The Effects of Mindfulness Meditation on Mind-Wandering and Its Underlying Mechanisms: A Postprint

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Abstract

Mind-wandering is a ubiquitous psychological phenomenon that brings about numerous impairments. Mindfulness meditation represents one of the important intervention methods for reducing or preventing mind-wandering. To this end, based on a systematic review of previous research, this study first examines the ameliorative effects of mindfulness meditation on mind-wandering through multiple dimensions including different durations, various forms, control group settings, and diverse populations; second, it elaborates on the underlying mechanisms by integrating neural mechanisms and relevant theoretical models; finally, it proposes recommendations for future research from perspectives such as types of mind-wandering and direct comparisons between different forms of mindfulness meditation, thereby exploring the improvement of mindfulness meditation on mind-wandering and constructing a comprehensive theoretical model.

Full Text

The Influence of Mindfulness Meditation on Mind Wandering and Its Mechanism

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Abstract

Mind wandering is a common psychological phenomenon that can create many hindrances for people. Mindfulness meditation is one of the most important

interventions to reduce or avoid mind wandering. To this end, based on a systematic review of previous studies, firstly, the improvement effect of mindfulness meditation on mind wandering is sorted out through different durations, different forms, control group settings and different groups; secondly, the mechanism is elaborated by combining the neural mechanism and relevant theoretical models; finally, future research suggestions are made around the types of mind wandering and the direct comparison of different forms of mindfulness meditation, to explore the effect of mindfulness meditation on mind wandering and to validate and enhance the existing theoretical models.

Keywords: mindfulness meditation, mind wandering, neural mechanism
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Mind wandering (MW) is a concept first introduced to the academic field by Smallwood and Schooler (2006). Mindfulness refers to paying attention to present-moment experience with curiosity, openness, and acceptance (Williams & Kabat-Zinn, 2011). Mindfulness and mind wandering are significantly negatively correlated, a view that has received widespread recognition among researchers (Mrazek et al., 2012; Wong et al., 2018; Belardi et al., 2022). Based on this perspective, some researchers have proposed that mindfulness meditation (MM) training can enhance mindfulness and thereby intervene in mind wandering (Mrazek et al., 2012). Researchers have found that mindfulness meditation can reduce the frequency of mind wandering, improve its disruptive effects on the general population, and even ameliorate mind wandering in special populations such as anxious individuals (Xu et al., 2017). What research exists on the influence of mindfulness meditation on mind wandering? What is the mechanism through which mindfulness meditation improves mind wandering? To address these questions, this article examines the influence of mindfulness meditation on mind wandering, its neural mechanisms, and relevant theoretical models, reviews related literature (see Table 1), summarizes the effects of mindfulness meditation on mind wandering, and discusses future research directions.

Given the adverse effects of mind wandering on people, adopting reasonable measures to reduce it is particularly important. As an intervention approach, mindfulness meditation has gained popularity in recent years. Mindfulness meditation aims to cultivate mindfulness—that is, to focus on current experience, emphasizing curiosity, openness, and acceptance. Mind wandering refers to a psychological process and state in which attention disengages from the primary task or external environment and turns toward internally generated thoughts and ideas (Schooler et al., 2011; Smallwood, 2013). Everyone experiences mind wandering, which consumes half of people' s daily lives and appears in almost all activities or behaviors (Banks et al., 2019). Previous studies have found that mind wandering is important for many psychological functions, such as creativity (Abd-Eldayem & Shaheen, 2021), problem-solving (Ruby et al., 2013), and delay discounting (Smallwood et al., 2013). However, the ubiquitous nature of mind wandering also produces many negative effects, such as affecting students'

classroom performance (Wammes et al., 2016), decreasing reading comprehension (吴国来 et al., 2017), increasing the probability of traffic accidents (Yoshida et al., 2023), and increasing negative emotions. Indeed, mind wandering is even considered a symptom of many psychological disorders such as depression (Chaieb et al., 2022).

1. Research on the Influence of Mindfulness Meditation on Mind Wandering

Research on the influence of mindfulness meditation on mind wandering has primarily examined several aspects: training duration (Mrazek et al., 2012; Rahl et al., 2017), intervention form (Giannandrea et al., 2019; Ahuja & Vashishtha, 2019), control group settings (Badart et al., 2018; Ueberholz & Fiocco, 2022), and populations (Whitmoyer et al., 2020; Mo et al., 2021).

