: Objective: To evaluate the effectiveness of meditation and mindfulness on neuroplasticity and human cognition. **Methods:** This is an integrative literature review, conducted according to the steps proposed by Mendes, Silveira, and Galvão (2008). The search was performed in the PubMed database, using the strategy ((meditation) OR (mindfulness)) AND ((neuronal plasticity) OR (synaptic plasticity)), with a filter for free full texts. Experimental and observational studies investigating the effects of meditation and mindfulness on neuroplasticity were included. **Results:** The reviewed studies indicate that meditation and mindfulness practices promote significant cognitive benefits, such as improved attention, inhibitory control, and executive functions, in addition to inducing functional and structural changes in the brain. Among the most consistent findings are increased gray matter in regions related to emotional regulation (amygdala and medial prefrontal cortex), interoceptive perception (insula), and memory (hippocampus), as well as modulation of the connectivity of neural networks of attention and self-reference. These results suggest that such interventions favor adaptive processes of neuroplasticity and reduce symptoms of anxiety and depression, making them promising strategies for promoting mental and cognitive health. **Conclusion:** Meditation and mindfulness have the potential to remodel brain architecture, improve cognitive functioning, and contribute as therapeutic and educational resources. Despite methodological limitations, future studies with greater rigor and standardization are needed to consolidate their clinical and scientific applicability.

Keywords: Meditation; Mindfulness; Neuroplasticity; Synaptic plasticity

INTRODUCTION

Neuroplasticity can be defined as the nervous system's ability to modify its activity in response to intrinsic or extrinsic stimuli, reorganizing its structure, functions, and connections, in addition to promoting the improvement of cognitive functions. Neurons play a fundamental role in this process, as they are responsible for transmitting nerve impulses between cells, enabling synapses, so that information can then be processed, assimilated, and learned. It is also responsible for lifelong brain reorganization and adaptation, allowing for the modification of cortical structure ( ), which directly shapes behavior and learning (Mateos-Aparicio & Rodríguez-Moreno, 2019).

Neuroplasticity can be influenced and modulated by several factors such as physical exercise, environment and personal context, motivation, neuromodulators, and neurodegenerative diseases. In other words, maintaining neuroplasticity depends on constant stimuli, which promote synaptic communication and proper brain function. There are several activities that can stimulate neuroplasticity. Music therapy, for example, has the potential to stimulate emotions by promoting communication between the region responsible for auditory processing and the cerebral amygdala, which is responsible for emotions. Neurofeedback is also used as a cognitive development technique by modulating neural frequencies through stimuli such as listening to classical music, with the intention of "educating" neurons to operate at an electrofrequency that is capable of increasing normal learning capacity, or even artistic and creative capacity, and is considered a training exercise for the brain (Puderbaugh & Emmady, 2023; University of São Paulo, 2022).

Among other tools, meditation, an ancient practice originally associated with spiritual rituals present in traditions such as Buddhism, Hinduism, and Christianity, consists of complex regimes of emotional and attentional regulatory training, which cultivate well-being and mental balance (Lutz et al. 2008), playing a major role in modulating neuroplasticity. This technique develops visible and multiple changes in brain functions related to emotional regulation (Ahmed et al. 2024), leading to reflection on the possibility of using meditation as a non-pharmacological alternative for improving cognition.

Mindfulness, on the other hand, consists of non-judgmental awareness, moment by moment, based on specific attention to the present moment, in a receptive and non-reactive way. It is understood that interventions based on mindfulness protocols show potential for improving executive functions of inhibitory control, working memory, and cognitive flexibility for both clinical and non-clinical populations. This practice can therefore be an effective form of treatment that can positively influence individuals' health and quality of life, reaching the biopsychosocial level, and can be applied to patients with different pathologies and age groups (Jon Kabat-Zinn, 1990; Almeida, Rocha & Silva, 2021).

It is understood how vast the study of the human brain is, and yet how scarce knowledge is from certain perspectives. The use of alternative therapies can be expanded as evidence of their effectiveness improves. Thus, this article aims to analyze the effect of mindfulness and meditation on neuroplasticity and cognition in order to understand the potential benefits of this technique for patients with impaired cognitive function and neuroplasticity.

MATERIAL AND METHOD

STUDY DESIGN AND RESEARCH QUESTION

This is an integrative literature review, which followed the steps agreed upon (MENDES; SILVEIRA; GALVÃO, 2008) such as identifying the theme and selecting the hypothesis or research question; establishing criteria for inclusion and exclusion of studies/sampling or literature search; definition of the information to be extracted from the selected studies/categorization of studies; evaluation of the included studies; interpretation of results; presentation of the review/synthesis of knowledge culminating in the full writing of the integrative review.

To structure the research question, the PICOS strategy (acronym for population, intervention, comparison, outcomes, and study type) presented in Table 1 was used, which led to the construction of the following guiding question: Can the practice of meditation and mindfulness modify neuroplasticity and brain structural architecture, in addition to influencing cognition?

P - Population	Adult individuals
I - Intervention/ exposure	Meditation and mindfulness practice
C - Comparison	-
O – Outcomes	Improved neuroplasticity and cortical increase
S- Study type	Experimental and observational

Table 1: Definition of terms for structuring the research question using the PICO acronym.

SEARCH STRATEGY

The Health Sciences Descriptors (DeCS/MeSH) were consulted to identify universal descriptors and relevant synonyms and/or alternative terms, and the following descriptors were selected: "term in Portuguese/term in English"; Meditation; Mindfulness; Neuroplasticity; Synaptic plasticity

After selecting the search terms, the search strategy was constructed using the Boolean operators "AND" and "OR":

((meditation) OR (mindfulness)) AND ((Neuronal Plasticity) OR (synaptic plasticity))

The *PubMed* database was used for the search, applying only the filter: *"Free full text"*.

International Journal of Health Science ISSN 2764-0159 DOI https://doi.org/10.22533/at.ed.1595302518099

SELECTION CRITERIA

The review included experimental articles, such as randomized clinical trials, and observational articles, such as prospective and retrospective cohorts. Review articles of any kind were excluded. In addition, other selection criteria used were: the use of meditation or mindfulness as an intervention, excluding studies that focused on other ways to improve neuroplasticity, such as physical exercise. Studies that improved cognitive and memory capacity and structural criteria, such as increased gray matter, were included.

After the articles were collected using the initial search strategy, the selection process was carried out by an evaluator, who followed a rigorous two-stage selection method. In the first stage, articles were selected by reading the titles and abstracts. In the second stage, articles were selected after reading the full texts for data extraction.

