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Exploring age-related brain degeneration in meditation practitioners

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A growing body of research suggests that meditation practices are associated with substantial psychological as well as physiological benefits. In searching for the biological mechanisms underlying the beneficial impact of meditation, studies have revealed practice-induced alterations of neurotransmitters, brain activity, and cognitive abilities, just to name a few. These findings not only imply a close link between meditation and brain structure, but also suggest possible modulating effects of meditation on age-related brain atrophy. Given that normal aging is associated with significant loss of brain tissue, meditation-induced growth and/or preservation might manifest as a seemingly reduced brain age in meditators (i.e., cerebral measures characteristic of younger brains). Surprisingly, there are only three published studies that have addressed the question of whether meditation diminishes age-related brain degeneration. This paper reviews these three studies with respect to the brain attributes studied, the analytical strategies applied, and the findings revealed. The review concludes with an elaborate discussion on the significance of existing studies, implications and directions for future studies, as well as the overall relevance of this field of research.

Keywords: aging; brain; meditation; MRI; preservation

Introduction

A few years ago, an English newspaper reported that "every minute that you spend reading this article, the average life expectancy in Britain will rise by 12 seconds. This time tomorrow, it will have increased by almost five hours." A similar message seems to be conveyed to thousands of Americans through recently erected billboards by a well-known insurance company announcing that "the number of 100-year-olds is expected to double by 2020." Few would argue that living longer is an attractive idea. However, the question of how we can make the increased number of years as enjoyable as possible arises, especially considering the likelihood of age-related cognitive decline, mental illness, physical impairment, and/or neurodegenerative diseases. This is where meditation comes into play, as it has been shown to positively affect well-being and contribute to personal resilience. Meditation is an easily approachable practice that can be integrated into anybody's daily routine without requiring any burdensome monetary investment, lengthy time commitment, special setup, or skills. It can be learned from attending a workshop, a lecture, or simply by reading a book. Moreover, meditation can be successfully practiced by people of every age, educational background, culture, and religion, and does not require specific beliefs or lifestyle changes. Thus, meditation appears extremely suitable, even for older people who may have limited mobility, finances, or willingness to make great adjustments to their current daily routines.

However, even today, the systematic study of meditation is still in its infancy. Nevertheless, scientific evidence is accumulating, and more and more studies support the idea that meditation practices are associated with significant psychological as well as physiological benefits, both in everyday life as well as in clinical settings. For more detailed information, such as theoretical and empirical support for these proposed benefits as well as critical discussions of study-specific limitations, the reader is referred to a large pool of existing meta-analyses and review

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papers.[1–12] In searching for the biological mechanisms underlying the beneficial impact of meditation, studies have revealed meditation effects on neurotransmitters, hormones, enzymes, and even telomere length and gene expression.[13–17] Together with reports documenting the effects of meditation on cerebral activity and blood flow[18–23] as well as on cognitive performance and mental capacity,[24–30] these findings imply a close link between meditation and brain structure. Such links might not only be evident on the microanatomical level but also may even manifest in the macrostructure of the brain and, as such, become observable via structural magnetic resonance imaging (MRI). Indeed, various cross-sectional MRI studies[31–37]—including the author's research[38–42]—have revealed significantly larger brain regions, more brain tissue, and thicker or more complex cerebral cortices in meditators compared to healthy control subjects.

