The Impact of Meditation on Attentional Capacity

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Date: 2019-09-14T00:00:00+00:00

Abstract

All meditation methods require the management of attention, which constitutes the core mechanism of meditation. Recent studies have demonstrated that meditation significantly enhances multiple attentional capacities, including sustained attention, executive attention, and selective attention allocation. Cognitive neuroscience research has revealed that meditation facilitates more efficient allocation of attentional resources; long-term meditators exhibit higher mismatch negativity amplitudes and lower beta wave amplitudes; meditation strengthens functional connectivity in brain regions associated with the central executive network and increases activity in brain regions related to the salience network; attention-focused meditation reduces activity in brain regions associated with the default mode network. Furthermore, as a method for improving attentional abilities, meditation is applicable not only to clinical populations with attention-related disorders, such as patients with attention deficit hyperactivity disorder and individuals with remitted depression, but also to healthy populations across various developmental stages, including children and older adults. Future research should investigate the long-term effects of meditation through longitudinal studies; explore the interaction between attention and emotion during meditation; and design more targeted meditation interventions based on population-specific characteristics.

Full Text

The Effects of Meditation on Attentional Capacity

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Abstract: All meditation methods require attentional regulation, making attention the core mechanism of meditation. Recent research has demonstrated that meditation significantly enhances multiple attentional capacities, including sustained attention, executive attention, and selective attention allocation. Cognitive neuroscience research reveals that meditation enables more efficient allocation of attentional resources. Long-term meditators exhibit higher mismatch negativity amplitudes and lower wave power. Meditation strengthens functional connectivity in brain regions associated with the central executive network and increases activation in regions related to the salience network. Focused attention meditation reduces activity in brain regions associated with the default mode network. Furthermore, as a method for improving attentional capacity, meditation is applicable not only to clinical populations with attention-related disorders such as attention-deficit/hyperactivity disorder patients and formerly depressed patients, but also to healthy groups across various age ranges, including children and older adults. Future research should employ longitudinal studies to investigate the long-term effects of meditation, explore the interaction between attention and emotion during meditation, and design more targeted meditation programs based on group characteristics.

Keywords: meditation; attention; focused attention meditation; open monitoring meditation; mindfulness

1. Introduction

Meditation represents a collection of self-regulatory practices that emphasize training attention and awareness to enhance voluntary control over mental processes, thereby improving overall psychological well-being and cultivating specific capacities such as tranquility, clarity, and concentration (Walsh & Shapiro, 2006). Meditation encompasses both traditional methods grounded in specific belief systems—such as vipassana, zen, yoga, and loving-kindness meditation —and modern approaches that have been secularized and integrated with psychotherapy, including mindfulness-based stress reduction (MBSR), mindfulness-based cognitive therapy (MBCT), and mindfulness-based relapse prevention (Khoury, Knäuper, Schlosser, Carrière, & Chiesa, 2016). As one of the most extensively applied and enduringly studied psychological training methods (Walsh et al., 2006), meditation has attracted growing participation in recent years due to its significant efficacy (Sedlmeier et al., 2012; Wang & Luo, 2017). Its applications have expanded from clinical settings to schools, elder care facilities, workplaces, and community settings (Creswell, 2017; Davidson & Kaszniak, 2015). Research on meditation in cognitive psychology and neuroscience has become increasingly prevalent (Chiesa, Calati, & Serretti, 2011; Lutz, Jha, Dunne, & Saron, 2015; Tang, Holzel, & Posner, 2015), with existing studies demonstrating that meditation positively influences various cognitive functions by enhancing attentional capacity, including working memory, executive function, long-term memory, and creative thinking (Chiesa et al., 2011; Malinowski, 2013; Tang et al., 2007).