1.1 Training Duration

Researchers have examined the influence of different training durations of mindfulness meditation on mind wandering, such as single sessions of 8 minutes (Mrazek et al., 2012), 4 days (Rahl et al., 2017), 4 weeks (Whitmoyer et al., 2020), and 7 years (Zanesco et al., 2018), all of which have found positive effects. Some researchers have examined the influence of different durations of the same training format. For example, Mrazek et al. (2013) examined changes in GRE performance, working memory capacity, and mind wandering after a 2-week mindfulness-based stress reduction (MBSR) training. Using the Operation Span Task (OSPAN) to assess working memory capacity and probe-caught and self-caught methods to investigate mind wandering during the GRE exam, researchers randomly assigned participants to a mindfulness meditation group or a nutrition group. The mindfulness group participated in two weeks of MBSR training, while the nutrition group learned about nutritional science and recorded their daily diet. Results showed that compared to the nutrition group or pre-training baseline, the mindfulness training improved GRE reading comprehension scores and working memory capacity while reducing the frequency of mind wandering during the GRE exam and improving working memory performance. These results indicate that two weeks of MBSR training is sufficient to improve mind wandering. In contrast, Giannandrea et al. (2019) examined the influence of 8-week MBSR on mind wandering. Participants were randomly assigned to an 8-week MBSR group or a control group and completed the Sustained Attention to Response Task (SART) and thought sampling before and after the intervention. The SART is a GO-NOGO task requiring responses to frequent non-target stimuli (digits 1-2 and 4-9) and withholding responses to infrequent target stimuli (digit 3). Thought sampling included both probe-caught and self-caught methods. Results showed no significant differences in mind wandering frequency between groups or across time points as measured by probes. However, compared to pre-intervention, individuals after MBSR training showed significantly reduced error rates on the SART (responding to

target stimuli). This indicates that 8-week MBSR can improve mind wandering to some extent and reduce errors caused by mind wandering. In summary, although both studies found improvement effects, the specific improved indicators were inconsistent. Two-week MBSR improved probe-caught and self-caught mind wandering frequency, while 8-week MBSR did not. Notably, while many studies have examined the effect of mindfulness meditation duration on mind wandering, few have used longitudinal designs to investigate its impact.

1.2 Training Form

Mindfulness meditation (MM) is a group of meditation practices centered on mindfulness techniques, mainly including Zen, Vipassana, Mindfulness-based Stress Reduction (MBSR), and Mindfulness-based Cognitive Therapy (MBCT) (Kabat-Zinn, 2003; Reangsing et al., 2021). These mindfulness meditation trainings can be further distinguished by different attention training methods: focused attention meditation (FA) and open monitoring meditation (OM) (Lutz et al., 2008). Additionally, mindfulness meditation can be differentiated by various training forms, such as mindful breathing exercises, sitting meditation, body scan, and mindful walking (King et al., 2019).

Comparisons across different studies reveal that different forms of mindfulness meditation have distinct effects (Lutz et al., 2008; Ooishi et al., 2021). Therefore, researchers have employed multiple forms to examine their influence on mind wandering. For example, Mrazek et al. (2012) examined the effect of a single session of mindfulness meditation on mind wandering. Using a 10-minute SART task to assess mind wandering, participants were randomly assigned to a mindfulness meditation group or two control groups (reading and passive rest). The mindfulness group was instructed to keep their eyes open and focus on their breath, while control groups read a newspaper or rested without sleeping. Results showed that compared to control groups, the mindfulness meditation group exhibited significantly lower SART error rates and reaction time variability, indicating that even a single session can improve mind wandering. Unlike Mrazek et al. (2012) who used mindful breathing, Somaraju et al. (2021) employed a body scan form of mindfulness meditation. Participants were randomly assigned to one of three 15-minute intervention groups: mindfulness meditation, muscle relaxation, or irrelevant video watching. Mind wandering during the task was assessed using the SART and a mind wandering questionnaire. Results showed no significant differences between the three groups on SART omission errors or temporal variability measures, suggesting that a 15-minute body scan intervention is insufficient to improve mind wandering. These findings indicate that different mindfulness meditation forms produce different results regarding mind wandering.