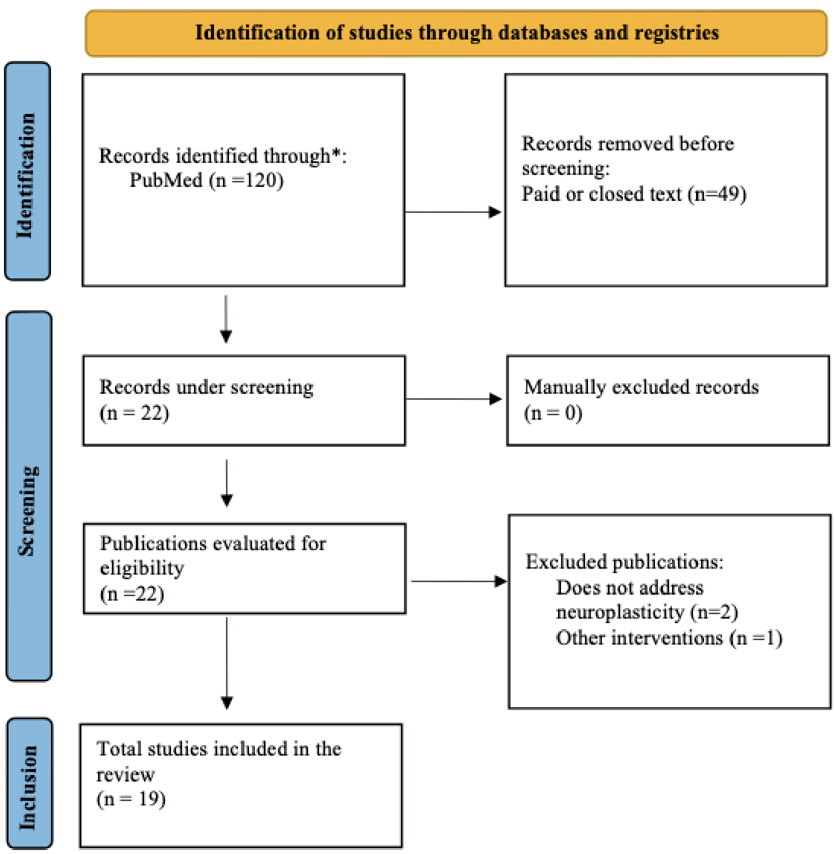
DATA EXTRACTION AND PRESENTATION OF RESULTS

For data extraction, information was considered on: author(s); sample characteristics; study design; characteristics of the intervention or exposure factor; characteristics of the comparator or control; and statistical data for the outcome of interest for each intervention/exposure and comparator/control group.

Results on cortical thickness, attentional data, and improvement in neuroplasticity were extracted. When available, the p-values associated with inferential statistics were presented, as well as the statistical test used.

RESULTS

The flowchart of the process of applying the search strategy and selecting articles is shown in Figure 1, adapted based on the PRISMA method.



Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Author (citation)	Article title	Study design	Sample	Comparator
Braboszcz et al. 2013 1	Plasticity of visual attention in Isha yoga meditation practitioners before and after a 3-month retreat	Observational	57 participants	Absent
Filippi et al. 2022 2	Meditation-induced effects on whole-brain structural and effective connectivity	Experimental	38 participants	19 control subjects
Bauer et al. 2020 3	Mindfulness training preserves sustained attention and resting state anticorrelation between default-mode network and dorsolateral prefrontal cortex: A randomized controlled trial	Randomized clinical trial	31 participants	16 control subjects
Taren et al. 2015	Mindfulness meditation training alters stress-related amygdala resting state functional connectivity: a randomized controlled trial	Randomized clinical trial	35 participants	17 control subjects
Allen et al. 2012	Cognitive-Affective Neural Plasticity following Active-Controlled Mindfulness Intervention	Randomized clinical trial	38 participants	19 control subjects
Farb et al. 2012	Mindfulness meditation training alters cortical representations of interoceptive attention	Cross-sectional	36 participants	20 control subjects
Lenhart et al. 2020	Cortical reorganization processes in meditation-naïve participants induced by 7 weeks of focused attention meditation training	Longitudinal	27 participants	26 control subjects
Leung et al. 2016	Meditation-induced neuroplastic changes in amygdala activity during negative affective processing	Longitudinal	33 participants	10 control subjects
Farb et al. 2007	Attending to the present: mindfulness meditation reveals distinct neural modes of self-reference	Experimental study	36 participants	16 control subjects
Babu et al. 2020	Rajyoga meditation induces gray matter volume changes in regions that process reward and happiness	Cross-sectional comparison	80 participants	40 control subjects
Yordanova et al. 2025	EEG oscillations reveal neuroplastic changes in pain processing associated with long-term meditation	Comparative experimental	35 participants	15 control subjects
Leung et al. 2012	Increased gray matter volume in the right angular and posterior parahippocampal gyri in loving-kindness meditators	Observational	25 participants	15 control subjects
Kang et al. 2012	The effect of meditation on brain structure: cortical thickness mapping and diffusion tensor imaging	Observational	92 participants	46 control subjects
Lumma et al. 2018	Change in emotional self-concept following socio-cognitive training relates to structural plasticity of the prefrontal cortex	Longitudinal	110 participants	59 control subjects
Joss et al. 2022	A pilot study on amygdala volumetric changes among young adults with childhood maltreatment histories after a mindfulness intervention	Longitudinal	36 participants	21 control subjects
Hernández et al. 2020	Larger whole brain gray matter associated with long-term Sahaja Yoga Meditation: A detailed area by area comparison	Observational	46 participants	23 control subjects
Lazar et al. 2005	Meditation experience is associated with increased cortical thickness	Observational	35 participants	15 control subjects
Hölzel et al. 2010	Mindfulness practice leads to increases in regional brain gray matter density	Longitudinal	33 participants	17 control subjects
Yang et al. 2016	State and Training Effects of Mindfulness Meditation on Brain Networks Reflect Neuronal Mechanisms of Its Antidepressant Effect	Longitudinal	13 participants	Absent

