Effects of Mindfulness Meditation on Mind-Wandering and Their Underlying Mechanisms

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Abstract

Mind-wandering is a ubiquitous psychological phenomenon that imposes numerous impairments. Mindfulness meditation represents a key intervention for mitigating or preventing mind-wandering. Accordingly, based on a systematic review of prior research, this study first delineates the ameliorative effects of mindfulness meditation on mind-wandering across multiple dimensions, including varied durations, diverse modalities, control group configurations, and different populations. Second, it explicates the underlying mechanisms by integrating neural mechanisms and relevant theoretical models. Finally, it proposes directions for future research concerning typologies of mind-wandering and direct comparisons among different mindfulness meditation modalities, thereby advancing the investigation of mindfulness meditation's improvement of mind-wandering and constructing a comprehensive theoretical framework.

Full Text

The Influence of Mindfulness Meditation on Mind Wandering and Its Mechanisms

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Abstract

Mind wandering is a ubiquitous psychological phenomenon that creates numerous obstacles in daily life. Mindfulness meditation represents one of the most important intervention methods for alleviating or preventing mind wandering.

This paper systematically reviews previous research, first examining the ameliorative effects of mindfulness meditation on mind wandering across multiple dimensions including training duration, intervention format, control group design, and participant populations. Second, we elaborate on the underlying mechanisms by integrating neurophysiological evidence with relevant theoretical models. Finally, we propose directions for future research, focusing on distinctions between types of mind wandering and direct comparisons of different mindfulness meditation formats, to further explore how mindfulness meditation improves mind wandering and to construct a comprehensive theoretical framework.

Keywords: mindfulness meditation, mind wandering, neural mechanism

Mind wandering (MW) was first introduced to academic discourse by Smallwood and Schooler (2006) and is also translated in Chinese as "心智游移" or "思维漫游" (Song et al., 2011). It refers to a psychological process and state in which attention shifts away from the primary task or external environment toward internally generated thoughts and ideas (Schooler et al., 2011; Smallwood, 2013). Mind wandering is a universal human experience, consuming approximately half of our daily lives and occurring across nearly all activities and behaviors (Banks et al., 2019). While research has identified important functions of mind wandering, such as enhancing creativity (Abd-Eldayem & Shaheen, 2021), problem-solving (Ruby et al., 2013), and delay discounting (Smallwood et al., 2013), its pervasive nature also produces numerous negative consequences. These include impaired classroom performance (Wammes et al., 2016), reduced reading comprehension (Wu et al., 2017), increased traffic accidents (Yoshida et al., 2023), and heightened negative emotions. Indeed, excessive mind wandering has been identified as a symptom of various psychological disorders, including depression (Chaieb et al., 2022).

Given these detrimental effects, developing effective strategies to reduce mind wandering is crucial. Mindfulness meditation has gained increasing attention as an intervention approach in recent years. The practice aims to cultivate mindfulness—an attentive state characterized by present-moment awareness, curiosity, openness, and acceptance (Williams & Kabat-Zinn, 2011). Researchers have widely acknowledged a significant negative correlation between mindfulness and mind wandering (Mrazek et al., 2012; Wong et al., 2018; Belardi et al., 2022). Based on this relationship, Mrazek et al. (2012) proposed that mindfulness meditation training could reduce mind wandering by enhancing mindfulness. Empirical evidence demonstrates that mindfulness meditation can decrease the frequency of mind wandering, mitigate its disruptive effects in general populations, and even ameliorate mind wandering in special populations such as individuals with anxiety (Xu et al., 2017). This raises two key questions: What research exists on the effects of mindfulness meditation on mind wandering, and what are the underlying mechanisms? This paper addresses these questions by reviewing the literature on mindfulness meditation's impact on mind wandering, examining its neural mechanisms, and discussing relevant

theoretical models (see Table 1 for a summary of selected studies), while also outlining future research directions.

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

Research examining the effects of mindfulness meditation on mind wandering has primarily investigated several key dimensions: training duration (Mrazek et al., 2012; Rahl et al., 2017), intervention format (Giannandrea et al., 2019; Ahuja & Vashishtha, 2019), control group design (Badart et al., 2018; Ueberholz & Fiocco, 2022), and participant populations (Whitmoyer et al., 2020; Mo et al., 2021).

1.1 Training Duration

Studies have examined mindfulness meditation interventions of varying lengths, including single 8-minute sessions (Mrazek et al., 2012), 4-day programs (Rahl et al., 2017), 4-week trainings (Whitmoyer et al., 2020), and even 7-year longitudinal practices (Zanesco et al. 2018), all demonstrating positive effects. Some researchers have specifically investigated different durations of the same training format. For instance, Mrazek et al. (2013) examined the effects of a 2-week mindfulness-based stress reduction (MBSR) program on students' GRE performance, working memory capacity, and mind wandering. Using the Operation Span Task (OSPAN) to assess working memory capacity and probe-caught and self-caught methods to measure mind wandering during the GRE, participants were randomly assigned to either a mindfulness meditation group or a nutrition group. The mindfulness group completed a two-week MBSR program, while the nutrition group learned about healthy eating and recorded their daily dietary intake. Results showed that compared to the nutrition group and pre-training baseline, the mindfulness training improved GRE reading comprehension scores and working memory capacity while reducing mind wandering frequency during the GRE and on working memory measures. These findings suggest that even two weeks of MBSR training can effectively improve mind wandering.