Rahl et al. (2017) directly compared different forms of mindfulness meditation on mind wandering. Participants were randomly assigned to four groups: attention monitoring only mindfulness meditation, attention monitoring plus acceptance mindfulness meditation, relaxation, and control. The attention monitor-

ing only condition involved mindfulness meditation training including sustained attention to breath sensations, body sensations, thoughts, and emotions, as well as meta-awareness of cognitive, emotional, and physical events. The attention monitoring plus acceptance condition used similar instructions but added acceptance and non-judgmental attitudes toward these experiences. The relaxation group imagined being in relaxing scenes (e.g., walking along a beach, through a forest) based on guided imagery, while the control group read neutral excerpts about geography and culture. All groups trained for 4 days, 20 minutes per day, and mind wandering was measured using the SART (responding to all digits except "3"). Results showed that the attention monitoring plus acceptance group exhibited the fewest errors compared to the other three groups, demonstrating that acceptance in mindfulness meditation training is important for reducing mind wandering. Thus, when examining the influence of mindfulness meditation on mind wandering, different forms should be considered, and future research should identify the most effective forms.

1.3 Control Group Settings

Using appropriate control groups in research on mindfulness meditation and mind wandering is important to avoid interference from extraneous variables and highlight the effects of mindfulness meditation. Ueberholz and Fiocco (2022) examined the role of expectation effects in mindfulness meditation training. Participants were randomly assigned to one of three groups: meditation condition (MC), priming + meditation condition (PMC), and control condition (CC). The MC group participated in 10 minutes of mindfulness meditation, specifically focusing attention on the breath followed by a body scan. Unlike MC, the PMC group read an infographic about mindfulness (covering concepts, neuroplasticity, and behavioral changes after intervention) before meditating. The CC group only read the infographic without meditating. Before and after the intervention, participants completed a Visual Analog Scale (VAS) to measure perceived stress and the SART task to assess mind wandering. Results showed that compared to CC, both PMC and MC exhibited less perceived stress and fewer omission errors. However, relative to CC, PMC showed higher accuracy and fewer errors (withholding responses to targets) on the SART. Reaction time variability did not differ significantly across the three groups. These results indicate that understanding information about mindfulness meditation beforehand has a priming effect; in other words, individuals' expectations influence the effectiveness of mindfulness meditation.

Additionally, both active and passive control groups should be considered. For example, when examining the effects of body scan, some researchers have used muscle relaxation training as an active control and video watching as a passive control. Muscle relaxation training, like body scan, promotes physical relaxation and calm states. By including a muscle relaxation group, other factors can be controlled, making the unique elements of mindfulness meditation more salient (Somaraju et al., 2021). Therefore, control groups can be used to control for

extraneous variables in studies of mindfulness meditation' s influence on mind wandering.

1.4 Research on Different Populations

Researchers have extended the study of mindfulness meditation' s influence on mind wandering to adolescents (Sanger & Dorjee, 2016), older adults (Whitmoyer et al., 2020), nurses (Mo et al., 2021), anxious individuals (Xu et al., 2017), and other groups, all finding positive improvement effects. For example, Sanger and Dorjee (2016) examined the influence of mindfulness meditation training on adolescent mind wandering using an Oddball paradigm. Participants responded to target stimuli (10% probability) and withheld responses to non-target stimuli (including 70% standard stimuli and 20% deviant stimuli) while EEG data were recorded. Standard stimuli were blue diamond images, two non-target deviant stimuli were shape-deviant and color-deviant images, and target stimuli were size-deviant images. Measurements before and after intervention showed that post-intervention, participants exhibited significantly increased N2 amplitude in response to irrelevant frequent stimuli and color-deviant non-target stimuli, indicating that mindfulness meditation training enhanced adolescents' ability to inhibit irrelevant stimuli and improved focus.

Whitmoyer et al. (2020) examined the influence of mindfulness meditation on attention in older adults using a GO-NOGO task variant. Participants responded to frequently occurring auditory stimuli (GO) and withheld responses to infrequent stimuli (NOGO). Probe-caught methods during the GO-NOGO task required participants to categorize their thoughts immediately before probe onset as: focused on task, task-related thoughts, or task-unrelated thoughts. Seventy-four community-dwelling older adults were randomly assigned to mindfulness meditation training or lifestyle education groups. Results showed that compared to lifestyle education, mindfulness meditation significantly reduced reaction time variability and task-unrelated thoughts in older adults, while task-related thoughts did not change significantly. These findings indicate that mindfulness meditation' s improvement effects on mind wandering can extend to older adult populations, and this improvement occurs through reducing task-unrelated thoughts rather than task-related thoughts. Previous studies across different age groups provide insights for future research from a developmental perspective.

