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ESSAY

A translational neuroscience perspective on mindfulness meditation as a prevention strategy

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Abstract

Mindfulness meditation research mainly focuses on psychological outcomes such as behavioral, cognitive, and emotional functioning. However, the neuroscience literature on mindfulness meditation has grown in recent years. This paper provides an overview of relevant neuroscience and psychological research on the effects of mindfulness meditation. We propose a translational prevention framework of mindfulness and its effects. Drawing upon the principles of prevention science, this framework integrates neuroscience and prevention research and postulates underlying brain regulatory mechanisms that explain the impact of mindfulness on psychological outcomes via self-regulation mechanisms linked to underlying brain systems. We conclude by discussing potential clinical and practice implications of this model and directions for future research.

Keywords

Translational neuroscience, Mindfulness meditation, Self-regulation, Prevention science

Implications

Practice: Practitioners should review the findings from more recent and more rigorous trials and partner with the research team to investigate whether these interventions are sufficiently manualized and portable to be able to be delivered as part of routine clinical practice.

Policy: Motivated by researchers and practitioners, policy makers should support the need for funding to help spur the translation from type I research to type 2 and 3 implementation work of low-cost and effective mindfulness preventions and interventions.

Research: Researchers should work with prevention scientists to conduct additional type 1 research that employs longitudinal, randomized, and actively controlled research designs and larger sample sizes to advance the understanding of the mechanisms of mindfulness meditation and connect neurobiological findings with findings from behavioral studies.

WHAT IS MINDFULNESS?

Different forms and styles of meditation can be found in almost all cultures and religions. The focus of this paper is on mindfulness meditation (not including other body–mind techniques, such as Yoga, Tai Chi, Qigong, etc.), which originates from Buddhist meditation traditions. Mindfulness meditation is composed of several key components aimed at progressively orienting the participant to an awareness of the connection and synergy between body and mind. Techniques employed to attain this state include body relaxation, breathing practice, mental imagery, and body and mind awareness [1–9].

Since the 1990s, mindfulness meditation has been an approach used to treat multiple mental and physical health conditions. More recently, it has received increasing attention by psychologists and neuroscientists. Although there is ongoing debate about the precise definition of mindfulness meditation, in current clinical and research contexts, mindfulness meditation is considered to be a state that is typically described as "nonjudgmental attention to experiences in the present moment" [1–5]. Mindfulness meditation can be subdivided into methods involving focused attention and those involving open monitoring of present-moment experience [2, 9].

Mindfulness meditation has been practiced widely, with the purpose of stress reduction and the promotion of health and well-being. This has included the reduction of chronic pain, as well as the treatment of mental health symptoms such as anxiety, depression, substance abuse, and other behavioral health conditions [2, 4]. It has also been implemented across a range of settings, including academic and professional workplace settings, schools, and counseling and clinical settings. Mindfulness research in the last two decades has supported the claim that it exerts beneficial effects on physical health, mental health, and cognitive performance [2, 4]. However, the underlying neural mechanisms associated with positive outcomes are not fully understood [2, 4]. We describe a translational prevention framework that integrates research in the fields of neuroscience and prevention science to help facilitate an understanding of the etiology of the mechanisms underlying the effectiveness of mindfulness meditation and provide guidance to further the understanding and prevention of behavioral health disorders.

A TRANSLATIONAL PREVENTION FRAMEWORK FOR MINDFULNESS MEDITATION

The translation of basic science discoveries into practical strategies to improve health is of critical importance to prevention science. The earliest stages of translational prevention science focus on the application of theory to translate discoveries in the basic sciences and apply them to guide intervention development. In this paper, we focus on type 1 translational research, which includes the transfer of knowledge from basic science to development and testing of an intervention or program. A core foundation of type 1 translational prevention science is that the intervention must have an "action theory" that corresponds to how the intervention will affect the underlying biologically based mechanisms of change, or mediators, as well as a conceptual theory that describes how the mediators will predict the hypothesized outcome variables [10]. The goal of this approach is to inform the development of personalized prevention approaches that are guided by basic science findings, using a theory-guided approach.

This approach is not without its challenges, and in particular, basic scientists are trained in basic biological processes but not in the development of preventive interventions, whereas prevention researchers typically have not received training in the basic biological sciences. The education training and methods of each discipline are quite distinct. For example, basic scientists may receive training in biological mechanisms at the cellular or genetic level and conduct laboratory-based research involving microscopes, neuroimaging techniques, or gene assays, whereas prevention scientists typically receive training in health and human development and how to change behavior via effective psychosocial interventions, but not in the biology or processes occurring "under the skin." This poses structural and training barriers to the integration of findings and approaches across disciplines and reduces the likelihood that links between a biological finding and the application of a corresponding theory-guided intervention will occur. Further, often, the key basic science findings originate from animal studies, whereas the preventive intervention expertise is typically in human populations. Although some aspects of biology can be directly translated across species, others cannot (e.g., "development" varies by species, including at what age different brain structures mature). As such, successful type 1 translational research is most readily facilitated through collaborations between experts in neuroscience, biology, or other basic sciences and experts in prevention research. Such collaborations help to bridge differences in the scientific cultures and their corresponding languages and techniques and align them within a common framework and purpose.