In contrast, Giannandrea et al. (2019) investigated the effects of an 8-week MBSR program on mind wandering. Participants were randomly assigned to either the 8-week MBSR group or a control group and completed the Sustained Attention to Response Task (SART) and thought sampling (TS) 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). TS included both probe-caught and self-caught methods. Results revealed no significant differences in mind wandering frequency between groups or across time points for either detection method. However, post-intervention error rates on the SART (responding to target stimuli) significantly decreased compared to pre-intervention. This indicates that 8-week MBSR can improve mind wandering to some extent by reducing errors

associated with it.

These studies demonstrate that while mindfulness meditation generally improves mind wandering, the specific metrics showing improvement vary. Notably, the 2-week MBSR improved both probe-caught and self-caught mind wandering frequency, whereas the 8-week program did not. Although numerous studies have examined training duration, few have employed longitudinal designs to investigate the temporal dynamics of mindfulness meditation's effects on mind wandering.

1.2 Training Format

Mindfulness meditation (MM) encompasses a group of meditation practices centered on mindfulness techniques, including Zen, Vipassana, Mindfulness-Based Stress Reduction (MBSR), and Mindfulness-Based Cognitive Therapy (MBCT) (Kabat-Zinn, 2003; Reangsing et al., 2021). These practices can be categorized based on attention training styles into focused attention meditation (FA) and open monitoring meditation (OM) (Lutz et al., 2008). Additionally, mindfulness meditation can be distinguished by specific practices such as mindful breathing exercises, sitting meditation, and body scan (King et al., 2019).

Comparative research indicates that different mindfulness meditation formats produce distinct effects (Lutz et al., 2008; Ooishi et al., 2021). Consequently, researchers have employed various formats to examine their impact on mind wandering. Mrazek et al. (2012) investigated the effects of a single session of mindfulness meditation using a 10-minute SART task. Participants were randomly assigned to a mindfulness meditation group or two control groups (reading and passive rest). The mindfulness group practiced open-eyed breath-focused meditation, while control groups either read a newspaper or relaxed without sleeping. Results showed that the mindfulness group exhibited significantly lower SART error rates and reduced reaction time variability compared to control groups, demonstrating that even a single session can improve mind wandering.

In contrast, Somaraju et al. (2021) used a body scan meditation format, randomly assigning participants to three 15-minute intervention groups: mindfulness meditation, muscle relaxation, or unrelated video viewing. Mind wandering was assessed using the SART and a mind wandering questionnaire. No significant differences emerged among the three groups on SART omission errors or reaction time variability, suggesting that 15 minutes of body scan meditation was insufficient to improve mind wandering. These divergent findings highlight how different meditation formats yield different outcomes.

Rahl et al. (2017) directly compared different mindfulness meditation formats by randomly assigning participants to four groups: attention-monitoring only mindfulness, attention-monitoring plus acceptance mindfulness, relaxation, and control. The attention-monitoring only condition involved sustained attention to breath sensations, body sensations, thoughts, and emotions, along with

meta-awareness of cognitive, emotional, and physical events. The attention-monitoring plus acceptance condition added instructions to maintain an accepting, non-judgmental attitude toward these experiences. The relaxation group imagined themselves in relaxing scenes (e.g., walking on 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 a SART task (responding to all digits except "3"). Results showed that the attention-monitoring plus acceptance group exhibited the lowest error rates compared to the other three groups, indicating that acceptance is a crucial component for reducing mind wandering. These findings underscore the importance of considering specific meditation formats when examining effects on mind wandering and suggest that future research should identify the most effective formats.

1.3 Control Group Settings

Appropriate control groups are essential in mindfulness meditation research to avoid confounding variables and highlight the unique effects of the intervention. Ueberholz and Fiocco (2022) investigated the role of expectancy effects by randomly assigning participants to three conditions: meditation alone (MC), priming plus meditation (PMC), and control (CC). The MC group completed a 10-minute mindfulness meditation (breath focus followed by body scan). The PMC group first read an infographic about mindfulness concepts, neuroplasticity, and behavioral changes before meditating. The CC group only read the infographic without meditating. Participants completed a Visual Analog Scale (VAS) for perceived stress and a SART task before and after the intervention. Results showed that both PMC and MC groups exhibited reduced perceived stress and fewer omission errors compared to CC. However, PMC demonstrated higher accuracy and fewer errors (withholding responses to targets) on the SART than CC, with no significant differences in reaction time variability across groups. These findings suggest that priming individuals with information about mindfulness creates expectancy effects that influence intervention outcomes.

Researchers must also consider active versus passive control groups. When examining body scan effects, Somaraju et al. (2021) used muscle relaxation training as an active control and video watching as a passive control. Muscle relaxation, like body scan, promotes physical relaxation and calm states, allowing researchers to isolate the unique components of mindfulness meditation. Thus, appropriate control group design is crucial for controlling extraneous variables in mindfulness meditation research on mind wandering.

1.4 Research Across Different Populations

Research has extended the investigation of mindfulness meditation's effects on mind wandering to diverse populations including adolescents (Sanger & Dorjee, 2016), older adults (Whitmoyer et al., 2020), nurses (Mo et al., 2021),

and anxious individuals (Xu et al., 2017), with positive effects observed across groups. Sanger and Dorjee (2016) examined mindfulness training in adolescents using an Oddball paradigm where participants responded to target stimuli (10% probability) and withheld responses to non-target stimuli (70% standard, 20% deviant). Standard stimuli were blue diamonds, deviant stimuli varied in shape or color, and target stimuli varied in size. EEG data recorded before and after intervention revealed significantly increased N2 amplitude in response to irrelevant frequent stimuli and color-deviant non-targets post-intervention, indicating enhanced ability to inhibit irrelevant stimuli and improved focus.