Furthermore, studies across different populations have found that the effectiveness of mindfulness meditation in reducing mind wandering may depend on characteristics of the target population. For instance, research on normal populations has found that mindfulness meditation reduces the occurrence of mind wandering. In individuals with negative emotions, however, mindfulness meditation's improvement of mind wandering appears to have a protective effect. Xu et al. (2017) examined the influence of mindfulness meditation on mind wandering in anxious individuals. Participants were randomly assigned to a mindfulness meditation group or control group and completed a sustained attention task

requiring synchronized responses to periodic sounds, with thought probes inserted to assess thought content and motivational states. Results showed that compared to pre-intervention, the proportion of mind wandering in the mindfulness group did not change significantly, while it increased significantly in the control group. This indicates that mindfulness meditation may prevent mind wandering from increasing over time, suggesting it has a protective effect specifically for anxious individuals.

In summary, previous research examining the influence of mindfulness meditation on mind wandering can be categorized from multiple perspectives, yet conflicting results sometimes exist even within the same perspective. For example, Lykins et al. (2012) found that long-term mindfulness meditation practice did not improve mind wandering, while Badart et al. (2018) found the opposite result—that long-term practice did improve mind wandering. These conflicting results may be due to differences in training format, duration, memory effects, etc. Therefore, understanding the effects of mindfulness should fully consider the specific conditions under which it works to refine the characteristics of intervention effects from different angles. Based on these considerations, future research should compare different durations, forms, control groups, and populations to establish an optimal improvement system.

2. Neural Mechanism Research on Mindfulness Meditation' s Influence on Mind Wandering

2.1 EEG Mechanisms

EEG studies on mindfulness meditation' s influence on mind wandering have primarily examined the relationship between mind wandering and relevant EEG components using both EEG and ERP methods. EEG is a widely used electrophysiological monitoring method for describing brain electrical activity. The EEG patterns during mindfulness meditation can reveal characteristics of different frequency bands, the dynamics of electrical activity in different brain regions, and their correlation with specific experiences. The human brain has spontaneous rhythmic oscillations in different frequency bands, mainly including alpha, beta, theta, delta, and gamma waves (王鑫麟 et al., 2022). It is well known that EEG features reflect meditators' experiences of entering deep, calm, and alert states during practice. Alpha waves prominently appear during eyes-closed wakefulness and are weak during attentional states, primarily located in posterior brain regions. Theta waves are associated with cognitive control, mainly in the frontomedial region, and are related to attention orientation and memory. Enhanced theta waves during mindfulness meditation indicate improved attention orientation and memory (Lomas et al., 2015).

Related EEG research primarily examines the relationship between mind wandering and EEG component amplitudes in experts versus novices during meditation. Brandmeyer and Delorme (2018) asked expert and non-expert groups to practice mindfulness meditation while auditory probes were pseudo-randomly

inserted and EEG signals were recorded. Results showed that compared to mind wandering, experts exhibited enhanced theta power in frontal cortex and alpha power in somatosensory cortex during meditation, while non-experts showed no such differences. Rodriguez-Larios et al. (2021) found inconsistent results. They also recorded EEG data from expert and novice groups during meditation with inserted probes. Results showed that compared to mind wandering, novices exhibited decreased alpha amplitude during meditation, while the expert group showed no significant difference. The former expert group had over one year of mindfulness practice experience, while the latter expert group had over three years, and their opposite results likely stem from inconsistent practice durations. Additionally, different meditation forms may have unique frequencies reflecting attention patterns. Some mindfulness meditations increase alpha amplitude, while others decrease alpha power (Hinterberger et al., 2014). For example, Hinterberger et al. (2014) measured EEG activity in experienced practitioners during different meditation forms, including Thoughtless Emptiness (TE), focused attention meditation, and open monitoring meditation. Compared to resting state or other meditation forms, TE showed reduced spectral EEG power in specific frequency bands. Compared to focused attention meditation, TE showed significant central and parietal gamma reduction. Compared to open monitoring meditation, TE showed decreased parietal alpha and beta amplitude. These results indicate that different mindfulness meditation forms produce different EEG manifestations. Furthermore, beta waves prominently appear during concentrated attention, mainly in the prefrontal region. Comparisons between mindfulness meditation and eyes-closed rest groups have shown inconsistent results: some found enhanced beta frequency and amplitude (Tanaka et al., 2014), while others reported no significant differences (Cahn et al., 2010). Researchers have explained these discrepancies by task specificity, as beta waves vary with cognitive task demands (Ray & Cole, 1985). Nevertheless, mindfulness meditation' s influence on mind wandering can be reflected in EEG component energy changes.