Attention refers to the capacity to focus awareness on a stimulus, thought, or behavior while ignoring other irrelevant stimuli, thoughts, or behaviors (Gazzaniga, Ivry, & Mangun, 2009). A stable and concentrated attentional state is a prerequisite for entering meditation, and all meditation methods require attentional management (Cahn & Polich, 2006). Attention constitutes the core mechanism through which meditation produces its diverse effects (Dahl, Lutz, & Davidson, 2015; Lindsay & Creswell, 2017; Lutz, Slagter, Dunne, & Davidson, 2008; Malinowski, 2013; Zhai et al., 2016). Based on different attentional orientations, meditation practices can be categorized into two forms: focused attention meditation (FA) and open monitoring meditation (OM) (Lutz et al., 2008; Malinowski, 2013; Wang & Liu, 2017). Focused attention meditation, also known as samatha or tranquility meditation, involves narrowing the attentional scope to concentrate exclusively on a selected target object. This process requires volitional effort, and when distraction occurs, practitioners must immediately redirect attention back to the target (Lutz et al., 2008). Open monitoring meditation, also known as vipassana or insight meditation, involves expanding the attentional scope to cultivate meta-awareness, observing present-moment conscious content—including floating perceptions, thoughts, and emotions—with an attitude of acceptance (Lutz et al., 2008). In actual meditation practice, FA and OM are typically combined, with different meditation methods emphasizing one or the other to varying degrees (Sedlmeier et al., 2012).

Although increasing empirical research has examined meditation' s effects on attentional capacity, comprehensive reviews systematically organizing these findings are lacking. Investigating this issue is significant not only for understanding meditation' s mechanisms of action and its relationship with cognitive functions, but also for providing theoretical guidance for the targeted application of meditation to enhance attention. Therefore, this article first examines which attentional capacities are affected by meditation, then analyzes the neural mechanisms underlying these effects, and subsequently explores the populations for whom meditation is suitable as an attention-enhancement method. Finally, we identify issues requiring attention in future research to provide reference for future work in this field.

2. Behavioral Manifestations of Meditation' s Effects on Attentional Capacity

Numerous recent studies have demonstrated that meditation influences multiple attentional capacities. Our review of recent behavioral research findings reveals that meditation enhances sustained attention (Badart, McDowall, & Prime, 2018; Jha et al., 2015; MacLean et al., 2010), executive attention (Becerra, Dandrade, & Harms, 2017; Elliott, Alan Wallace, & Giesbrecht, 2014; Tsai & Chou, 2016), attentional blink, and inattentional blindness (Colzato, Sellaro, Samara, Baas, & Hommel, 2015; Schofield, Creswell, & Denson, 2015; Van Vugt & Slagter, 2014). However, it remains unclear whether meditation positively affects the alerting and orienting subsystems of attention (Becerra et al., 2017; Elliott et al., 2014; Tsai et al., 2016).

Meditation improves sustained attention. MacLean et al. (2010) investigated the potential mechanisms through which meditation enhances sustained attention using a sustained-attention task (SAT), measuring changes in visual resolution, attentional vigilance, and perceptual sensitivity before, during, and after three months of FA training. In this task, participants were required to respond quickly and accurately when low-frequency vertical short lines appeared, while withholding responses to high-frequency vertical long lines, with auditory feedback for correct and incorrect responses. The angular difference between long and short lines served as the criterion for visual resolution magnitude. Results showed that participants exhibited reduced threshold values, improved visual resolution, and enhanced vigilance after meditation. The researchers proposed that prolonged attentional focus during information processing leads to attentional resource depletion and decreased perceptual sensitivity, resulting in reduced attentional vigilance and sustained attention failure. Meditation, however, improves visual resolution related to perceptual sensitivity, reducing cognitive resources required for target discrimination and thereby facilitating sustained attention.

Subsequently, Jha et al. (2015) examined the impact of mindfulness training on attentional lapses in soldiers under high-stress conditions. Participants were divided into four groups: didactic mindfulness training soldiers, participatory mindfulness training soldiers, waitlist control soldiers, and waitlist control civilians. The study used the sustained attention to response task (SART) to measure changes in attentional lapses before and after training. Results indicated that waitlist control soldiers showed significantly poorer performance at post-test compared to pre-test, and their post-test performance was significantly worse than that of waitlist control civilians, suggesting that prolonged high demands increase attentional lapses caused by mind wandering. However, soldiers who received mindfulness training maintained consistent performance across pre- and post-tests and demonstrated fewer lapses than waitlist control soldiers, with participatory training proving more effective than didactic training. These findings suggest that although prolonged high demands increase attentional lapses, participatory mindfulness training can enhance attentional performance under high pressure.