Table 1: Description and characteristics of studies

Author (citation)	Intervention or exposure	Results
Braboszcz et al. 2013	Shoonya and Samyama meditation for 30-50 minutes; Lingasanchalana meditation for 2-3 hours; Yoga postures for 2 hours; physical exercises for 40 minutes; chanting for 1 hour	PRE-INTERVENTION Stroop task: -Accuracy of incongruent stimuli: 86.5% correct responses -Accuracy for congruent stimuli: p=0.9 -Accuracy for neutral stimuli: p=0.7 -IS: 1.8 (p<0.05) Reaction time: no change Attention blink task: -Short T2 detection rate: 59% -T1 detection rate: 84% -Long T2 detection rate: 75% Global-local letter matching task -Accuracy (global and local tests): p>0.05 -Local vs. global reaction time: p=0.04 POST-INTERVENTION: Stroop task: - Accuracy for incongruent stimuli: 87.4% correct responses -IS: 0.8 (p<0.05) Reaction time: no change Attention blink task: -Short T2 detection rate: 70% - T1 detection rate: 87% -Long T2 detection rate: 81% Global-local letter matching task -Accuracy (global and local tests): p>0.05 *Accuracy—fewer errors in congruent tests than in incongruent tests p<0.001 - Local vs. global reaction time: p=0.1 Attention blink and global-local performance without significant correlation Accuracy of responses to incongruent stimuli: Association with age (p < 0.005) Previous experience in meditation (p < 0.005).
Filippi et al. 2022	>1,000 hours of Vipassana meditation.	CONTROL GROUP Classification accuracy (p < 0.0001) EC+MLR: 78% EC+1NN: 78% FC+MLR: 79% FC + 1NN: 64% INTERVENTION GROUP: Classification accuracy (p < 0.0001) EC+MLR: 87% EC+1NN: 68% FC+MLR: 81% FC + 1NN: 77% Significant increase in structural connectivity in the left hemisphere between: Somatomotor ↔ Putamen Somatomotor ↔ FEF Visual ↔ Putamen (p = 0.02; via NBS) EC more informative than FC for classifying meditators vs. controls during meditation (p < 0.0001) MLR with EC: 87% accuracy for meditation vs. rest (p < 0.0001) 68% accuracy for distinguishing groups during meditation with EC (p = 0.005 vs. SC)
Bauer et al. 2020	Four 45-minute classes per week, totaling approximately 24 hours of practice and instruction.	PRE-INTERVENTION (both groups): Sustained attention test accuracy (SART Go-Accuracy): p = 0.83 DMN–DLPFC anticorrelation at rest: p = 0.93 SART accuracy correlated with DMN–DLPFC anticorrelation: p = 0.005 (FWE-corrected)

	Activities involved mindfulness and breathing exercises.	POST-INTERVENTION (mindfulness group): SART accuracy (Go-Accuracy) significantly better than control group: p = 0.01 DMN–DLPFC anticorrelation preserved, while in the control group it decreased: Group × time interaction: p = 0.002 (FWE-corrected) Mindfulness maintained anticorrelation (p = 0.81); control showed reduction: p = 0.04 Correlation between improved attention and increased anticorrelation only in the mindfulness group: p = 0.03
Taren et al. 2015	Intensive 3-day mindfulness training with body scan practices Sitting meditation and walking Mindful eating Mindful movements (gentle yoga postures).	PRE-INTERVENTION Resting functional connectivity (rsFC) between: Right amygdala ↔ subgenual anterior cingulate cortex (sgACC): present No difference between groups at baseline (P = 0.877) POST-INTERVENTION Mindfulness significantly reduced rsFC between: Right amygdala ↔ sgACC (MNI coordinates: 0, 18, −12) P < 0.05 (corrected for multiple comparisons), k = 28 voxels Left amygdala ↔ ACC: no significant difference (p > 0.05)
Allen et al. 2012	In-person sessions of 2 hours per week (totaling 12 hours); involved practices of focused attention on breathing, body scan, compassion practices.	PRE-INTERVENTION Groups did not differ in age, education, or gender (p > 0.3) No difference between groups in baseline task scores EAT (error awareness and stop accuracy): no group x time interaction (F(1,36) = 1, ns) Affective Stroop (RTs): no significant group x time difference (F(1,36) = 1, ns) POST-INTERVENTION Executive Function – Stroop Task (AS task) Significant group x time x task interaction: F(1,36) = 5.59; p = 0.02 Significant reduction in Stroop conflict in the MT group: t(18) = 2.42; p = 0.03 SRL without significant change: t(18) = −0.72; p = 0.48 Metacognition and Inhibition – EAT Task Both groups improved over time: Error Awareness: F(1,36) = 16.35; p < 0.001 Stop Accuracy: F(1,36) = 11.05; p = 0.002 Only in the MT group did practice predict improvement in Stop Accuracy: r = 0.52; p = 0.028 Difference between MT vs. SRL slopes: F(1,33) = 5.01; p = 0.032
Farb et al. 2012	Weekly group sessions with instruction in formal mindfulness practices.	PRE-INTERVENTION Groups matched by age and gender (p > 0.05) No structural differences between groups in insular or cortical regions (except caudate) IA and EA activated distinct cortical networks in both groups POST-INTERVENTION BOLD activation (fMRI) Triple interaction (group × task × insular region): F(7,238) = 3.02; p < 0.005 Greater activation of the dorsal anterior insula during IA in the MT group Accessory gyrus: F(1,34) > 4.50; p = 0.041 Anterior short gyrus: F(1,34) = 7.14; p = 0.012 DMPFC (dorsomedial prefrontal cortex): Group × task interaction: t(19) = 6.82; p < 0.001 DMPFC deactivated in AI in the MT group, not in the control group
Lenhart et al. 2020	Focused Attention Meditation (FAM) training lasting 7 weeks.	PRE-INTERVENTION Participants: 27 healthy adults with no previous experience with meditation No significant initial differences between hemispheres or regions (intraindividual control) State anxiety (STADI-S): mean 15.5 (SD ±4.8) POST-INTERVENTION Gray Matter Changes (VBM) Significant increase in gray matter volume in: Bilateral anterior insula: p = 0.001