While the unique brain anatomy in meditators may constitute an innate cerebral characteristic that attracted them toward meditation and/or helped maintain an ongoing practice, it is also possible that brain anatomy has been altered through the actual practice of meditation. In support of this possibility, recent longitudinal MRI studies have provided direct confirmation for meditation-induced anatomical brain changes such as increased gray matter density and fractional anisotropy (FA), as well as decreased radial diffusivity (RD) and axial diffusivity (AD).[a,43–45] With respect to the underlying processes for such anatomical changes, at least two potential mechanisms exist: on the one hand, it is possible that engaging the brain in intense mental processes during meditation affects brain structure by inducing changes as a result of dendritic branching, synaptogenesis, myelinogenesis, or even adult neurogenesis (i.e., aspects related to neuroplasticity). On the other hand, meditation might positively affect autonomic regulation and immune activity, which may lead to neuronal preservation, restoration, and/or inhibition of apoptosis (i.e., aspects related to neuroprotection). Both mechanisms are not mutually exclusive and may occur jointly. Thus, it is reasonable to assume that some brain regions are changed through neuroplastic processes, whereas others are only better maintained through neuroprotection. It is equally plausible that there is a powerful combination of both effects for a single brain region. Given that normal aging is associated with a significant loss of brain tissue, meditation-induced growth and/or resistance to neurodegeneration might manifest as a reduced brain age (i.e., cerebral measures characteristic of younger brains) in long-term meditation practitioners.

With this in mind, it is surprising that there are only three published studies,[36,37,42] cross-sectional in nature, that examined if meditators show less age-related decline of brain tissue than nonmeditators. The first study,[36] published in 2005, was based on a comparison of 15 control subjects and 20 practitioners of Insight meditation (also commonly referred to as Vipassana). The second study,[37] published in 2007, compared 13 control subjects and 12[b] practitioners of Zen meditation. The third study,[42] published in 2011, was based on comparing 27 control subjects and 27 meditators practicing a conglomerate of meditation styles (including Vipassana, Zen, and Shamatha). Table 1 provides an overview of the sample characteristics for each of the three studies.[36,37,42] The subsequent sections will further describe these existing studies with respect to their morphological measures, analytical strategies, and significant findings.

Existing studies in detail

Morphological measures

The brain consists of two main tissue types: gray matter (which contains primarily neuronal cell bodies, synapses, and dendrites) and white matter (which contains primarily axons). Whereas the first[36] and second[37] studies focused on gray matter attributes, such as cortical thickness and gray matter volume, the third study[42] examined FA, which constitutes a white matter attribute. In general, MRI-based morphological measures are considered approximations of the underlying microarchitecture, including their possible capacities and functional implications. More specifically, measuring the thickness of the cortex (study 1) or the volumetric

[a]FA, RD, and AD constitute morphometric measures related to white matter efficiency.

[b]The original sample contained 13 controls and 13 meditators. However, the MR image of one meditation practitioner was corrupted by an artifact and subsequently removed from the image analyses.

Table 1. Number of subjects, age (in years), and meditation practice (experience, style)

	Number of subjects	Age of subjects: mean ± SD	Meditation experience: mean ± SD	Meditation style
S1	20 MED (13 M, 7 F)	MED: 38.2 ± n.r.	9.17 ± 7.1 years	Vipassana
	15 CTL (10 M, 5 F)	CTL: 36.8 ± n.r.	(70 h minimum)	
S2	13 MED (10 M, 3 F)	MED: 37.2 ± 6.9	n.r.	Zen
	13 CTL (10 M, 3 F)	CTL: 35.5 ± 5.7	(3 years minimum)	
S3	27 MED (11 M, 16 F)	MED: 51.6 ± 12.3	23.3 ± 12.2 years	Various styles[a]
	27 CTL (11 M, 16 F)	CTL: 51.4 ± 12.4	(5 years minimum)	

[a]Styles include Shamatha, Vipassana, and Zen, which are practiced by about 55% of all meditators, exclusively or in combination with other styles.
S1 = study 1; S2 = study 2; S3 = study 3; MED = meditators; CTL = controls; M = males; F = females; SD = standard deviation; n.r. = not reported.

amount of gray matter (study 2) gives an estimate of the amount of actual gray matter tissue (e.g., cell bodies, synapses, dendrites). Thus, larger gray matter volumes (or thicker cortices) are usually interpreted as reflective of more numerous processing units. Comparable assumptions exist with respect to FA (study 3): larger FA values are commonly understood as reflective of an enhanced connectivity between different parts of the brain. However, associations between FA, a white matter attribute, and the actual characteristics of white matter are less direct: FA quantifies restrictions in the diffusion of water molecules and, as such, is largely determined by the number, density, and diameter of axons, as well as their coherence in orientation and degree of myelination. These characteristics dictate a fiber tract's ability to rapidly relay electrical signals, where an increased number of transmitting units, larger axonal diameters, and/or stronger myelination may result in more effective signal transduction. All aforementioned MRI-based morphological measures—cortical thickness, gray matter volume, and FA—are known to decrease with age, as consistently reported in normative samples.[46–54]