ERP research primarily examines the relationship between mind wandering and relevant ERP component amplitudes in individuals before and after mindfulness meditation or between meditation and control groups during sustained attention tasks. Commonly examined components include N2, P3, and MMN. The N2 component appears in three situations: (a) detection of novel or mismatching stimuli; (b) cognitive control functions such as response inhibition, conflict monitoring, and error monitoring; and (c) visual attention (Folstein & Van Petten, 2008). The P3 component reflects attentional processing during target identification and memory updating, primarily related to attention shifting, sustained attention, and control (Klee et al., 2020). The MMN typically occurs approximately 100-150 ms after stimulus presentation and is concentrated frontocentrally. As a difference wave between standard and deviant stimuli, MMN is influenced by attention direction—larger when attention is focused on the current task (Alain & Woods, 1997) and smaller during mind wandering (Braboszcz & Delorme, 2011).

Liu et al. (2023) examined EEG responses during mind wandering in mindfulness meditation and control groups using ERP and a SART variant. Participants responded to all digits except "3"while probes assessed attentional focus and participants actively reported when they noticed mind wandering. Results showed that compared to pre-test, the mindfulness group exhibited significantly larger N2 amplitude post-test. Larger N2 amplitude indicates greater conscious focus on the current task and enhanced attention monitoring and response inhibition. Compared to pre-test and control group, individuals after mindfulness meditation showed significantly larger P3 amplitude, indicating enhanced attentional maintenance. These findings demonstrate that mindfulness meditation' s improvement of mind wandering can be reflected in N2 and P3 components. These results have been supported in adolescent and older adult populations (Klee et al., 2020; Sanger & Dorjee, 2016). Additionally, Liu (2017) examined the physiological mechanisms of mindfulness meditation intervention on mind wandering using a sustained attention task requiring responses to frequent stimuli and withholding responses to infrequent targets. Results showed that compared to pre-test, the mindfulness group exhibited significantly larger MMN amplitude post-test, while the control group showed no significant difference. Increased MMN amplitude indicates that mindfulness meditation enhances sustained attention and reduces mind wandering. These results suggest that mindfulness meditation' s improvement effects can be examined through MMN amplitude changes.

2.2 Brain Region Mechanisms

Previous studies have found that mind wandering is associated with the brain' s default mode network (DMN) (Ho et al., 2020; He et al., 2021). The DMN includes regions such as the medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), precuneus, temporoparietal junction (TPJ), and hippocampus (He et al., 2021). Initial research on the DMN and mind wandering was conducted during resting-state fMRI, which detects spontaneous signals from various brain regions without requiring task performance. Researchers have used two main methods to measure mind wandering during resting-state fMRI: (1) having individuals complete questionnaires or report mind wandering status after scanning, and (2) using probe-caught or self-caught methods during scanning to investigate mind wandering (Chou et al., 2017). Researchers have also examined the DMN-mind wandering relationship during task states. For example, Christoff et al. (2009) used the SART task requiring participants to withhold responses to digit "3" (5% probability) while responding to other digits. Thought probes were pseudo-randomly inserted, and participants rated their attention to the task on a 7-point scale while fMRI monitored brain network changes. Results showed that during mind wandering, individuals' DMN regions (mainly ventral anterior cingulate cortex, precuneus, and temporoparietal junction) were activated, as was the executive network (mainly dorsal anterior cingulate cortex and dorsolateral prefrontal cortex). Researchers have noted that during both resting and task states, DMN region activity increases during

mind wandering (Webb et al., 2021; Christoff et al., 2009), and antagonistic relationships between the DMN and anti-correlated networks weaken (Mittner et al., 2014).