		Inferior frontal gyrus (pars opercularis and orbitalis): p = 0.001–0.005 Caudate nucleus (E and D): p = 0.001–0.002 Superior frontal gyrus (BA10): p = 0.003 Right anterior cerebellum: p = 0.004 Significant reductions in gray matter volume in: Inferior parietal and superior/middle temporal cortex (bilateral): p < 0.001 Medial prefrontal cortex (mPFC): p < 0.001 Right parahippocampal gyrus → fusiform gyrus: p = 0.001 Medial/posterior cingulate cortex (PCC, MCC): p < 0.001–0.01 White Matter Changes (FA – DWI) Increased fractional anisotropy in: Right hippocampus: p = 0.016 Right basal ganglia: p = 0.012 Right periventricular white matter: p = 0.001 Anxiety Questionnaire (STADI-S) Significant reduction in state anxiety: From 15.5 to 12.6 points (mean) → p = 0.004 Also improvement in the subscales of arousal (p = 0.012) and worry (p = 0.012) No significant changes in trait anxiety or depression (p > 0.05) Correlation between structural changes and psychological improvement Reduction in state anxiety correlated with increased GM in: Medial/posterior cingulate cortex and bilateral mPFC: p < 0.001 PCC and precuneus: p = 0.014–0.091
Leung et al. 2016	Awareness-Based Compassion Meditation (ABCM) training	PRE-INTERVENTION No difference between groups in anxiety (p = 0.645) or affective image ratings (valence/arousal) (p > 0.5) Greater right amygdala activity in the ABCM group during negative image processing (MNI: 27, 0, −21): p = 0.014 (FWE corrected) POST-INTERVENTION Amygdala activity (fMRI – sad > neutral) Significant group × time interaction in the right amygdala: MNI: 27, 0, −18; p = 0.012 (FWE corrected); F = 17.65 Significant reduction in the ABCM group; no change in the control group Regression: group predicted 47.4% of variance (R^2 = 0.474), p < 0.001 Education and baseline did not alter the result (p = 0.886 and p = 0.541) Sensitivity analysis (jack-knife) 19/20 repeated analyses maintained significance in the same voxel of the right amygdala → robust result Practice × neuroplasticity correlation Reduced right amygdala activity correlated with compassion practice: r = −0.730; p = 0.017 (ABCM); no correlation in the control group Anxiety (Taylor Manifest Anxiety Scale) Significant group × time interaction: F(1,18) = 10.13; p = 0.005 Maintained after controlling for education level: F(1,17) = 6.028; p = 0.025 Reduction in the ABCM group: t(9) = −3.943; p = 0.003 Control group: no significant change (p = 0.560) PRE-INTERVENTION (novice group) BOLD activation (EF vs. NF) Slight reduction in activity in regions of the cortical midline (medial PFC and posterior cingulate): BA 25, BA 10, and BA 23/31: Z = 3.16 to 3.29 Increased activation on the left in: DLPFC (BA 45/46): Z = 3.60 VLPFC (BA 47): Z = 3.13 Posterior parietal cortex (BA 39/40): Z = 3.06 Functional connectivity Strong coupling of the right insula with vmPFC: R = 0.609; p < 0.001

Farb et al. 2007	Mindfulness-Based Stress Reduction (MBSR) course, lasting 8 weeks	POST-INTERVENTION (MT group) BOLD activation (EF vs. NF) Significant reduction in activity in the cortical midline: Dorsal mPFC (BA 9/10/32): F = 19.09; p < 0.001 Ventral mPFC (BA 10): F = 11.88; p < 0.003 Left dorsal amygdala: Z = 3.20 Significant increase in right activation: Lateral PFC (BA 46/45): F = 14.75; p < 0.001 Right insula: F = 14.41; p < 0.001 Secondary somatosensory cortex (SII/BA 40): F > 10.28; p < 0.003 Inferior parietal lobe (BA 39): Z = 3.11 Functional connectivity Decoupling of the right insula with vmPFC: R = 0.056; significant reduction compared to novices Fisher's r-to-Z = 13.36; p < 0.001 Increased connectivity right insula ↔ DLPFC: R = 0.783; Fisher's r-to-Z = 12.09; p < 0.001
Babu et al. 2020	Regular practice of Rajyoga Meditation (RM)	PRE-INTERVENTION Comparison between RM and NM: OHQ (subjective happiness): RM > NM RM: 131.88 ± 16.74 vs. NM: 118 ± 18.17 t = 3.33; p = 0.001 Correlation OHQ × meditation time (RM): r = 0.276; p = 0.084 → trend toward significance POST (INTERGROUP ANALYSIS – VBM) Increase in GMV in RM (vs. NM) Upper right frontal rotation (SFG): MNI: 16, 62, 8; k = 280 p = 0.005 (FWE TFCE corrected) Left inferior orbitofrontal cortex (OFC): MNI: −38, 42, −16; k = 45 p = 0.037 Bilateral precuneus: Right: MNI: 10, −57, 27; k = 264 → p = 0.011 Left: MNI: −14, −57, 32; k = 112 → p = 0.019 Correlation between GMV × Happiness Score (OHQ) in the RM group Right superior frontal gyrus (SFG): MNI: 18, 63, 2; k = 357 → p = 0.008 Left middle OFC: MNI: −20, 42, −16; k = 58 → p = 0.002 Right insula: MNI: 30, 15, −10; k = 155 → p = 0.001 Left anterior cingulate cortex (ACC): MNI: −9.45, 6; k = 195 → p = 0.027 GMV × Practice time correlation (RM) Bilateral ventral pallidum (VP): Left: MNI: −15, 4, −2; k = 220 → p = 0.009 Right: MNI: 14, 4, −3; k = 203 → p = 0.016
Yordanova et al. 2025	Long-term meditation practice in the Theravada Buddhist tradition.	PRE-INTERVENTION (control group – STM): -Greater temporal and spatial synchronization of pain-related oscillations in S1 and S2-IC: -Theta-alpha PLF: p = 0.008 (S1), p = 0.018 (S2-IC) -Beta PLF: p = 0.01 (S1) -Gamma-1 PLF: p = 0.001 (S1), p = 0.015 (S2-IC) -PLF gamma-2: p = 0.001 (S1) -R-PLV theta-alpha: p = 0.05 (S1), p = 0.04 (S2-CI) -R-PLV beta: p = 0.05 (S1) -R-PLV gamma-2: p = 0.008 (S2-CI) POST-INTERVENTION (experienced group – LTM): -Increased pre-stimulus alpha and gamma activity in contralateral somatosensory regions: -Alpha: p = 0.02 (S1), p = 0.006 (S2-CI) -Gamma: p = 0.02 (S1), p = 0.05 (S2-CI)

International Journal of Health Science ISSN 2764-0159 DOI https://doi.org/10.22533/at.ed.1595302518099