Whitmoyer et al. (2020) investigated mindfulness meditation's effects on attention in older adults using a GO-NOGO task variant with frequent and infrequent auditory stimuli. Probe-caught thought sampling during the task classified thoughts as task-focused, task-related, or task-unrelated. Seventy-four community-dwelling older adults were randomly assigned to mindfulness meditation or lifestyle education groups. Results showed that compared to the lifestyle education group, the mindfulness group exhibited significantly reduced reaction time variability and task-unrelated thoughts, with no significant change in task-related thoughts. These findings demonstrate that mindfulness meditation's benefits extend to older adults by specifically reducing task-unrelated thoughts rather than task-related ones.

Furthermore, the effectiveness of mindfulness meditation in reducing mind wandering may depend on population characteristics. While studies with typical populations show reduced mind wandering frequency, research with individuals experiencing negative emotions suggests a protective effect. Xu et al. (2017) examined mindfulness meditation in anxious individuals, randomly assigning participants to mindfulness or control groups. Using a sustained attention task with periodic auditory stimuli and thought probes to assess mental content and motivational states, results showed that mind wandering frequency did not significantly change in the mindfulness group post-intervention but increased significantly in the control group. This suggests that mindfulness meditation may protect against the natural increase in mind wandering over time in anxious individuals, rather than reducing its baseline frequency.

In summary, research on mindfulness meditation and mind wandering has examined multiple dimensions, though conflicting results sometimes emerge even within the same dimension. For example, Lykins et al. (2012) found no improvement in mind wandering with long-term meditation practice, while Badart et al. (2018) found the opposite. Such discrepancies may stem from differences in training format, duration, or measurement methods. Therefore, understanding mindfulness meditation's effects requires careful consideration of specific conditions under which it operates. Future research should compare different durations, formats, control groups, and populations to identify optimal intervention parameters and establish a comprehensive improvement system.

2. Neural Mechanisms

2.1 EEG Mechanisms

EEG studies of mindfulness meditation's effects on mind wandering have employed both continuous EEG and event-related potentials (ERPs). EEG is an electrophysiological monitoring method widely used to characterize brain activity, revealing frequency-specific patterns, dynamic changes across brain regions, and correlations with subjective experiences. The human brain exhibits spontaneous rhythmic oscillations in several frequency bands: alpha, beta, theta, delta, and gamma (Wang et al., 2022). These EEG signatures reflect meditators' experiences of entering states of deep calm and alertness. Alpha waves are prominent during eyes-closed wakefulness but diminish during attentional states, primarily in posterior brain regions. Theta waves, associated with cognitive control and located primarily in frontal-midline regions, relate to attentional orienting and memory processes. Enhanced theta during mindfulness meditation thus indicates improved attentional orienting and memory (Lomas et al., 2015).

EEG research has primarily compared expert and novice meditators' brain activity during meditation and mind wandering. Brandmeyer and Delorme (2018) recorded EEG from expert and non-expert groups during mindfulness meditation with randomly inserted auditory probes. Results showed that compared to mind wandering episodes, experts exhibited enhanced frontal theta and somatosensory alpha power during meditation, while non-experts showed no such differences. Conversely, Rodriguez-Larios et al. (2021) found that compared to mind wandering, novice meditators showed decreased alpha amplitude during meditation, while experienced meditators showed no significant difference. The discrepancy between these findings—one showing increased alpha in experts, the other showing decreased alpha in novices—likely reflects differences in meditation experience (one year vs. three years). Additionally, different meditation formats produce unique frequency patterns reflecting attentional styles. Some formats increase alpha power while others decrease it (Hinterberger et al., 2014). Hinterberger et al. (2014) measured EEG in experienced meditators during different meditation states: thoughtless emptiness (TE), focused attention, and open monitoring. Compared to rest and other meditation forms, TE showed reduced activity in specific frequency bands, with significant central-parietal gamma reduction compared to focused attention and parietal alpha-beta decreases compared to open monitoring. These results demonstrate format-specific EEG signatures. Beta waves, prominent during concentrated attention in frontal regions, have shown mixed results in mindfulness studies, with some reporting increased frequency and amplitude (Tanaka et al., 2014) and others finding no differences (Cahn et al., 2010). Task-specific demands may explain these inconsistencies, as beta activity varies with cognitive load (Ray & Cole, 1985). Nevertheless, mindfulness meditation's effects on mind wandering are clearly reflected in changes in EEG power spectra.

ERP research has examined differences between pre- and post-meditation or

between meditation and control groups during sustained attention tasks, commonly measuring N2, P3, and mismatch negativity (MMN) components. The N2 component appears in three contexts: (a) detection of novel or mismatched stimuli, (b) cognitive control functions such as response inhibition, conflict monitoring, and error detection, and (c) visual attention (Folstein & Van Petten, 2008). The P3 component reflects attentional processing during target identification and memory updating, relating to attentional shifting, maintenance, and control (Klee et al., 2020). MMN typically occurs 100-150 ms post-stimulus at frontocentral sites and represents the difference wave between standard and deviant stimuli, with amplitude modulated by attentional focus—larger during task-focused attention (Alain & Woods, 1997) and smaller during mind wandering (Braboszcz & Delorme, 2011).