More recently, Badart et al. (2018) employed a response switching task (RST) presented under single-channel visual, single-channel auditory, and dual-channel visual-auditory conditions to compare sustained attention differences between long-term FA meditators and non-meditators. Results revealed that meditators exhibited fewer attentional lapses than non-meditators across all conditions, indicating that long-term FA practice enhances general, non-modality-specific attentional processes.

Attention can be divided into three functionally independent subsystems: alerting, orienting, and executive. Research using the attention network test (ANT) has consistently found that meditation enhances executive attention, while findings regarding its effects on alerting and orienting remain inconsistent. Elliott et al. (2014) used the ANT to investigate the mechanisms through which FA enhances attentional subsystems. Results showed that FA improved executive attention capacity and reduced functional coupling between the executive and alerting attention networks. Strong coupling between these networks reflects competition for shared neural resources, and FA may enhance the efficiency of these shared resources, enabling both networks to operate simultaneously and ultimately improving the function of both attentional subsystems.

A similar but slightly different finding emerged from Becerra et al.'s (2017) study, which found that the FA group showed significant improvements in executive and orienting attention compared to the control group, while alerting attention showed no significant change. Additionally, research indicates that OM and FA have different effects on attentional subsystems. Tsai et al. (2016) conducted both a cross-sectional study comparing FA meditators, OM meditators, and non-meditators on ANT performance, and a longitudinal study examining the effects of three months of FA training on attentional subsystems. The cross-sectional study revealed that both long-term meditation groups exhibited higher executive attention capacity than the control group, with the OM group showing higher orienting capacity than the other two groups. The longitudinal study demonstrated that short-term FA training improved executive attention. These results suggest that FA enhances executive attention, while OM improves both executive and orienting attention.

Meditation influences selective attentional allocation by expanding attentional scope through more rational distribution of attentional resources. Specifically, meditation improves identification of upcoming target stimuli, reducing attentional blink (AB), and enhances detection of unexpected non-target stimuli, reducing inattentional blindness (IB). Colzato et al. (2015) used a rapid serial visual presentation (RSVP) task to compare the effects of OM and FA on attentional blink in meditation novices. Attentional blink refers to the difficulty in identifying a second target stimulus (T2) when it follows closely after a first target (T1) in a rapidly presented stream of distractors, likely due to competition for limited attentional resources between T1 and T2. Results showed that the OM group exhibited less attentional blink than the FA group, indicating that brief meditation practice can alter attentional allocation patterns. OM reduces top-down attentional control, creating parallel information processing that decreases competition between task-relevant and irrelevant information, thereby expanding attentional scope and reducing attentional blink. Conversely, FA enhances top-down control, creating serial single-channel processing that increases competition between relevant and irrelevant information.

Similarly, van Vugt et al. (2014) divided meditators with over two years of experience into more-experienced and less-experienced groups, comparing their attentional blink differences after OM and FA practice. Results revealed that more-experienced meditators showed less attentional blink after OM than after FA, while less-experienced meditators showed no significant difference between the two conditions. This suggests that meditators at more advanced stages can more flexibly select task-relevant information and control their attentional states after OM practice. Additionally, Schofield et al. (2015) investigated the effects of mindful raisin-eating training on inattentional blindness. Inattentional blindness refers to the frequent failure to notice distinctive, salient non-target objects when attention is focused on a particular event or object. In their experiment, letters T and F moved across a computer screen, colliding with the edges, and participants were required to count these collisions while an unexpected "+" stimulus moved across the screen. If participants could report one feature of the unexpected stimulus, they were considered to have detected it; otherwise, inattentional blindness was assumed to have occurred. Results showed that the mindfulness training group exhibited less inattentional blindness than the control group, indicating that mindfulness training promotes active rather than passive attention and improves detection of unexpected stimuli during target tasks.