		-This predictive activity suppressed post-stimulus synchronizations: -E.g., gamma-1 PLF in S1 predicted by pre-stimulus alpha in S2-IC: p = 0.001 -Greater lateral asymmetry (right > left) in pre-stimulus alpha activity during pain: -S1: p = 0.002 -S2-IC: p = 0.02
Leung et al. 2012	Practice of Loving--Kindness Meditation (LKM) in the Theravada Buddhist tradition.	PRE-INTERVENTION (control group): - Lower gray matter volume in the regions: - Right angular gyrus - Right posterior parahippocampal gyrus - No significant correlation with hours of practice (p > 0.8) POST-INTERVENTION (LKM group): - Significant increase in gray matter volume: - Right angular gyrus (BA 39): p = 0.015 - Right posterior parahippocampal gyrus (BA 36): p = 0.049 - Trend toward increase in left temporal lobe (ITG and MTG): - p = 0.091 (not significant) - Negative correlation between right angular gyrus volume and hours of practice, controlling for age/education: p = 0.028
Kang et al. 2012	Brain Wave Vibration (BWV) practice.	PRE-INTERVENTION (control group): - Thinner cortical thickness in frontal and temporal regions: - vmPFC/OFC (p = 0.009 to <0.001) - Superior frontal (p = 0.005 to <0.001) - Middle/inferior temporal (p = 0.001 to <0.001) - Greater cortical thickness in posterior regions (compared to meditators): - Cuneus cortex, inferior parietal, postcentral, PCC (p = 0.005 to 0.032) - Lower FA (DTI) in frontal and temporal regions: - vmPFC, MPFC, occipital cortex (p < 0.001, FDR q < 0.05) POST-INTERVENTION (meditators group): - Significant increase in cortical thickness in the following regions (p < 0.05): - Bilateral vmPFC/OFC (p = 0.002 to <0.001) - Superior frontal cortex (p = 0.001 to 0.007) - Middle/inferior temporal (p < 0.001) - Significant reduction in cortical thickness in posterior regions (p < 0.05): - PCC (p = 0.003 to 0.017), inferior parietal (p = 0.001 to 0.032), cuneus (p = 0.002) - Increased white matter integrity (FA) in regions with greater cortical thickness (p < 0.001) - Weak positive correlation between cortical thickness in the superior frontal cortex and practice time: - r = 0.313; p = 0.034 (not significant after Bonferroni) PRE-INTERVENTION (control group/baseline): - Low use of emotional words in self-descriptions (TST) - No association with cortical thickness (p > 0.05)
Lumma et al. 2018	A 3-month mental training program.	POST-INTERVENTION (training group): - Significant increase in the use of emotional words after training: - Perspective vs. Control: p = 0.003 - Perspective vs. Presence: p < 0.001 - Perspective vs. Affect: p < 0.001 - Significant association between increase in emotional words and cortical thickness: - Right mPFC and dlPFC: p-FWE < 0.05 - Negative emotional words: - Right dlPFC: p-FWE < 0.05 - Left orbitalis (extending to dlPFC): p-FWE < 0.05 - More stringent analysis (p-FWE < 0.02): - Only right dlPFC (associated with negative words) remained significant

Joss et al. 2022	Mindfulness-Based Stress Reduction (MBSR) lasting 8 weeks.	PRE-INTERVENTION (control group): - No differences between groups in bilateral amygdala volume: $p > 0.42$ - No correlation between amygdala volume and childhood trauma severity: $p > 0.34$ POST-INTERVENTION (mindfulness group): - No significant effect of group, time, or group × time interaction on amygdala volumes ($p > 0.32$) - Significant correlation between childhood trauma severity and volume increase: - Early trauma (1–6 years) → left amygdala: $r = 0.57$, $p < 0.05$ - Late trauma (13–18 years) → right amygdala: $r = 0.45$, $p = 0.09$ - Baseline volume of the right amygdala correlated with post-intervention volumetric change: - $r = 0.65$, $p < 0.01$ - Fisher's test: $Z = 3.56$, $p < 0.0001$ - Change in right amygdala volume correlated with: - Sessions attended: $r = 0.51$, $p = 0.05$ - Time spent practicing at home: $r = 0.47$, $p = 0.08$ - Increase in self-compassion (SCS): $r = 0.55$, $p < 0.05$ - Change in left amygdala correlated with: - Reduction in perceived stress (PSS): $r = -0.73$, $p < 0.01$ - Reduction in sensitivity to rejection (A-RSQ): $r = -0.63$, $p = 0.01$ - Reduction in interpersonal distress (IRI-PD): $r = -0.59$, $p < 0.05$ - Variance explained by psychological scales: - Left amygdala: 77.24% (PSS: $p < 0.01$, A-RSQ: $p < 0.05$) - Right amygdala: 56.47% (SCS: $p < 0.05$)
Hernández et al. 2020	Regular practice of Sahaja Yoga Meditation (SYM).	PRE-INTERVENTION (control group): - Lower gray matter volume in the brain as a whole: $p = 0.005$; FDR $q = 0.007$ - Significantly lower GMV in the following lobes (compared to meditators): - Left frontal lobe: $p = 0.004$; $q = 0.016$ - Right frontal lobe: $p = 0.002$; $q = 0.016$ - Right temporal lobe: $p = 0.002$; $q = 0.016$ - Brainstem: $p = 0.003$; $q = 0.016$ POST-INTERVENTION (meditators group): - Significant increase in GMV in 11 AAL areas with $q < 0.05$, including: - Right middle temporal gyrus (MTG.R): $p = 0.001$; $q = 0.0291$ - Right inferior frontal opercular gyrus (IFGoperc.R): $p = 0.002$; $q = 0.0291$ - Right precentral gyrus (PreCG.R): $p = 0.003$; $q = 0.0291$ - Left middle frontal gyrus (MFG.L): $p = 0.009$; $q = 0.0393$ - Left olfactory cortex (OLF.L): $p = 0.009$; $q = 0.0393$ - Right orbital MFG (MFGorb.R): $p = 0.012$; $q = 0.0477$ - Increase in GMV throughout the brain: +6.9%; $p = 0.005$; $q = 0.007$ - Right hemisphere: +7.03%; $p = 0.004$; $q = 0.007$ - Left hemisphere: +6.72%; $p = 0.007$; $q = 0.007$ PRE-INTERVENTION (control group): - Average cortical thickness with no overall difference between groups: $p > 0.10$ - Significantly different cortical distribution between groups: - Left hemisphere: $p = 0.0025$ - Right hemisphere: $p = 0.013$ - Overall (bilateral): $p = 0.0001$ - Expected reduction in thickness with age in BA 9/10: $r = -0.76$, $p = 0.001$
Lazar et al. 2005	Insight Meditation (Vipassana) practice.	POST-INTERVENTION (meditators group): - Significant increase in cortical thickness: - Right anterior insula: $p = 1.2 \times 10^{-5}$ - Middle and superior frontal sulci (BA 9/10): $p = 1.8 \times 10^{-5}$ - Left superior temporal gyrus (auditory cortex): $p = 3.7 \times 10^{-4}$ - Central sulcus (BA 3a – somatosensory): $p = 6.0 \times 10^{-4}$ - Significant group × age interaction in BA 9/10: $p = 0.002$ - Correlation between occipitotemporal thickness and change in breathing (practice proxy): $r = 0.72$, $p < 0.001$ - Controlling for age: $r = 0.75$, $p < 0.001$ - Correlation between thickness and years of practice (occipitotemporal): $r = 0.627$, $p = 0.007$ - Correlation between thickness in the insula and breathing (controlling for age): $r = 0.48$, $p = 0.04$