Mindfulness meditation imaging research primarily examines its influence on the DMN. Brewer et al. (2011) investigated brain imaging in expert and novice groups during mindfulness meditation and resting states. Results showed that during mindfulness meditation, the expert group exhibited lower PCC activity than the control group. During focused attention meditation, experts showed lower PCC and left angular gyrus activity than controls. During open monitoring meditation, experts showed lower superior temporal gyrus and medial temporal gyrus activity. Additionally, functional connectivity analysis revealed stronger coupling between posterior cingulate, dorsal anterior cingulate, and dorsolateral prefrontal cortex in experts during mindfulness meditation. Mindfulness meditation reduces DMN activity, which is importantly related to mind wandering. These findings indicate that mindfulness meditation' s improvement of mind wandering can be examined by measuring DMN activity levels, and that different mindfulness meditations may produce varying degrees of improvement by affecting different DMN regions. These results have been supported by multiple subsequent studies (Garrison et al., 2015; Scheibner et al., 2017; Mooneyham et al., 2017).

3. Theoretical Models of Mindfulness Meditation' s Influence on Mind Wandering

3.1 Naturalistic Cognitive Fluctuations Model

Hasenkamp et al. (2012) proposed a naturalistic cognitive fluctuations model based on focused attention meditation practice, dividing the process between mind wandering and attention into four stages: mind wandering (MW), awareness of MW, shifting attention, and sustained focus. Mind wandering represents attentional lapse, awareness of MW represents recognizing that one is mind wandering, shifting attention represents redirecting attention back to the breath task, and sustained focus represents maintaining attention on the breathing task. Focused attention meditation is not a single cognitive state but rather a dynamic process between mind wandering and attention maintenance states, including brief awareness and attention shifting phases. Hasenkamp et al. (2012) used fMRI to examine brain activity during different stages. Experienced meditators completed a focused breathing task and pressed a button when they noticed mind wandering, then redirected attention to breathing. Results showed that during mind wandering, brain regions related to the DMN were activated; during awareness of mind wandering, the salience network was activated; and during attention shifting and sustained focus, the executive network was active. Additionally, activity in certain brain regions significantly correlated with meditation practice time, particularly during the attention shifting stage. The cognitive processes generated during this stage (such as attentional disengagement

and reorientation) are primary cognitive skills trained in focused attention meditation. In this stage, all correlations were negative—more meditation experience was associated with lower neural activity. These findings indicate that these stages do exist between mind wandering and attention, providing empirical support for the theoretical model. More meditation experience is associated with shorter transitions from mind wandering to attention, demonstrating that mindfulness meditation improves mind wandering by affecting these stages. Other researchers have also found that mindfulness meditation enhances mind wandering awareness (Liu et al., 2023), attention shifting (Jankowski & Holas, 2020), and attention maintenance (Ueberholz & Fiocco, 2022), further supporting this model' s applicability for revealing the mechanism through which mindfulness meditation influences mind wandering.

Notably, this theory has certain limitations requiring further refinement. For example, the timing of the four stages from mind wandering to attention cannot be measured precisely, only approximated. Moreover, some stages may occur in parallel rather than serially, so different stages may overlap or be confounded, particularly the awareness and attention shifting stages.

3.2 The Cycle of Meditation and Mind Wandering

Brandmeyer and Delorme (2021) proposed a new theoretical model based on the naturalistic cognitive fluctuations model—the cycle of meditation and mind wandering. This cyclic model includes individuals' attentional change processes: attentional concentration, spontaneous thought, meta-awareness, and attentional reorientation. Specifically, individuals begin mindfulness meditation by (a) concentrating attention, after which (b) attention shifts to spontaneous thought content until the individual (c) becomes aware of mind wandering and (d) reorients attention back to the meditation focus. Mind wandering during meditation provides opportunities to examine its nature and cultivates awareness of the dynamics of ongoing thought through the cyclical nature of the meditation process.