3. Neural Mechanisms of Meditation' s Effects on Attentional Capacity

While numerous behavioral studies have demonstrated meditation' s significant facilitative effects on various attentional capacities, do these behavioral improvements correspond to changes in electrophysiological activity and brain function? In recent years, researchers have begun employing techniques such as steady-state visually evoked potentials (SSVEP), event-related potentials (ERP), electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) to investigate the neural mechanisms underlying meditation' s effects on attentional capacity.

3.1. Effects of Meditation on Attention-Related Electrophysiological Activity

Meditation enhances attentional network efficiency, enabling more effective allocation of attentional resources. Schone, Gruber, Graetz, Bernhof, and Malinowski (2018) combined a multiple object tracking (MOT) task with SSVEP to investigate whether eight weeks of breath observation meditation could improve the efficiency of sustained visual attention neural networks. The MOT task requires participants to simultaneously track two to five target objects among fifteen flickering moving objects, demanding selective attention, executive control, and visual short-term memory (Meyerhoff, Papenmeier, & Huff, 2017). SSVEP represents cortical network oscillatory responses to flickering stimuli at a fixed fundamental frequency, with its amplitude positively correlated with the amount of cortical resources allocated to the task (Vialatte, Maurice, Dauwels, & Cichocki, 2010). Results showed that the meditation group improved their MOT performance while exhibiting reduced SSVEP amplitude, whereas the control group showed no significant changes. This suggests that breath observation training enables more efficient utilization of neural resources, consistent with findings from Moore, Gruber, Derose, and Malinowski (2012). That study used ERP to record changes in P3 and N2 amplitudes during a Stroop task before and after 16 weeks of daily 10-minute breath observation meditation in both meditation and control groups. The study found that N2 amplitude increased significantly across all Stroop conditions in the meditation group while decreasing in the control group. In the Stroop incongruent condition, P3 amplitude decreased significantly in the meditation group while increasing in the control group. Increased N2 amplitude indicates enhanced focused attention capacity and more sensitive detection and inhibition of automatic responses. Decreased P3 amplitude suggests reduced attentional resources required for object identification (Cahn et al., 2006). These results demonstrate that meditation improves attentional control by enabling more efficient allocation of cognitive resources.

Similarly, Norris, Creem, Hendler, and Kober (2018) found that, in individuals with low neuroticism, the meditation group showed larger N2 amplitude than the control group under ANT incongruent conditions, while P3b amplitude showed no difference. Long-term meditation practice cultivates specific attentional patterns, primarily manifested as higher mismatch negativity (MMN) amplitude and lower   power, though different meditation styles produce differential EEG effects. Biedermann et al. (2016) compared MMN differences between meditators and non-meditators during breath-counting meditation. Results revealed that meditators exhibited larger MMN amplitude than non-meditators in both meditative and non-meditative states. MMN reflects automatic processing of deviant stimuli in the human brain, representing a pre-attentive processing stage (Näätänen, Paavilainen, Rinne, & Alho, 2007). These findings indicate that meditators possess enhanced low-level attentional capacity. However, different meditation styles may differentially affect MMN. Fucci et al. (2018) compared EEG activity during FA and open presence (OP) meditation in expert Tibetan Buddhist meditators. OP represents an advanced form of OM that directs attention to consciousness itself, requiring awareness of conscious experience content like OM but without the effort to maintain vigilance. The study found that expert meditators exhibited higher late frontal negativity (LFN) and lower MMN amplitude during OP compared to FA. MMN is associated with prediction error signals, while LFN is associated with attentional monitoring of the sensory environment (Näätänen et al., 2007). These results suggest that, compared to FA, OP enhances attentional monitoring of the sensory environment while reducing habitual perceptual judgments.

Furthermore, Tanaka et al. (2015) found in their EEG study that both long-term meditators and novices exhibited higher frontal   power during OM than during rest, with novices showing higher frontal   power than long-term meditators.   waves represent a medium-low frequency brainwave indicating alertness and attentional states, with enhanced prefrontal   power occurring when attention is focused on specific objects (Cahn et al., 2006). Novice meditators require top-down attentional control and effortful maintenance of attention, resulting in higher prefrontal   power. In contrast, OM cultivates a bottom-up dynamic attentional pattern, and long-term meditators' lower   power suggests that extended meditation practice establishes bottom-up pathways that enhance attentional states.