Hölzel et al. 2010	Mindfulness-Based Stress Reduction (MBSR) lasting 8 weeks.	PRE-INTERVENTION (control group): - No difference between groups in gray matter volume: - Hippocampus: $p = 0.956$ - PCC: $p = 0.81$ - TPJ: $p = 0.40$ - Lateral cerebellum: $p = 0.17$ - No correlation between changes in density and mindfulness practice: $p > 0.33$ POST-INTERVENTION (MBSR group): - Significant increase in gray matter (GM) density: - Left hippocampus: $p = 0.014$ (FWE corrected) - Group × time interaction (ANOVA): $p = 0.035$ - Exploratory analysis of the entire brain (cluster-wise, $p < 0.05$ corrected): - PCC: $p < 0.001$ - Left TPJ: $p = 0.002$ - Cerebellum/vermis/brainstem: $p = 0.002$ - Lateral cerebellum: $p = 0.004$ - Control group showed no significant changes in the same regions: - TPJ: $p = 0.40$ - Vermis: $p = 0.88$ - Lateral cerebellum: $p = 0.79$ - PCC: significant reduction: $p = 0.001$
Yang et al. 2016	Self-observation--based mindfulness training, lasting 40 days	PRE-INTERVENTION (TP1 – before training): - CES-D scale: mean of 16.23 ± 9.54 (above the clinical cutoff point) - Functional connectivity of pgACC and dACC with DMN without training effect ($p > 0.1$) - No significant difference in Regional Homogeneity (ReHo) between TP1 and TP2 ($p > 0.05$) POST-INTERVENTION (TP2 – after 40 days): - Changes in functional connectivity (RSFC): - pgACC → reduced connectivity with: - PCC/Precuneus: $p < 0.05$ (FWE-corrected) - dmPFC, STG, MOG, ITG: $p < 0.05$ - pgACC → increased connectivity with: - TPJ/IPL, IFG, ITG: $p < 0.05$ - dACC → increased connectivity with: - PCC and cerebellum: $p < 0.05$ - Reduction with cuneus/calcarine sulcus: $p < 0.05$ - ICA (DMN): - During meditation (vs. rest): - Increased consistency in precuneus and TPJ: $p < 0.05$ - Reduction in activity in dACC, sgACC, insula, SFG, IFG: $p < 0.05$ (FWE) - ReHo (Regional Homogeneity): - MS > RS: increased ReHo in dACC, MPFC, putamen, TPJ: $p < 0.05$ (FWE-corrected) - No longitudinal changes in ReHo (TP1 vs. TP2): $p > 0.05$ - Symptom scales: - CES-D (depression): significant reduction: $p < 0.001$ - STAI-trait (trait anxiety): significant reduction: $p < 0.01$ - POMS – tension: $p < 0.05$ (uncorrected)

Table 2: Results of data extraction from selected articles after reading the full text