Liu et al. (2023) compared ERPs between mindfulness and control groups during mind wandering using a modified SART paradigm requiring responses to all digits except "3," with probe-caught detection and self-initiated responses when participants noticed mind wandering. Results showed significantly increased N2 amplitude post-intervention in the mindfulness group compared to pre-intervention and control groups. Larger N2 amplitude indicates greater task-focused awareness, reflecting enhanced attentional monitoring and response inhibition. The mindfulness group also showed significantly increased P3 amplitude, indicating improved attentional maintenance. These findings are supported by studies in adolescent and older adult populations (Klee et al., 2020; Sanger & Dorjee, 2016). Additionally, Liu (2017) examined physiological mechanisms of mindfulness meditation on mind wandering using a sustained attention task and found significantly increased MMN amplitude post-intervention in the mindfulness group but not the control group. Increased MMN amplitude suggests enhanced attentional focus and reduced mind wandering. Together, these results demonstrate that mindfulness meditation's ameliorative effects on mind wandering can be indexed by changes in N2, P3, and MMN components.

2.2 Brain Region Mechanisms

Research has linked mind wandering to the default mode network (DMN), which includes the medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), precuneus, temporoparietal junction (TPJ), and hippocampus (He et al., 2021). Initial DMN research on mind wandering used resting-state fMRI, which measures spontaneous brain signals without task demands. Researchers have measured mind wandering during resting-state fMRI either by having participants complete questionnaires after scanning or by using probe-caught or self-caught methods during scanning (Chou et al., 2017). Task-based studies have also examined DMN-mind wandering relationships. Christoff et al. (2009) used a SART task requiring responses to all digits except "3" (5% probability) while fMRI monitored brain networks and thought probes assessed attentional focus. Results showed that during mind wandering, both DMN regions (ventral anterior cingulate, precuneus, TPJ) and executive network regions (dorsal anterior

cingulate, dorsolateral prefrontal cortex) were activated. Research indicates that DMN activity increases during mind wandering in both resting and task states (Webb et al., 2021; Christoff et al., 2009), with weakened antagonistic relationships between the DMN and opposing networks (Mittner et al., 2014).

Neuroimaging studies of mindfulness meditation's effects on mind wandering have primarily examined its impact on the DMN. Brewer et al. (2011) compared expert and novice meditators during meditation and rest states. Results showed that during mindfulness meditation, experts exhibited lower PCC activity than controls. During focused attention meditation, experts showed reduced PCC and left angular gyrus activity, while during open monitoring meditation, they showed reduced superior temporal gyrus and medial temporal activity. Functional connectivity analysis revealed stronger coupling between the PCC, dorsal anterior cingulate, and dorsolateral prefrontal cortex in experts during meditation. Since reduced DMN activity is associated with decreased mind wandering, these findings suggest that mindfulness meditation's ameliorative effects can be assessed through DMN activity, with different meditation formats potentially affecting distinct DMN regions. These results have been replicated in multiple subsequent studies (Garrison et al., 2015; Scheibner et al., 2017; Mooneyham et al., 2017).

3. Theoretical Models

3.1 Naturalistic Cognitive Fluctuations Model

Based on focused attention meditation practice, Hasenkamp et al. (2012) proposed a model of naturalistic cognitive fluctuations between mind wandering and attentional states. The model delineates four phases: mind wandering (MW), awareness of MW, shifting attention, and sustained focus. Mind wandering represents attentional lapse, awareness represents recognition of wandering, shifting involves redirecting attention to the breath, and sustained focus involves maintaining concentration on the breath. Focused attention meditation is not a single cognitive state but a dynamic process cycling between mind wandering and sustained attention, with brief phases of awareness and attentional shifting. Hasenkamp et al. (2012) used fMRI to examine brain activity across these phases in experienced meditators performing breath-focus tasks, who pressed a button when noticing mind wandering and redirected attention to the breath. Results showed DMN activation during mind wandering, salience network activation during awareness, and executive network activation during attention shifting and sustained focus. Additionally, brain activity in certain regions correlated negatively with meditation experience, particularly during the attention shifting phase, where more experienced meditators showed lower neural activation. These findings provide empirical support for the model's phases and suggest that mindfulness meditation improves mind wandering by shortening the transition time between mind wandering and attention. Other research has confirmed that mindfulness meditation enhances mind wandering awareness (Liu et al., 2023), attentional shifting (Jankowski & Holas, 2020), and sustained attention

(Ueberholz & Fiocco, 2022), further supporting this theoretical framework.

However, the model has limitations requiring further refinement. The timing of the four phases cannot be measured precisely, only approximated. Additionally, some phases may occur in parallel rather than serially, creating potential overlap and confusion, particularly between awareness and attention shifting.

3.2 The Cycle of Meditation and Mind Wandering Model

Building on the naturalistic cognitive fluctuations model, Brandmeyer and Delorme (2021) proposed the cycle of meditation and mind wandering. This cyclical model encompasses attentional changes: focused concentration, spontaneous thought, meta-awareness, and attentional redirection. The process begins with (a) focused concentration, after which (b) attention shifts to spontaneous thoughts until (c) meta-awareness of mind wandering emerges, prompting (d) attentional redirection back to the meditation focus. Mind wandering during meditation provides opportunities to examine its nature and cultivate awareness of ongoing thought dynamics through this cyclical process.