3.2. Effects of Meditation on Attention-Related Brain Function

Meditation initially requires volitional effort to maintain attention on a selected target object, while advanced stages demand moment-to-moment monitoring of present experience with an attitude of acceptance. This process involves the coordinated functioning of the central executive network (CEN), which is involved in selecting, locating, and maintaining target objects in mind, and the salience network (SN), which is involved in bottom-up detection and orientation to salient internal and external events (Bilevicius, Smith, & Kornelsen, 2018; Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012; Lutz et al., 2015). Meditation enhances functional connectivity in CEN-related brain regions and increases activation in SN-related regions. Taren et al. (2017) found that a three-day MBSR training increased resting-state functional connectivity between the dorsolateral prefrontal cortex (dlPFC)—a key CEN region involved in attention management (Goldman-Rakic, 1995)—and both dorsal networks (superior parietal lobule, supplementary visual field, middle frontal gyrus) and ventral networks (right inferior frontal gyrus, middle temporal gyrus, angular gyrus). The dorsal network is involved in goal-directed sustained behavioral control and attention allocation (Tops & Boksem, 2011). Enhanced resting-state connectivity between dorsal regions and dlPFC may indicate that attentional focus in mindfulness enhances top-down attentional control via dlPFC and improves behavioral selection capacity by strengthening dorsal neural circuits. The ventral network is also involved in top-down attention management but differs from the dorsal network in its role in detecting salient events and generating immediate responses (Tops et al., 2011). Its enhanced connectivity with dlPFC may suggest that open monitoring in mindfulness training improves awareness of internal and external stimuli.

Kozasa et al. (2018) investigated brain activity differences between meditators and non-meditators during a Stroop color-word task before and after a seven-day intensive meditation retreat. The study found that, compared to non-meditators, meditators showed enhanced activation in SN-related brain regions such as the anterior cingulate cortex (ACC) and insula after the retreat. These results indicate that meditation training enhances meditators'awareness of the present moment. Additionally, the study found that non-meditators showed reduced activation in attention-related brain regions at post-test, similar to meditators' pre-test levels, with no significant behavioral differences between groups. This pattern of equivalent behavioral performance with lower attention-related brain activation can be interpreted as meditation improving neural efficiency in non-meditators.

FA requires suspending discursive thought, which reduces activity in the default mode network (DMN) associated with mind wandering and spontaneous thinking. OM does not require suppressing discursive thought but instead emphasizes enhanced monitoring of wandering thoughts, resulting in stronger intra-DMN functional connectivity compared to FA. Scheibner, Bogler, Gleich, Haynes, and Bermpohl (2017) distinguished between internal FA (focusing on breath) and external FA (focusing on sounds) based on attentional focus, and used thought probes to divide FA states into three phases: attentional focus, mind wandering, and refocusing. After five days of FA training, meditation novices underwent fMRI scanning to compare brain activity across the three phases of both FA types. Results showed that, regardless of focus type, the attentional focus phase reduced activation in DMN-related regions—including the medial prefrontal cortex, posterior cingulate cortex (PCC), and left temporoparietal junction—compared to the mind wandering phase. Internal attention showed lower PCC activation than external attention, suggesting that internal attention may be more effective for attentional focus. Additionally, the refocusing phase activated the left inferior frontal gyrus, which is involved in impulse control and inhibition of automatic responses, indicating its important role in suppressing mind wandering and returning to the focus target in FA. Consistent with these findings, Tomasino, Chiesa, and Fabbro (2016) also found reduced medial prefrontal cortex activity in the DMN after eight weeks of breath observation meditation. Their study additionally found that breath observation meditation reduced dlPFC activity associated with sustained monitoring and focus, while enhancing activity in the left anterior/caudate insula associated with attentional and bodily awareness.