Note: AAL: Automated Anatomical Labeling, ACC: Anterior cingulate cortex, ACC: Anterior cingulate cortex, ACC: Anterior cingulate cortex, ACC: Anterior cingulate cortex, ACC: Anterior cingulate cortex, ABCM: Mindfulness Compassion Meditation, AH-GLM: Ad-hoc general linear model, Alpha: Frequency range of 8–12 Hz, A-RSQ: Adult Rejection Sensitivity Questionnaire, DMN–DLPFC anticorrelation: Negative correlation between DMN and DLPFC, ANOVA: Analysis of variance test, ANCOVA: Analysis of covariance, Arousal: Degree of emotional excitement caused by a stimulus, BA: Brodmann area, BA: Brodmann area, BA10: Brodmann area 10 – anterior prefrontal cortex, BA36: Brodmann area 36, BA39: Brodmann area 39, Beta: Frequency range of 16–25 Hz, BOLD: Blood oxygen level in the brain, CCAsg: Subgenual anterior cingulate cortex, CES-D: Center for Epidemiological Studies Depression Scale, DLPFC: Dorsolateral prefrontal cortex, DLPFC: Dorsolateral prefrontal cortex, DLPFC: Dorsolateral prefrontal cortex, DLPFC: Dorsolateral prefrontal cortex, DMN: Default Mode Network, DMN: Default Mode Network, SD: Standard Deviation, DTI: Diffusion Tensor Imaging, dACC: Dorsal anterior cingulate cortex, dlPFC: Dorsolateral Prefrontal Cortex, EA: Attention to external stimuli, EC: Effective Connectivity, EF: Experiential Focus, FA: Fractional Anisotropy – measure of white matter, FA (DTI): Fractional Anisotropy, FC: Functional Connectivity, Fisher's r-to-Z: Statistical transformation to compare correlation coefficients (R) between groups, F: F-statistic (used in ANOVA tests to compare variances between groups), F: Statistical value used in ANOVA, F(x,y) = value: ANOVA F-statistic, FDR: False discovery rate, FDR q-value: Q-value adjusted for false discovery rate, FWE: Statistical correction for multiple comparisons, used to reduce false positives in neuroimaging, FWE: Family-Wide Error Correction, FWE: Correction for multiple testing family error, FWE-corrected: Statistical correction to avoid false positives, fMRI: Neuroimaging technique used to measure brain activity, fMRI: Functional Magnetic Resonance Imaging, Gamma-1: Frequency range of 30–35 Hz, Gamma-2: Frequency range of 38–42 Hz, GM: Gray Matter, GM: Gray Matter, GMV: Gray Matter Volume (GMV), GMV: Cerebral gray matter volume, Go-Accuracy: Accuracy in "Go trials," IFG: Inferior frontal gyrus, IA: Attention to internal bodily sensations, IRI-PD: Interpersonal Reactivity Index – Personal Distress, IS: Stroop interference, ITG: Inferior temporal gyrus, ITG: Inferior temporal gyrus, Jack-knife: Sensitivity analysis method that tests the robustness of results by iteratively excluding a subject from the sample, K: "k" represents the number of voxels (three-dimensional brain image units), KNN: k-nearest neighbor algorithm, k: Kolmogorov-Smirnov test statistic, LKM: Compassion and Loving-Kindness Meditation, LTM: Experienced group with prolonged meditation practice, MCC: Middle Cingulate Cortex, MBSR: Program structured around formal practices such as body scanning, breath awareness, and sitting meditation, MBSR: Mindfulness-Based Stress Reduction, MNI: Standard coordinate system used to map brain regions in neuroimaging, MNI: Standardized coordinates for brain localization in neuroimaging, MOG: Middle occipital gyrus, MPFC: Medial prefrontal cortex, mPFC: Medial prefrontal cortex, MT: Mindfulness Training - Experimental group, MTG: Middle temporal gyrus, MPRAGE: Resonance sequence, Alpha level: Level of significance, usually 0.05, NF: Narrative focus, NM: Control group, non-meditators, OHQ: Subjective Happiness Questionnaire, OFC: Orbitofrontal cortex, OFC: Orbitofrontal cortex, PCC: Posterior cingulate cortex, PCC: Posterior cingulate cortex, PCC: Posterior cingulate cortex, PCC: Posterior cingulate cortex, PCC: Posterior cingulate cortex, Pars orbitalis: Subregion of the brain, P: Statistical significance value, POMS: Profile of Mood States, PLF: Index of temporal synchronization of neural oscillations between trials, p-FWE: Family-wise error corrected p-value, pgACC: Pregenual anterior cingulate cortex, PCC: Posterior cingulate cortex, PSS: Perceived Stress Scale, R^2: Coefficient of determination (indicates the proportion of variance explained in a regression model), R-PLV: Spatial synchronization index of oscillations between brain regions, Relat dif %: Relative percentage difference, ReHo: Regional Homogeneity, RM: Rajyoga Meditation Group, ROI: Specific anatomical region analyzed in the brain, ROI: Region of interest, RTs: Participant response time in tests, RSFC: Resting-state functional connectivity, rsFC: Resting-State Functional Connectivity, S1: Primary somatosensory cortex, S2-IC: Secondary somatosensory cortex and insula, SART: Sustained Attention Task, SC: Structural Connectivity, SCS: Self-Compassion Scale, sgACC: Subgenual anterior cingulate cortex, SFG: Superior frontal gyrus, SRL: Active control group, with shared reading sessions and literature discussion, STADI-S: State Anxiety Inventory, STAI-trait: Trait Anxiety Inventory, STM: Control group with little meditation experience, STG: Superior temporal gyrus, Slope: Slope (regression coefficient), SYM: Sahaja Yoga Meditation, TFCE: Statistical analysis technique in neuroimaging, Theta-alpha: Frequency range of 4–10 Hz, T: T-statistic (used to compare means between two groups or moments), TIV: Total intracranial volume (TIV), TP1 / TP2: Time Point 1 / 2 (before and after meditation training), TPJ: Temporoparietal Junction, TST: Twenty Sentences Test, Valence: Degree of positivity or negativity of an emotional stimulus, VBM: Voxel-Based Morphometry, VBM: Voxel-based morphometry, VP: Ventral pallidum, VLPFC: Ventrrolateral Prefrontal Cortex, vmPFC: Ventromedial Prefrontal Cortex, vmPFC: Ventromedial Prefrontal Cortex, Z: Z-statistic – Standardized measure of brain activation in neuroimaging analyses, Z-score: Standardized statistic of brain activation.

SUMMARY OF RESULTS

The studies analyzed present varied samples in terms of number of participants, duration of practice, and type of meditative intervention. Some studies, such as those by Filippi et al. (2022) and Yordanova et al. (2025), involved experienced meditators with more than 1,000 hours of practice, while others, such as Bauer et al. (2020) and Allen et al. (2012), used short-term interventions (around 8 weeks or less). In general, most studies involved healthy adults, with control groups well matched for age, gender, and education.

Cognitively, several articles reported improvements in attention, inhibitory control, and performance on executive tasks after meditation practice. There was an increase in the accuracy of attentional tasks and less interference in Stroop tests, accompanied in some cases by changes in functional brain connectivity, such as the anticorrelation between DMN and DLPFC (Braboszcz et al. (2013), Allen et al. (2012), Bauer et al. (2020)). In addition, there was also a reduction in connectivity between certain regions (Taren et al., 2015 and Yang et al., 2016).

As for structural changes in the brain, there was an increase in gray matter in areas related to emotional self-regulation, attention, and body perception. Studies such as those by Lenhart et al. (2020), Hernández et al. (2020), and Hölzel et al. (2010) highlight significant changes in regions such as the insula, medial prefrontal cortex, cingulate cortex, and hippocampus. Similarly, Lazar et al. (2005) found increased cortical thickness in areas such as the medial frontal sulcus and anterior insula, while Kang et al. (2012) pointed to thickening in the bilateral vmPFC/OFC, superior frontal cortex, and middle/inferior temporal cortex. Babu et al. 2020 found an increase in the right superior frontal gyrus, left inferior orbitofrontal cortex, and bilateral precuneus, which was related to happiness, as evidenced in the right superior frontal gyrus, left middle orbitofrontal cortex, right insula, and left anterior cingulate cortex.

Joss et al. (2022) found no significant changes in amygdala volumes after the intervention, although they identified correlations between volumetric changes and psychosocial variables, such as stress and self-compassion.

Leung et al. (2016) and Lenhart et al. (2020) pointed to a significant reduction in state anxiety associated with structural changes in limbic and prefrontal regions. Similarly, Lumma et al. (2018) detected greater cortical thickness and an increase in emotional expression after training.

For Farb et al. 2007, after the intervention, the specialized group showed a marked reduction in activity in the cortical midline and left dorsal amygdala. In contrast, there was a significant increase in activation in the right lateral prefrontal cortex, right insula, and secondary somatosensory cortex. Farb et al. 2012 points out that there was a statistically significant difference between groups, task types, and insular region, with greater activation in certain regions in the group that performed meditation.

DISCUSSION

The practice of meditation and mindfulness has been used to regulate brain functions and increase performance, both subjectively and by increasing the brain regions responsible for such activities. The studies analyzed converge in demonstrating that meditative practice promotes functional and structural plasticity in multiple neural networks, albeit with variations according to the style and intensity of training.