Many mindfulness practices emphasize non-judgmental redirection of attention to the breath or meditation focus. Through such training, practitioners develop sustained attention (Ainsworth et al., 2013; Tang & Posner, 2009), metacognitive awareness of thoughts (Brandmeyer & Delorme, 2018), and equanimity toward mental content (Hofmann et al., 2011). Sustained attention—the ability to maintain focus on a specific stimulus without distraction—has been shown to improve with mindfulness meditation (Norris et al., 2018). Norris et al. (2018) used ERPs to examine the effects of brief mindfulness meditation on three attentional subnetworks in individuals with varying neuroticism levels. Participants were randomly assigned to a 10-minute mindfulness group or control group while completing the Attention Network Test. Results showed that low-neuroticism individuals in the mindfulness group exhibited larger N2 amplitudes than controls, while high-neuroticism individuals showed no difference, indicating that brief mindfulness meditation's effects on sustained attention and orienting are moderated by neuroticism.

Meta-awareness involves intermittent explicit evaluation of one's current mental state, enabling attentional redirection when mind wandering is detected. Research has identified meta-awareness as a crucial factor influencing mind wandering frequency and duration, with its restoration helping regulate mind wandering (Schooler et al., 2011). For example, Sayette et al. (2009) found that alcohol consumption increased mind wandering frequency and reduced self-caught mind wandering compared to a placebo, demonstrating that meta-awareness deficits lead to increased mind wandering. Mindfulness meditation has been shown to enhance meta-awareness and reduce mind wandering frequency (Liu et al., 2023). Equanimity—defined as a calm mental state or disposition toward all experiences regardless of emotional valence—represents a key component of mindfulness meditation that changes how individuals relate to their internal thoughts

and experiences over time (Desbordes et al., 2015). Banks et al. (2019) examined how mindfulness meditation affects internal thought content during sustained attention tasks, randomly assigning participants to mindfulness, guided relaxation, or waitlist control groups. Results showed that mindfulness meditation reduced negatively valenced mind wandering compared to controls, indicating that mindfulness decreases mind wandering driven by negative internal information. Together, these processes create a self-regulating closed-loop feedback system for mind and body. By incorporating changes in thought content, this cyclical model provides new insights for research on mindfulness meditation's ameliorative effects on mind wandering, suggesting that improvement occurs through attentional regulation, enhanced meta-awareness, and equanimity toward mental content.

Both theoretical models are based on the occurrence and development of mind wandering during meditation, raising questions about whether these phases represent natural processes or meditation-induced changes. Additionally, whether these phases occur sequentially and whether mindfulness meditation's effects follow this sequential pattern remains unclear. Furthermore, both models are based on focused attention meditation; their applicability to other formats such as open monitoring meditation requires further investigation. Notably, existing theories of mind wandering propose various causes, including executive control deficits and failures (McVay & Kane, 2010; Smallwood, 2013; Schooler et al., 2011; Cheng & Cao, 2014). Whether mindfulness meditation improves mind wandering by affecting these factors—for instance, by improving executive control—represents an important direction for future theoretical development.

4. Summary and Future Directions

This review has summarized research examining mindfulness meditation's effects on mind wandering across four dimensions—training duration, format, control group design, and population—while exploring underlying neural mechanisms and theoretical explanations. Although valuable findings have emerged, several issues warrant further investigation.

4.1 Unclear Distinction Between Mind Wandering Types

Mind wandering can be categorized as intentional (conscious, purposeful, and controllable, where attention can be returned to the task despite task-unrelated thoughts) or unintentional (purposeless, effortful, and uncontrollable). Previous research has typically treated mind wandering as a unitary construct without distinguishing between intentional and unintentional types (Somaraju et al., 2021; Ueberholz & Fiocco, 2022; Liu et al., 2023). Even when conceptual distinctions have been made, methodological approaches have largely ignored this differentiation (Brandmeyer & Delorme, 2021; Konjedi & Maleeh, 2021).

Distinguishing between mind wandering types is essential. Phillips et al. (2016) combined re-reading with thought probes during a reading task, finding that

re-reading increased mind wandering frequency compared to initial reading. Follow-up experiments using probes to assess intentionality revealed that this effect was driven entirely by increased intentional mind wandering, with no effect on unintentional mind wandering. Research has identified numerous differences between the two types: intentional mind wandering is more future-oriented (Seli et al., 2017), more susceptible to motivational influences (Seli et al., 2017), and associated with distinct neural mechanisms (Martel et al., 2019). Given these significant differences, examining mindfulness meditation's effects on mind wandering should consider the distinct characteristics of intentional versus unintentional mind wandering to clarify which type is more affected. While previous research links mind wandering to negative emotions (Banks et al., 2019), intentional mind wandering can be regulated through motivation, whereas methods for improving unintentional mind wandering remain unclear. Therefore, mindfulness meditation's effects on unintentional mind wandering warrant more thorough investigation, as it may be particularly effective for reducing spontaneous, uncontrolled mind wandering.

4.2 Limited Direct Comparisons of Different Mindfulness Meditation Formats

As reviewed, mindfulness meditation includes various formats such as focused attention and open monitoring meditation, with focused attention further subdivided into breath awareness, body scan, and walking meditation. Previous research has typically examined single formats in isolation, neglecting direct comparisons between different formats.

Studies have found that breath awareness improves mind wandering while body scan does not (Somaraju et al., 2021; Mrazek et al., 2012). However, these comparisons are confounded by differences in intervention duration and experimental tasks, making it unclear whether effects stem from duration or format differences. Additionally, control group selection influences outcomes (Somaraju et al., 2021; Ueberholz & Fiocco, 2022). Future research should directly compare different mindfulness meditation formats to identify the most effective practices at each training stage, providing empirical support for developing optimal intervention protocols. For example, studies could examine the effects of short-term breath awareness, body scan, and sitting meditation on mind wandering to identify the most effective format and determine optimal durations for each.