Analyses and findings

The first study[36] analyzed the link between age and cortical thickness in two predetermined brain regions that were defined based on a preceding analysis (also part of that study) comparing meditators and controls with respect to cortical thickness. Cortical thickness was measured at thousands of points across the cerebral cortex as the distance between inner (white/gray) and outer (gray/cerebrospinal fluid) boundaries using an automated method.[55] Significant group differences (meditators > controls) were observed within the right insula and right frontal cortex (BA9/BA10). After extracting the mean cortical thickness within these two regions for each subject, researchers tested for group-by-age interactions. The study revealed a significant group-by-age interaction for the right frontal region (BA9/BA10) with significant age-related decreases in the control group ($r = -0.76$; $P = 0.001$) but nonsignificant decreases in the meditation group ($r = -0.05$; $P = 0.83$). The researchers also acknowledged that "the average cortical thickness of the 40- to 50-year-old meditation participants was similar to the average thickness of the 20- to 30-year-old meditators and controls." They further suggested "that regular practice of meditation may slow the rate of neural degeneration at this specific locus." Thus, mechanisms related to neuroprotection (preservation) seem to be in effect. The location of the right BA9/BA10 is illustrated in Figure 1A.

The second study[37] analyzed the link between age and total gray matter volume, as well as local gray matter volume determined for thousands of voxels across the entire brain through an automated, standardized method known as voxel-based morphometry (VBM).[56] With respect to total gray matter (adjusted for individual head size), there was a trend for a significant age-by-group interaction "with an estimated rate of change of −4.7 mL/year for the control group versus +1.8 mL/year for the meditators group." Moreover, analyses exposed marginally significant age-related decreases in the control group ($r = -0.54$; $P = 0.056$) and nonsignificant