Many mindfulness meditation practices emphasize non-judgmentally shifting attention back to the breath or focal target. Through this training, practitioners learn to develop sustained attentional focus (Ainsworth et al., 2013; Tang & Posner, 2009), metacognitive awareness of thoughts (Brandmeyer & Delorme, 2018), and cultivate equanimity toward thought content (Hofmann et al., 2011). Sustained attention refers to the ability to focus on specific stimuli for extended periods without interference. Previous research has found that mindfulness meditation enhances sustained attention (Norris et al., 2018). Norris et al. (2018) used ERP to examine the effects of brief mindfulness meditation on three attention subnetworks in individuals with different neuroticism levels. Participants were randomly assigned to 10-minute meditation or control groups while completing the Attention Network Test with EEG recording. Results showed that compared to controls, the meditation group exhibited larger N2 amplitude in low-neuroticism individuals but not in high-neuroticism individuals, indicating that brief mindfulness meditation' s effects on sustained attention and atten-

tional orientation are moderated by neuroticism level.

Meta-awareness involves intermittent explicit evaluation of one' s current mental state; when aware of mind wandering, individuals redirect attention to the current task. Previous research has identified meta-awareness as an important factor affecting mind wandering, and restoring meta-awareness helps regulate its frequency and duration (Schooler et al., 2011). For example, Sayette et al. (2009) randomly assigned male participants to alcohol or placebo beverage groups to complete a reading task with thought probes and self-captures to distinguish whether individuals were aware of mind wandering. Results showed that compared to placebo, the alcohol group exhibited higher mind wandering frequency and reduced self-detection of mind wandering, indicating that meta-awareness deficits lead to more frequent mind wandering. Other research has found that mindfulness meditation enhances meta-awareness and reduces mind wandering frequency (Liu et al., 2023). Equanimity can be defined as maintaining a calm mental state or dispositional tendency toward all experiences or objects, regardless of their emotional valence (pleasant, unpleasant, or neutral), and represents a key component of mindfulness meditation. Over time, mindfulness meditation changes how individuals respond to and relate to their internal thoughts and experiences (Desbordes et al., 2015). For example, Banks et al. (2019) examined how mindfulness meditation influences changes in internal thought content and experience during sustained attention. Participants were randomly assigned to mindfulness meditation, guided relaxation, or waitlist control groups and completed the SART with randomly inserted thought probes assessing the emotional valence of internal thoughts (task-related vs. unrelated, positive vs. negative). Results showed that compared to controls, the mindfulness meditation group exhibited reduced negative mind wandering rates, indicating that mindfulness meditation reduces mind wandering caused by internal negative information.

Together, these processes create a self-regulating closed-loop feedback system for mind and body. This cyclic model considers changes in thought content, providing new insights for research on mindfulness meditation' s improvement of mind wandering. Thus, mindfulness meditation improves mind wandering through attention regulation, enhanced meta-awareness, and equanimity toward thought content.

Both theoretical models described above are based on individuals' natural cognitive fluctuations during meditation. Therefore, when using these models to explain mindfulness meditation's influence on mind wandering, we must consider whether the stages represent inherent developmental processes of mind wandering itself or changes induced by mindfulness meditation intervention. Moreover, do these stages occur sequentially, and does mindfulness meditation improve mind wandering sequentially through these stages? Additionally, these models are based on focused attention meditation—whether they apply to other forms like open monitoring meditation requires further investigation and validation.

4. Summary and Future Directions

This review summarizes research examining mindfulness meditation' s influence on mind wandering from four perspectives: duration, form, control group settings, and populations, and attempts to explain the mechanism through neural mechanisms and theoretical models. Although valuable findings have been achieved, several issues require resolution in future research.

4.1 Unclear Distinction Between Types of Mind Wandering

Mind wandering can be divided into intentional mind wandering (conscious, purposeful, and controllable, where attention can be returned to the task when disengaged, but still produces task-unrelated thoughts) and unintentional mind wandering (purposeless, effortful, and uncontrollable). Previous research has treated mind wandering as a single construct, directly examining mindfulness meditation' s influence without distinguishing between intentional and unintentional types (Somaraju et al., 2021; Ueberholz & Fiocco, 2022; Liu et al., 2023). Although some researchers have conceptually distinguished mind wandering, methodological approaches have largely ignored this distinction (Brandmeyer & Delorme, 2021; Konjedi & Maleeh, 2021).