4.3 Theoretical Construction Requires Further Verification and Refinement

Previous research has relied heavily on first-person measures such as self-caught and probe-caught detection and SART tasks, with limited use of third-person measures, particularly ERPs. Although some ERP studies exist, they have focused primarily on long-term meditation or other attentional processes (Liu et al., 2023; Norris et al., 2018), failing to capture the neural mechanisms of short-term mindfulness meditation's effects on mind wandering. Furthermore,

research lacks investigation of the temporal course of improvement, preventing precise description of critical time points in the ameliorative process.

Future research should incorporate ERP technology to verify the temporal dynamics proposed in existing theories, examining whether attentional orienting or meta-awareness improves first. Additionally, investigating differential effects across processing stages is crucial. Studies have used various experimental tasks that may measure the same cognitive processes differently. For instance, Mrazek et al. (2013) inserted thought probes during GRE exams and found significant differences in mind wandering frequency pre- and post-meditation, whereas Giannandrea et al. (2019) used probes during SART tasks and found no significant differences. Whether these divergent results can be fully explained by existing theories remains unclear. Moreover, how mindfulness meditation's effects on mind wandering differ across task difficulty levels and what these differences signify require further investigation.

The cycle of meditation and mind wandering model posits that equanimity toward thought content is central to mindfulness meditation's ameliorative effects (Brandmeyer & Delorme, 2021), yet how equanimity improves mind wandering requires further verification. Additionally, existing theories are based on focused attention meditation; their applicability to other formats like open monitoring meditation needs exploration. Notably, theories of mind wandering propose various causes, including executive control deficits and failures (McVay & Kane, 2010; Smallwood, 2013; Schooler et al., 2011; Cheng & Cao, 2014). Whether mindfulness meditation improves mind wandering by affecting these factors—for example, by enhancing executive control—represents a promising direction for theoretical integration and refinement.

References

Abd-Eldayem, R. M. A., & Shaheen, N. A. E. A. (2021). Mindfulness as a mediator between mind-wandering and creative abilities. *American Journal of Applied Psychology*, 10(6), 136–145.

Ahuja, S., & Vashishtha, S. (2019). Effect of surat-shabd-yoga meditation on mind wandering & metacognition. *Journal of Consciousness Exploration & Research*, 10(8), 621–629.

Ainsworth, B., Eddershaw, R., Meron, D., Baldwin, D. S., & Garner, M. (2013). The effect of focused attention and open monitoring meditation on attention network function in healthy volunteers. *Psychiatry Research*, 210(3), 1226–1231.

Alain, C., & Woods, D. L. (1997). Attention modulates auditory pattern memory as indexed by event-related brain potentials. *Psychophysiology*, 34(5), 534–546.

Badart, P., McDowall, J., & Prime, S. L. (2018). Multimodal sustained attention superiority in concentrative meditators compared to nonmeditators. *Mindfulness*, 9(3), 824–835.

Banks, J. B., Jha, A. P., Hood, A. V., Goller, H. G., & Craig, L. L. (2019). Reducing the TUTs that hurt: The impact of a brief mindfulness induction on emotionally valenced mind wandering. *Journal of Cognitive Psychology*, 31(8), 785–799.

Belardi, A., Chaieb, L., Rey-Mermet, A., Mormann, F., Rothen, N., Fell, J., & Reber, T. P. (2022). On the relationship between mind wandering and mindfulness. *Scientific Reports*, 12(1), 1–15.

Braboszcz, C., & Delorme, A. (2011). Lost in thoughts: Neural markers of low alertness during mind wandering. *Neuroimage*, 54(4), 3040–3047.

Brandmeyer, T., & Delorme, A. (2018). Reduced mind wandering in experienced meditators and associated EEG correlates. *Experimental Brain Research*, 236(9), 2519–2528.

Brandmeyer, T., & Delorme, A. (2021). Meditation and the wandering mind: A theoretical framework of underlying neurocognitive mechanisms. *Perspectives on Psychological Science*, 16(1), 39–66.

Brewer, J. A., Worhunsky, P. D., Gray, J. R., Tang, Y. Y., Weber, J., & Kober, H. (2011). Meditation experience is associated with differences in default mode network activity and connectivity. *Proceedings of the National Academy of Sciences*, 108(50), 20254–20259.

Cahn, B. R., Delorme, A., & Polich, J. (2010). Occipital gamma activation during Vipassana meditation. *Cognitive Processing*, 11(1), 39–56.

Chaieb, L., Hoppe, C., & Fell, J. (2022). Mind wandering and depression: A status report. *Neuroscience & Biobehavioral Reviews*, 133, 104505.

Chou, Y. H., Sundman, M., Whitson, H. E., Gaur, P., Chu, M. L., Weingarten, C. P., … & Chen, N. K. (2017). Maintenance and representation of mind wandering during resting-state fMRI. *Scientific reports*, 7(1), 1–11.

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences*, 106(21), 8719–8724.

Desbordes, G., Gard, T., Hoge, E. A., Hölzel, B. K., Kerr, C., Lazar, S. W., … & Vago, D. R. (2015). Moving beyond mindfulness: Defining equanimity as an outcome measure in meditation and contemplative research. *Mindfulness*, 6(2), 356–372.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, 45(1), 152–170.