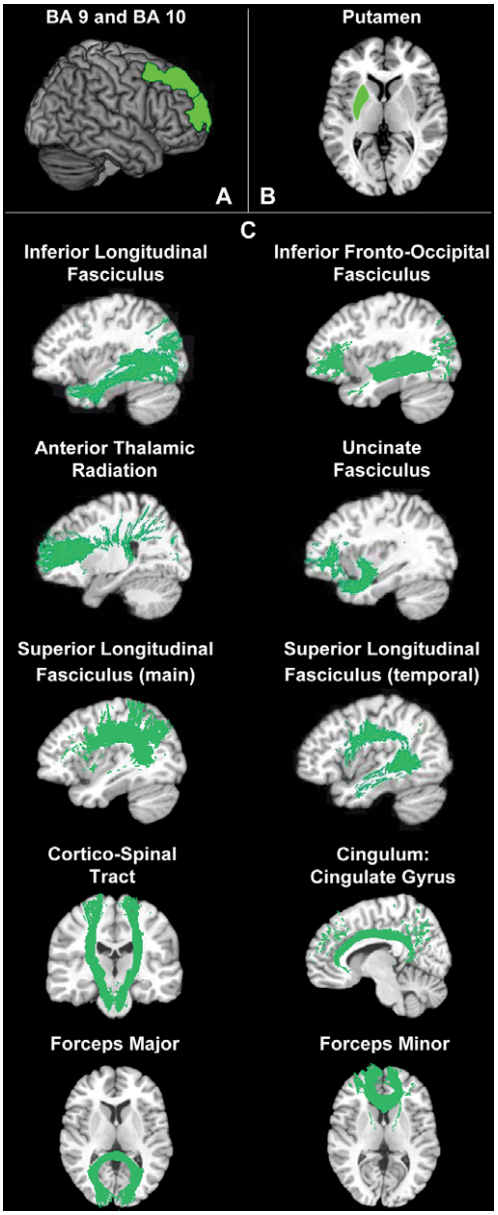

Figure 1. Reduced age-related decrease in meditation practitioners. Illustrated are the brain regions (in green) where significant group-by-age interactions were detected with respect to cortical thickness (A), gray matter volume (B), and fractional anisotropy (C) by existing research (studies 1–3). Note that the areas outlined in A and B do not constitute the actual significance clusters from studies 1 and 2 but rather are provided to index the respective location in the brain. The areas outlined in C show the fiber tracts from which measures were obtained in study 3. However, for simplicity, in most cases, only one hemisphere is depicted. For all these regions (A–C) the negative slopes of the regression lines, indicating an age-related decrease, were less steep in meditation practitioners. For the respective scatter plots, please refer to the figures in the original publications.[36,37,42]

increases in the meditation group ($r = 0.006$; $P = 0.83$). The apparent gain of total gray matter over time in meditators suggests mechanisms related not only to neuroprotection (preservation) but also to neuroplasticity (growth). The outcomes of the VBM analysis in this study serve to strengthen this assumption. More specifically, with respect to voxel-wise gray matter (also adjusted for head size), there was a significant age-by-group interaction within the left putamen. When extracting the mean gray matter values from this significance cluster and examining the group-specific correlations with age, there was a significant negative correlation within controls ($r = -0.80$; $P = 0.0011$) and a trend for a significant positive correlation within meditators ($r = 0.55$; $P = 0.063$). The location of the left putamen is illustrated in Figure 1B.

The third study[42] analyzed the link between age and mean FA in 20 predefined fiber tracts (i.e., nine fiber tracts in each hemisphere and two interhemispheric tracts) by applying an automatic mapping approach and using a well-established white matter tractography atlas.[57] The study revealed that FA and age were mostly negatively correlated (i.e., smaller FA in older subjects), both in meditators and controls. However, significant group-by-age interactions were revealed for 17 out of the 20 fiber tracts examined. Post hoc analyses with respect to these 17 tracts unequivocally revealed that the age-related decrease in meditators was less prominent than the age-related decrease in controls. Moreover, in meditators, there was a nonsignificant age-related increase over time within the right cortico-spinal tract (i.e., larger FA in older subjects). The patterns of change in FA over time in meditators (diminished decline and even gain) are in close agreement with the previously proposed processes related to neuroprotection as well as neuroplasticity. An overview of tract-specific correlation coefficients (r) and significance values (P), separately within meditators and controls, is provided in Table 2. The location of the fiber tracts is illustrated in Figure 1C.

Significance of existing studies and implications for future studies

These initial three studies[36,37,42] provide preliminary data suggesting that meditation may slow, stall, or even reverse age-related brain degeneration. However, further research is needed. For example, in addition to replicating these findings in larger and

Table 2. Tract-specific correlations

White matter fiber tract	Correlation (r)	
	Controls	Meditators
Inferior longitudinal fasciculus		
Left	-0.761^{***}	-0.212
Right	-0.720^{***}	-0.155
Inferior fronto-occipital fasciculus		
Left	-0.783^{***}	-0.442^{*}
Right	-0.786^{***}	-0.278
Anterior thalamic radiation		
Left	-0.753^{***}	-0.495^{**}
Right	-0.756^{***}	-0.465^{*}
Uncinate fasciculus		
Left	-0.729^{***}	-0.497^{**}
Right	-0.812^{***}	-0.244
Superior longitudinal fasciculus (main)		
Left	-0.726^{***}	-0.162
Right	-0.683^{***}	-0.186
Superior longitudinal fasciculus (temporal)		
Left	-0.760^{***}	-0.087
Right	-0.716^{***}	-0.107
Cortico-spinal tract		
Left	-0.601^{***}	-0.100
Right	-0.600^{***}	0.043
Cingulum: Cingulate gyrus		
Left[a]	$[-0.483^{*}]$	$[-0.117]$
Right	-0.497^{**}	-0.096
Cingulum: Hippocampus		
Left[a]	$[-0.482^{*}]$	$[-0.094]$
Right[a]	$[-0.401^{*}]$	$[-0.140]$
Forceps major	-0.645^{***}	-0.178
Forceps minor	-0.762^{***}	-0.628^{***}