Distinguishing between mind wandering types is necessary. For example, Phillips et al. (2016) combined re-reading (second reading) with thought probes to examine mind wandering during reading tasks. Results showed that compared to first reading, re-reading produced more mind wandering. Subsequent experiments using probes indicating intentionality found that re-reading' s effect on mind wandering was entirely driven by increased intentional mind wandering, with no effect on unintentional mind wandering. Additionally, previous research has found many differences between intentional and unintentional mind wandering: different temporal orientations (intentional more future-oriented than unintentional; Seli et al., 2017), different susceptibility to motivation (intentional more easily influenced by motivation; Seli et al., 2017), and different neural mechanisms (Martel et al., 2019). Therefore, given significant differences between intentional and unintentional mind wandering in both experimental and daily life contexts, examining mindfulness meditation' s influence requires considering their distinct characteristics to clarify which type is more affected. Previous research indicates that mind wandering correlates negatively with negative emotions (Banks et al., 2019), and intentional mind wandering can be regulated by motivation, while improvement methods for unintentional mind wandering remain unclear. Thus, mindfulness meditation' s improvement effects on unintentional mind wandering warrant more detailed investigation—specifically, whether mindfulness meditation has greater improvement effects on spontaneous versus intentional mind wandering.

4.2 Direct Comparison of Different Mindfulness Meditation Forms

As reviewed, mindfulness meditation has different forms, including focused attention and open monitoring meditation, with focused attention further subdivided into breath awareness, body scan, and walking meditation. Previous research has examined single forms but neglected direct comparisons between different forms.

Previous studies have found that mindful breathing improves mind wandering while body scan does not (Somaraju et al., 2021; Mrazek et al., 2012), but these used different intervention durations and experimental tasks, confounding results. Whether improvement effects derive from duration or form remains unclear. Additionally, control group selection affects result differences (Somaraju et al., 2021; Ueberholz & Fiocco, 2022). Longitudinal studies examining different durations' effects are also needed. Therefore, future research should directly compare different mindfulness meditation forms to identify the most effective forms for each training stage, providing empirical support for establishing a comprehensive system. For example, researchers could separately examine the effects of short-term mindful breathing, body scan, and sitting meditation on mind wandering to identify the most effective form and determine optimal durations for different forms.

4.3 Theoretical Construction Requires Validation and Improvement

Previous research has primarily used first-person measures such as self-caught detection, probe-caught detection, and SART, with less third-person measurement, especially using ERP. Although some ERP studies exist, they have focused more on long-term meditation or other attention forms (Liu et al., 2023; Norris et al., 2018), which cannot reflect the neural mechanisms of short-term mindfulness meditation on mind wandering. Additionally, research on the time course of mindfulness meditation' s improvement of mind wandering is lacking, making it impossible to accurately describe time nodes for different improvement stages. Therefore, future research should employ ERP technology to validate the time course of existing theories, such as examining whether attention orientation or meta-awareness is improved first.

In addition to the time course, exploring differential reasons arising from different processing stages is necessary. Previous studies have used different experimental tasks, and different tasks measuring the same cognitive process present different characteristics. For example, Mrazek et al. (2013) inserted thought probes during GRE exams and found significant differences in mind wandering frequency pre- and post-mindfulness meditation. Giannandrea et al. (2019) used probes during the SART task and found no significant differences. Despite using the same paradigm (thought probes), different results emerged that may not be fully explained by existing theories. Furthermore, under different difficulty conditions within the same task, what specific differences exist in mindfulness meditation' s improvement effects, and what do these differences indicate?

The cycle of meditation and mind wandering model posits that equanimity toward thought content is central (Brandmeyer & Delorme, 2021), yet how mindfulness meditation improves mind wandering through equanimity requires further validation. Moreover, existing theories of mindfulness meditation' s improvement of mind wandering are based on focused attention meditation—whether they apply to other forms like open monitoring meditation warrants investigation.

Notably, mind wandering theories propose various causes, suggesting it results from lacking executive control, executive control failure, or current concerns (McVay & Kane, 2010; Smallwood, 2013; Schooler et al., 2011; 程凯 & 曹贵康, 2014). Does mindfulness meditation improve mind wandering by affecting these factors? For example, does it reduce mind wandering by improving executive control? Therefore, integrating these theories could further improve theoretical models of mindfulness meditation' s influence on mind wandering, representing a direction for future research.

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