Garrison, K. A., Zeffiro, T. A., Scheinost, D., Constable, R. T., & Brewer, J. A. (2015). Meditation leads to reduced default mode network activity beyond an active task. *Cognitive, Affective, & Behavioral Neuroscience*, 15(3), 712–720.

Giannandrea, A., Simione, L., Pescatori, B., Ferrell, K., Olivetti Belardinelli, M., Hickman, S. D., & Raffone, A. (2019). Effects of the mindfulness-based stress reduction program on mind wandering and dispositional mindfulness facets. *Mindfulness*, 10(1), 185–195.

Hasenkamp, W., Wilson-Mendenhall, C. D., Duncan, E., & Barsalou, L. W. (2012). Mind wandering and attention during focused meditation: A fine-grained temporal analysis of fluctuating cognitive states. *Neuroimage*, 59(1), 750–760.

He, H., Hu, L., Zhang, X., & Qiu, J. (2021). Pleasantness of mind wandering is positively associated with focus back effort in daily life: Evidence from resting state fMRI. *Brain and Cognition*, 150, 105731.

Hinterberger, T., Schmidt, S., Kamei, T., & Walach, H. (2014). Decreased electrophysiological activity represents the conscious state of emptiness in meditation. *Frontiers in psychology*, 5, 99.

Ho, N. S. P., Poerio, G., Konu, D., Turnbull, A., Sormaz, M., Leech, R., … & Smallwood, J. (2020). Facing up to the wandering mind: Patterns of off-task laboratory thought are associated with stronger neural recruitment of right fusiform cortex while processing facial stimuli. *Neuroimage*, 214, 116765.

Hofmann, S. G., Grossman, P., & Hinton, D. E. (2011). Loving-kindness and compassion meditation: Potential for psychological interventions. *Clinical Psychology Review*, 31(7), 1126–1132.

Jankowski, T., & Holas, P. (2020). Effects of brief mindfulness meditation on attention switching. *Mindfulness*, 11(5), 1150–1158.

Kabat-Zinn, J. (2003). Mindfulness-based interventions in context: Past, present, and future. *Clinical Psychology: Science and Practice*, 10(2), 144–156.

King, B. G., Conklin, Q. A., Zanesco, A. P., & Saron, C. D. (2019). Residential meditation retreats: Their role in contemplative practice and significance for psychological research. *Current Opinion in Psychology*, 28, 223–227.

Klee, D., Colgan, D. D., Hanes, D., & Oken, B. (2020). The effects of an internet-based mindfulness meditation intervention on electrophysiological markers of attention. *International Journal of Psychophysiology*, 158, 154–162.

Konjedi, S., & Maleeh, R. (2021). The dynamic framework of mind wandering revisited: How mindful meta-awareness affects mental states' constraints. *Consciousness and Cognition*, 95, 103194.

Liu, Y., Hou, Y., Quan, H., Zhao, D., Zhao, J., Cao, B., … & Yuan, H. (2023). Mindfulness training improves attention: Evidence from behavioral and event-related potential analyses. *Brain Topography*, 36(4), 243–254.

Lomas, T., Ivtzan, I., & Fu, C. H. (2015). A systematic review of the neurophysiology of mindfulness on EEG oscillations. *Neuroscience & Biobehavioral Reviews*, 57, 401–410.

Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences*, 12(4), 163–169.

Lykins, E. L., Baer, R. A., & Gottlob, L. R. (2012). Performance-based tests of attention and memory in long-term mindfulness meditators and demographically matched nonmeditators. *Cognitive Therapy and Research*, 36(1), 74–80.

Martel, A., Arvaneh, M., Robertson, I., Smallwood, J., & Dockree, P. (2019). Distinct neural markers for intentional unintentional unrelated thought. *BioRxiv*. Advance online publication. https://doi.org/10.1101/705061

McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin*, 136(2), 188–197.

Mittner, M., Boekel, W., Tucker, A. M., Turner, B. M., Heathcote, A., & Forstmann, B. U. (2014). When the brain takes a break: A model-based analysis of mind wandering. *Journal of Neuroscience*, 34(49), 16286–16295.

Mo, X., Qin, Q., Wu, F., Li, H., Tang, Y., Cheng, Q., & Wen, Y. (2021). Effects of breathing meditation training on sustained attention level, mindfulness attention awareness level, and mental state of operating room nurses. *American Journal of Health Behavior*, 45(6), 993–1001.

Mooneyham, B. W., Mrazek, M. D., Mrazek, A. J., Mrazek, K. L., Phillips, D. T., & Schooler, J. W. (2017). States of mind: Characterizing the neural bases of focus and mind-wandering through dynamic functional connectivity. *Journal of Cognitive Neuroscience*, 29(3), 495–506.

Mrazek, M. D., Franklin, M. S., Phillips, D. T., Baird, B., & Schooler, J. W. (2013). Mindfulness training improves working memory capacity and GRE performance while reducing mind wandering. *Psychological Science*, 24(5), 776–781.

Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: Finding convergence through opposing constructs. *Emotion*, 12(3), 442–448.

Norris, C. J., Creem, D., Hendler, R., & Kober, H. (2018). Brief mindfulness meditation improves attention in novices: Evidence from ERPs and moderation by neuroticism. *Frontiers in Human Neuroscience*, 12, 315.

Ooishi, Y., Fujino, M., Inoue, V., Nomura, M., & Kitagawa, N. (2021). Differential effects of focused attention and open monitoring meditation on autonomic cardiac modulation and cortisol secretion. *Frontiers in Physiology*, 12, 675899.