However, different meditation styles may differentially affect the DMN. Marzetti et al. (2014) used MEG and EEG to measure differences in intra-DMN functional connectivity and connectivity between the DMN and fronto-parietal control network (FP) in the frequency band among Theravada Buddhist monks with extensive meditation experience during FA, OM, and rest states. Results showed that, compared to FA, OM enhanced functional connectivity in the band between the DMN core region PCC and left-hemisphere DMN, FP, and left superior frontal gyrus (lSFG). Enhanced intra-DMN connectivity may reflect OM' s greater engagement in thought and mental imagery compared to FA. Simultaneously, enhanced connectivity between PCC and lSFG may indicate that OM improves meta-awareness through monitoring thoughts and mental imagery, enabling meditators to maintain meditative states continuously. Furthermore, enhanced connectivity between DMN and FP may suggest that meditators increase sustained monitoring of thoughts during OM, reducing interfering thoughts and strong self-identification.

4. Effects of Meditation on Attentional Capacity Across Different Populations

Due to meditation' s significant efficacy, its applications have expanded from clinical settings to schools, elder care facilities, workplaces, and communities (Davidson et al., 2015). As a method for enhancing attentional capacity, meditation can be applied not only to general college student populations but also to improving children' s attentional capacity (Felver, Tipsord, Morris, Racer, & Dishion, 2014; Lim & Qu, 2017; Tarrasch, 2018; Li et al., 2019), preventing attentional decline in older adults (Malinowski, Moore, Mead, & Gruber, 2017; Prakash et al., 2012; Sperduti, Makowski, & Piolino, 2016), alleviating symptoms of attention-deficit/hyperactivity disorder, and altering attentional biases in formerly depressed patients (Schoenberg et al., 2014; Sibalis et al., 2017; Verhoeven, Vrijsen, van Oostrom, Speckens, & Rinck, 2014).

4.1. Effects of Meditation on Children' s Attentional Capacity

Short-term meditation training improves multiple attentional capacities in both primary school and preschool children. Felver et al. (2014) investigated the effects of mindfulness training on executive attention in 9-12 year-old schoolchildren. The study compared a mindful family stress reduction (MFSR) training group with a waitlist control group, examining changes in children's ANT performance before and after eight weeks of training. Results showed that the training group exhibited significantly reduced reaction times in the ANT executive attention system compared to the control group, along with significantly higher orienting scores. These findings indicate that mindfulness training effectively cultivates children' s attention management capacity.

Subsequently, Tarrasch (2018) used the continuous performance task (CPT) and conjunctive visual search task to investigate the effects of ten weeks of mindfulness training on sustained and selective attention in 9.6-10.7 year-old schoolchildren. The CPT results showed that only the mindfulness group reduced omission errors, which reflect response inhibition capacity. This suggests that mindfulness training improved sustained attention and reduced impulsivity. The conjunctive visual search task revealed that when the matrix contained 16 items, only the mindfulness group improved accuracy. When the matrix contained 32 items, both groups improved, but the mindfulness group showed greater improvement. These results demonstrate that mindfulness training enhances selective attention.

Researchers have also examined meditation' s effects on preschool children' s attentional capacity. Lim et al. (2017) used the global-local test (GLT) to investigate how mindfulness training affects 4-6 year-old preschool children' s ability to control attentional scope. The GLT measures attentional scope by requiring children to quickly and accurately select from two response figures the one most similar to a target figure. Each response figure is a global shape composed of 15 smaller local shapes. Children were scored based on whether they responded according to the global or local features, with higher scores indicating global processing and lower scores indicating local processing. Results showed that children who used global processing strategies at pre-test reduced their use of global strategies at post-test, while those who used local processing strategies reduced their use of local strategies. These findings indicate that mindfulness training reduces children' s automatic default response patterns and improves their capacity to control attentional scope. More recently, Li et al. (2019) found that mindfulness training conducted twice weekly for 12 sessions significantly improved sustained attention capacity in 3-4 year-old children compared to a control group.