[a]The group-by-age interaction was not significant.
$***P \leq 0.001$; $**P \leq 0.01$; $*P \leq 0.05$ for significant correlations within groups (controls/meditators).

independent samples, it will be intriguing to expand the spectrum of cerebral measurements. Furthermore, while the three existing studies have focused on either a specific style or a conglomerate of different styles, future studies may want to consider exploring possible differential effects of various meditation styles. Moreover, follow-up studies may determine what constitutes the critical amount of meditation—not only in relation to overall practice (total hours and years) but also with respect to the length, frequency, and regularity of practice sessions—in order to accomplish desirable effects. Last but certainly not least, future studies will have to include neurocognitive measures to address if the preservation of brain tissue is related to the preservation of mental capacities, and which cognitive domains are particularly affected. Eventually, longitudinal studies—preferably using random assignments to mindfulness interventions and an active control condition—will help to discriminate between cause and effect. It is important to note though that in the framework of aging-related research, longitudinal studies will be severely compromised by feasibility constraints. That is, budgetary limitations but also other factors (related to, for example, subject attrition) are likely to demand relatively short training/intervention periods limited to weeks, months, or a couple of years, at best. Possible age-defying effects of meditation, however, may only be marginal after short periods of time and thus remain undetected. Moreover, given that meditation is highly individualistic where each practitioner must find his/her own meditation style, teacher, and routine, short-term longitudinal findings may be additionally compromised by the assigned instructor, dictated technique, or artificiality of the practice setting. Consequently, cross-sectional studies using long-term meditators will continue to be extremely valuable to further explore possible modulating effects of meditation on brain aging—even more so if potential confounding variables (e.g., diet, exercise, economic status, level of education, intelligence) are carefully accounted for.

Overall relevance and outlook

As acknowledged at the beginning of this review, life expectancy around the world has risen dramatically (and is expected to rise further), with more than 10 years of life gained since 1970. It is important to note that, after the age of 40, the human brain decreases in volume and weight by approximately 5% every decade. Thus, age-related cognitive decline, as well as increased risk of mental illnesses and neurodegenerative diseases, is a valid concern that reflects reality. Techniques or practices that can diminish (or even reverse) the negative impact of aging on the human brain are therefore largely desirable, even more so if intervention tools are cost- and time-effective and easily accessible. Preliminary evidence for the brain-preserving effects of meditation exists, as reviewed in this paper. However, given

the extremely sparse data, it is imperative to continue investigating aspects of age-related brain degeneration in the framework of meditation. Demonstrating that an active meditation practice diminishes age-related brain atrophy could have an extremely positive impact, not only physiologically (i.e., the actual preservation of brain tissue) but also psychologically: rather than resigning to the fact that dwindling brain tissue is a common symptom of aging, people would be equipped with a powerful tool to actively influence their aging processes. Exploring these potential side effects of meditation may not only motivate individuals to integrate meditation into their daily routines but also, in the long run, may lead to the integration of meditation as an effective preventive and/or interventional approach into mainstream healthcare programs. For example, the apparent potential of meditation to slow age-related brain atrophy may become relevant for individuals suffering from neurodegenerative diseases or a variety of disorders associated with the pathological loss of brain tissue. At this point, further research in normative samples is required before specifically addressing the brain-preserving potential of meditation in these aforementioned pathological conditions. However, every journey starts with a first step, and by adding specific knowledge with respect to the modulating effects of meditation on age-related cerebral decline, the initial three studies discussed here have built a scientifically solid basis to conduct hypothesis-driven follow-up research.

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Conflicts of interest

The author declares no conflicts of interest.

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