Phillips, N. E., Mills, C., D'Mello, S., & Risko, E. F. (2016). On the influence of re-reading on mind wandering. *Quarterly Journal of Experimental Psychology*, 69(12), 2338–2357.

Rahl, H. A., Lindsay, E. K., Pacilio, L. E., Brown, K. W., & Creswell, J. D. (2017). Brief mindfulness meditation training reduces mind wandering: The critical role of acceptance. *Emotion*, 17(2), 224.

Ray, W. J., & Cole, H. W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science*, 228(4700), 750–752.

Reangsing, C., Rittiwong, T., & Schneider, J. K. (2021). Effects of mindfulness meditation interventions on depression in older adults: A meta-analysis. *Aging & Mental Health*, 25(7), 1181–1190.

Rodriguez-Larios, J., de Oca, E. A. B. M., & Alaerts, K. (2021). The EEG spectral properties of meditation and mind wandering differ between experienced meditators and novices. *Neuroimage*, 245, 118669.

Ruby, F. J., Smallwood, J., Sackur, J., & Singer, T. (2013). Is self-generated thought a means of social problem solving?. *Frontiers in Psychology*, 4, 962.

Sanger, K. L., & Dorjee, D. (2016). Mindfulness training with adolescents enhances metacognition and the inhibition of irrelevant stimuli: Evidence from event-related brain potentials. *Trends in Neuroscience and Education*, 5(1), 1–11.

Sayette, M. A., Reichle, E. D., & Schooler, J. W. (2009). Lost in the sauce: The effects of alcohol on mind wandering. *Psychological Science*, 20(6), 747–752.

Scheibner, H. J., Bogler, C., Gleich, T., Haynes, J. D., & Bermpohl, F. (2017). Internal and external attention and the default mode network. *Neuroimage*, 148, 381–389.

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences*, 15(7), 319–326.

Seli, P., Ralph, B. C., Konishi, M., Smilek, D., & Schacter, D. L. (2017). What did you have in mind? Examining the content of intentional and unintentional types of mind wandering. *Consciousness and Cognition*, 51, 147–156.

Smallwood, J. (2013). Distinguishing how from why the mind wanders: A process-occurrence framework for self-generated mental activity. *Psychological Bulletin*, 139(3), 519–535.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, 132(6), 946–958.

Smallwood, J., Ruby, F. J., & Singer, T. (2013). Letting go of the present: Mind-wandering is associated with reduced delay discounting. *Consciousness and Cognition*, 22(1), 1–7.

Somaraju, L. H., Temple, E. C., Bizo, L. A., & Cocks, B. (2021). Brief mindfulness meditation: Can it make a real difference?. *Current Psychology*, 36,

1–13.

Tang, Y. Y., & Posner, M. I. (2009). Attention training and attention state training. *Trends in Cognitive Sciences*, 13(5), 222–227.

Tanaka, G. K., Peressutti, C., Teixeira, S., Cagy, M., Piedade, R., Nardi, A. E., . . .Velasques, B. (2014). Lower trait frontal theta activity in mindfulness meditators. *Arquivos de Neuro-Psiquiatria*, 72(9), 687–693.

Ueberholz, R. Y., & Fiocco, A. J. (2022). The effect of a brief mindfulness practice on perceived stress and sustained attention: Does priming matter?. *Mindfulness*, 13(7), 1757–1768.

Wammes, J. D., Seli, P., Cheyne, J. A., Boucher, P. O., & Smilek, D. (2016). Mind wandering during lectures II: Relation to academic performance. *Scholarship of Teaching and Learning in Psychology*, 2(1), 33–48.

Webb, C. A., Israel, E. S., Belleau, E., Appleman, L., Forbes, E. E., & Pizzagalli, D. A. (2021). Mind-wandering in adolescents predicts worse affect and is linked to aberrant default mode network-salience network connectivity. *Journal of the American Academy of Child & Adolescent Psychiatry*, 60(3), 377–387.

Whitmoyer, P., Fountain-Zaragoza, S., Andridge, R., Bredemeier, K., Londeree, A., Kaye, L., & Prakash, R. S. (2020). Mindfulness training and attentional control in older adults: A randomized controlled trial. *Mindfulness*, 11(1), 203–218.

Williams, J. M. G., & Kabat-Zinn, J. (2011). Mindfulness: Diverse perspectives on its meaning, origins, and multiple applications at the intersection of science and dharma. *Contemporary Buddhism*, 12(1), 1–18.

Wong, K. F., Massar, A. A. S., Chee, M. W., & Lim, J. (2018). Towards an objective measure of mindfulness: Replicating and extending the features of the breath-counting task. *Mindfulness*, 9(5), 1402–1410.

Xu, M., Purdon, C., Seli, P., & Smilek, D. (2017). Mindfulness and mind wandering: The protective effects of brief meditation in anxious individuals. *Consciousness and Cognition*, 51, 157–165.

Yoshida, K., Sawamura, D., Yagi, M., Nakashima, Y., Saito, R., Yamamura, N., … & Sakai, S. (2023). Detecting inattentiveness caused by mind-wandering during a driving task: A behavioral study. *Applied Ergonomics*, 106, 103892.

Zanesco, A. P., King, B. G., MacLean, K. A., & Saron, C. D. (2018). Cognitive aging and long-term maintenance of attentional improvements following meditation training. *Journal of Cognitive Enhancement*, 2, 259–275.

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