In the attentional domain, evidence shows that both brief interventions and intensive retreats increase efficiency in executive control. A three-month retreat for experienced meditators resulted in greater accuracy in incongruent Stroop task trials, in correlation with previous meditation experience (Braboszcz et al., 2013), while short programs, such as a twelve-hour mindfulness program, also reduced Stroop interference and improved behavioral inhibition (Allen et al., 2012). Complementarily, even shorter training sessions were able to preserve the anticorrelation between the default mode network (DMN) and the dorsolateral prefrontal cortex (DLPFC), a mechanism that has been associated with sustained attention performance (Bauer et al., 2020), suggesting that strengthening executive control is an early effect., a mechanism associated with better sustained attention performance (Bauer et al., 2020), suggesting that strengthening executive control is an early and robust effect of meditative practice, supported by regulation between self-referential and prefrontal networks.

In the sphere of functional connectivity, consistent changes are seen in the limbic-cingulate axis and interoceptive regions. An intensive three-day training program has been found to be sufficient ( ) to reduce resting-state connectivity between the amygdala and subgenual cingulate cortex, suggesting rapid modulation of emotional reactivity (Taren et al., 2015). Similarly, mindfulness-based stress reduction (MBSR) programs shifted insular connectivity from self-referential areas to executive control regions, in addition to reducing activity in the mPFC and amygdala during states of experiential attention (Farb et al., 2007). In group practices, interoceptive focus was associated with greater activation of the dorsal anterior insula and deactivation of the dorsomedial medial prefrontal cortex, signaling less interference from self-referential processes (Farb et al., 2012). In longer protocols, such as forty days of training, the reconfiguration of connectivity included the anterior cingulate and was associated with a reduction in symptoms of depression and anxiety (Yang et al., 2016), reinforcing meditation as a modulator of the relationship between regions involved in self-perception, emotional processing, and cognitive control.

With regard to structural neuroplasticity, findings indicate increases in gray matter in areas critical for memory, emotional regulation, and interoceptive processing. Eight weeks of MBSR were sufficient to increase volume in the hippocampus, precuneus, temporoparietal junction, and cerebellum (Hölzel et al., 2010), while experienced meditators in insight and Vipassana practices showed greater cortical thickness in the prefrontal cortex (BA9/10), anterior insula, and somatosensory cortices, as well as attenuation of age-related cortical thinning (Lazar et al., 2005). In novice practitioners, seven weeks of focused attention resulted in increases in the anterior insula, inferior frontal gyrus, caudate, and cerebellum, parallel to a reduction in anxiety (Lenhart et al., 2020). Other traditions, such as Sahaja Yoga, showed a 6.9% global expansion of gray matter (Hernández et al., 2020), and Brain Wave Vibration promoted increases in prefrontal and temporal regions, with parallel greater integrity of frontal white matter (Kang et al., 2012). In terms of structural connectivity, networks involving the putamen, somatomotor cortex, and frontal cortex showed distinct patterns between Vipassana meditators and controls, with 87% accuracy in classifiers (Filippi et al., 2022). These findings reinforce that, regardless of tradition, consistent practice is associated with broad and multifocal structural reorganization.

In addition, other relevant findings can be cited beyond the sphere of neuroplasticity and cognition, such as emotional and even pain perception. Changes in limbic regions, especially the amygdala, stand out as central to the interface between emotion and compassion. Compassion practices reduced the reactivity of the right amygdala to sad stimuli, an effect proportional to the intensity of the practice and associated with lower anxiety (Leung et al., 2016). Similarly, in the context of MBSR, although no mean group effects were detected in amygdala volume, individual changes correlated with history of trauma, engagement, and increased self-compassion, suggesting that limbic modulation may depend on interindividual factors (Joss et al., 2022). Electrophysiological studies reveal that experienced meditators have distinct neural dynamics, with increased pre-stimulus activity in somatosensory and insular regions, which suppresses the post-stimulus response typically observed in controls. This pattern indicates a proactive, possibly predictive, mechanism of pain regulation, in contrast to the reactive response of non-meditators, which is more associated with suffering (study on pain in long- and short-term meditators).

Finally, different meditative styles emphasize partially distinct circuits. Rajyoga has been associated with greater subjective happiness and increased volume in prefrontal and reward regions, such as the ventral pallidum (Babu et al., 2020). nd loving-kindness meditation showed an increase in regions such as the angular gyrus and parahippocampal gyrus, although with a negative correlation in relation to hours of practice, suggesting synaptic pruning or increased efficiency. Vipassana, in addition to structural and functional changes, showed that states of meditation can be distinguished from rest by highly accurate classifiers (Filippi et al., 2022). In summary, if on the one hand specific styles modulate different networks—social, reward, or interoceptive—on the other hand, the convergence of findings lies in the reduction of self-referential ruminative patterns and the strengthening of top-down control, showing that meditation acts as a powerful agent of brain reorganization at multiple levels.

CONCLUSION

This review shows that meditation and mindfulness have measurable effects on brain neuroplasticity, confirming their ability to promote both functional and structural changes, with significant cognitive repercussions. The main findings point to an increase in gray matter in regions related to emotional regulation (amygdala, medial prefrontal cortex), interoceptive processing (insula), and memory (hippocampus), in addition to the functional modulation of neural networks of attention and self-reference. Such changes translate clinically into gains in sustained attention, greater executive control, better emotional regulation, and reduced anxiety and depressive symptoms, highlighting the breadth of cognitive and psychosocial benefits associated with the practice.

Although the literature has limitations, such as small sample sizes, heterogeneity of meditative styles, and a predominance of cross-sectional designs, the convergence of results allows us to consistently affirm that meditation and mindfulness are capable of remodeling brain architecture, favoring adaptive processes that support mental health and cognitive performance. In this sense, it can be concluded that meditative practice not only modifies neuroplasticity and brain structure but also improves cognitive functioning in an integrated manner.

In terms of applicability, these findings reinforce the potential of meditation as a complementary strategy in clinical and educational contexts, especially in the management of stress-related disorders, anxiety, and depression. Future perspectives should prioritize longitudinal trials with greater methodological rigor, standardization of practices, and multimodal neuroimaging integration in order to elucidate specific mechanisms and optimize protocols adapted to different population profiles.

Thus, meditation and mindfulness emerge not only as contemplative and spiritual practices, but as tools capable of inducing brain plasticity and sustaining lasting cognitive changes, paving the way for their consolidation as a therapeutic and scientific resource in the 21st century. Meditating is training the brain to reorganize itself: a simple practice, but one with the power to reconfigure circuits, restore balance, and expand the frontiers of human cognition.

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