4.2. Effects of Meditation on Older Adults' Attentional Capacity

Older adults with long-term meditation practice demonstrate better attentional capacity across multiple domains compared to non-meditating older adults, suggesting that meditation can prevent cognitive aging. Sperduti et al. (2016) investigated the effects of long-term meditation on attentional decline during aging using the ANT to compare executive attention among older adults without meditation experience, long-term meditating older adults, and younger adults without meditation experience. Results showed that older adults exhibited significantly lower executive attention than younger adults, while long-term meditating older adults showed no significant difference from younger adults. These findings indicate that long-term meditation prevents decline in specific attentional systems.

Earlier, Prakash et al. (2012) found that long-term meditating older adults outperformed non-meditating older adults on attention span, attentional switching, distraction inhibition, information processing speed, and visuospatial attention. The researchers concluded that long-term meditation enhances multiple attentional capacities in older adults and can be used to prevent age-related cognitive decline. Regarding meditation' s effects on neural activity related to attention in older adults, Malinowski et al. (2017) found that breath observation meditation significantly improved older adults' Stroop task reaction times and frontocentral N2 amplitude, with a correlation between the two measures. This suggests that breath observation meditation produces more efficient behavioral responses by modulating neural resources during task processing. Furthermore, N2 amplitude is primarily associated with the right angular gyrus and right superior parietal lobule in the dorsal attention system, indicating that breath observation meditation improves target orientation in visuospatial attention and may represent an effective strategy for offsetting age-related cognitive decline.

4.3. Effects of Meditation on Attentional Capacity in Clinical Populations

Meditation positively influences attentional capacity in both attention-deficit/hyperactivity disorder (ADHD) patients and formerly depressed patients. ADHD is a common neurodevelopmental disorder characterized by inattention and/or hyperactivity-impulsivity that interferes with development and daily functioning (Thomas, Sanders, Doust, Beller, & Glasziou, 2015). Sibalis et al. (2017) investigated the effects of mindfulness-based interventions on attentional control in adolescents with ADHD using EEG to measure theta/beta ratio (TBR) changes before and after a 20-week integrative mindfulness martial arts (MMA) intervention compared to a waitlist control. Results showed that the intervention group exhibited decreased TBR at post-test on a GO/NO-GO task, while the control group showed increased TBR. TBR represents the ratio of theta to beta waves, with theta reflecting unfocused thinking and mind wandering, and beta reflecting active thinking and focused attention (Arns, Conners, & Kraemer, 2012). ADHD patients typically show higher TBR, reflecting symptoms of inattention and unfocused thinking. These results indicate that mindfulness interventions improve attentional control capacity and promote active rather than passive attention in adolescents with ADHD.

Similarly, Schoenberg et al. (2014) used ERP to compare Pe and N2 changes during a CPT task before and after 12 weeks of MBCT in adult ADHD patients versus a waitlist control. The study found that the MBCT group showed significantly increased Pe and N2 amplitudes compared to the control group. Pe represents error awareness, and increased Pe amplitude indicates improved ADHD inattention symptoms. N2 is associated with conflict monitoring and response inhibition, and increased N2 amplitude indicates improved inhibitory control and reduced hyperactive-impulsive behaviors. Beyond ADHD, meditation has been applied to improve attentional capacity in formerly depressed patients. Depression-related cognitive impairment primarily manifests as executive attention deficits and negative bias. Since executive attention involves identifying and selecting relevant information from interfering background information, its impairment also leads to problems with selective and sustained attention (De Raedt & Koster, 2010). Numerous studies have shown that MBCT reduces depression relapse frequency, prompting investigation into whether MBCT can alter attentional processes related to sad mood in formerly depressed patients. Verhoeven et al. (2014) used an emotional Stroop task to compare selective attention changes before and after eight weeks of MBCT versus a waitlist control in formerly depressed patients. Results showed that MBCT reduced reaction speed on the emotional Stroop task, particularly for depression-related words, compared to the control group. This indicates that MBCT improves formerly depressed patients' ability to inhibit automatic processing of irrelevant information and reduces their susceptibility to depression-related environmental information.

5. Summary and Outlook

Reviewing these research findings, this article first establishes that meditation enhances general, non-modality-specific sustained attention. Meditation also improves selective attentional allocation, including reduced attentional blink and inattentional blindness. Meditation' s effects on the three attentional subsystems are inconsistent, with executive attention showing significant improvement while the effects on alerting and orienting subsystems remain unclear. Second, we analyzed the underlying neural mechanisms of these behavioral effects. On one hand, meditation influences attention-related electrophysiological activity by improving attentional network efficiency and enabling more effective attentional resource allocation. Long-term meditation practice cultivates specific attentional patterns, manifested electrophysiologically as higher MMN amplitude and lower power. On the other hand, meditation affects attention-related brain function by enhancing activation in SN-related brain regions and increasing functional connectivity between the core CEN region dlPFC and both ventral and dorsal networks. FA reduces DMN activity, while OM enhances intra-DMN connectivity and connectivity between DMN and FP compared to FA. Finally, we examined the populations for whom meditation is suitable as an attention-enhancement method, finding that meditation improves multiple attentional capacities in primary and preschool children, prevents attentional aging in older adults, alleviates inattention and hyperactivity symptoms in ADHD patients, and alters attentional biases in formerly depressed patients.

Although numerous empirical studies have explored meditation' s effects on attentional capacity, many questions remain unanswered. Future research can explore the following directions:

First, existing longitudinal studies examine short-term meditation effects by comparing changes before and after meditation practice in one or more novice groups. However, these studies lack standardized, rigorous operational criteria, and it remains unclear what training contexts, durations, and frequencies produce optimal effects. Notably, recent research has found that novices may experience attentional impairment during initial meditation practice due to effortful learning of meditation techniques or effortful maintenance of attentional focus in FA, which consumes attentional resources (Lymeus, Lindberg, & Hartig, 2018; Lymeus, Lundgren, & Hartig, 2016). Therefore, future research should investigate what meditation protocols and guidance methods can effectively avoid negative effects during initial practice for novices. Existing cross-sectional studies examine long-term meditation effects by comparing performance differences between experienced meditators with years of practice and novices at a single time point. However, cross-sectional designs cannot exclude pre-existing differences between participants, making causal inferences difficult. For example, it is challenging to determine whether long-term meditation practice enhances attentional capacity or whether individuals with higher attentional capacity are more inclined to engage in long-term practice. Furthermore, longitudinal studies tracking practitioners from novice to expert levels are lacking, which are needed to examine the dynamic changes in meditation' s effects on attention. Future research should investigate whether critical periods exist during meditation training, how long attentional improvements last, and whether meditation has developmental effects on attentional capacity across the lifespan.

Second, different meditation methods share common elements beyond attentional regulation, including specific intentions, attitudes, ethical frameworks, postures, and contextual backgrounds. It remains unclear whether these elements moderate meditation' s effects on attentional capacity. People practice meditation for various purposes, such as overcoming physical and mental difficulties or achieving self-transcendence. Which intentions are more conducive to developing focused capacity? Buddhist meditation emphasizes practicing with compassion, with the *Lamrim Chenmo* defining "samatha" as "concentrating the mind on a virtuous object with one-pointedness, including all samadhis in the samatha category" (Tsongkhapa, 2004). This indicates that Buddhist FA includes not only controlling attention to achieve one-pointedness but also maintaining a virtuous mind free from greed, hatred, and delusion. What role does this specific ethical framework play in developing focused, calm mental states? Additionally, meditation practice typically requires specific postures, but the relationship between these postures and stable attention remains unclear.

Finally, extensive research has shown that meditation improves emotion regulation capacity and alters brain regions involved in emotional processing (Chen et al., 2011; Liu, Wang, & Chen, 2016). Future research should explore the interaction between attention and emotion in meditation: does meditation improve attentional capacity, which in turn enhances emotional flexibility, or does the reverse pathway dominate? Additionally, inability to regulate attentional processes contributes to various psychological and behavioral problems, including ADHD, depression, addiction, anxiety, and academic failure, along with abnormal brain function and structure. Can meditation alleviate these symptoms by improving attentional capacity in these populations, and what are the underlying neural mechanisms? Future research should also develop more targeted training protocols based on the specific needs of these populations.

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Note: Figure translations are in progress. See original paper for figures.