Our conceptual framework, shown in Fig. 1 and described below, aims to integrate knowledge from the biological sciences (specifically, neuroscience) and prevention science to illustrate an action theory and a conceptual theory describing how mindfulness meditation can lead to activation of specific brain regions which are associated with specific domains of self-regulation, which then result in improved self-regulation and, ultimately, to improved mental health. The active ingredients of mindfulness meditation focus on increasing awareness of one's thoughts, emotions, and actions. The mechanisms hypothesized to be affected by mindfulness meditation practices include specific neurobiological structures that are associated with the self-regulation capacities of attention, emotion regulation, and self-awareness. These brain structure and behavioral mediators are then hypothesized to predict a set of longer-term outcomes associated with self-regulation, including attention-deficit hyperactivity disorder (ADHD), depression, drug abuse, and antisocial behavior [11, 12].

To illustrate support for this translational prevention model, in the sections below, we first review neuroscience evidence that indicates that attention, emotion regulation, and self-awareness are each associated with distinct brain structures and systems that are malleable via psychosocial interventions. Second, we provide a review of studies on mindfulness meditation research that have used functional magnetic resonance imaging (fMRI) and shown that mindfulness interventions are associated with changes in these brain systems and with changes in associated self-regulation outcomes. Third, we summarize evidence on the effects of mindfulness meditation on longer-term self-regulation mental health outcomes, such as ADHD, anxiety, depression, and substance use to illustrate support for out translational framework from the field of prevention science. Fourth, we conclude with implications and future directions for translational neuroscience prevention research related to mindfulness meditation. The work described in this paper is not intended to serve as a systematic review of the literature; rather, we describe key findings from both neuroscience and prevention science that serve as illustrative examples of our translational framework.

AN INTEGRATED TRANSLATIONAL MODEL OF MINDFULNESS MEDITATION

It has been suggested that mindfulness meditation affects at least three components that interact closely to constitute a process of enhanced self-regulation: *enhanced attention control*, *improved emotion regulation*, and *altered self-awareness* (diminished self-referential processing and enhanced body awareness) (see Fig. 1). Integrating knowledge from the field of prevention science with the field of neuroscience, we propose an integrated translational framework for mindfulness meditation in which we suggest that the underlying brain regions and networks affected by mindfulness meditation may be associated with observable changes at the behavioral level in specific mental processes, including attention control, emotion regulation, and self-awareness [2]. For example, mindfulness meditation changes anterior cingulate cortex (ACC), prefrontal cortex (PFC), and striatum associated with attention control, PFC and limbic areas related

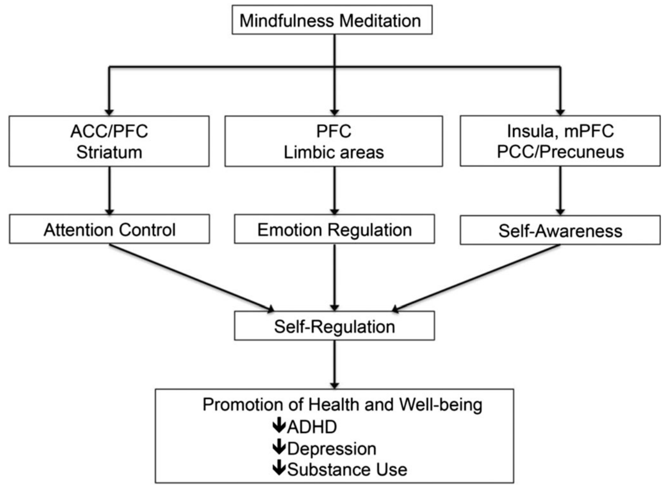

Fig. 1 | Integrated translational framework illustrating the neurobiological and behavioral mechanisms whereby mindfulness meditation could affect self-regulation outcomes

to emotion regulation, and insula, medial PFC (mPFC), posterior cingulate cortex (PCC) and precuneus involved in self-awareness. As such, mindfulness meditation may affect self-regulatory outcomes through its effects on specific brain systems. Figure 1 illustrates this framework, and below, we overview the three neurobiological mechanisms hypothesized to be affected by mindfulness meditation. Figure 2 draws on evidence from neuroscience to show the brain regions involved in the components of mindfulness meditation. Note that we illustrate the three brain systems and corresponding observable self-regulatory skills as separate constructs but recognize that they are correlated with one another and that changes in one system can affect changes in another system.

Neurobiological mechanisms underlying attention control—Attention can be viewed as a system of anatomical areas that consists of three or more specialized networks. These networks carry out the functions of alerting, orienting, and executive control or resolving conflict. Neuroimaging studies show that the brain regions involved in attention control mainly include the ACC, the adjacent PFC, and the striatum/basal ganglia [13]. Similarly, brain systems shown to be activated in the broad construct of self-regulation cover the same ACC/mPFC and striatum [7, 14, 15]. Thus, the overlap of brain regions associated with attention control and self-regulation suggests a neurobiological pathway whereby mindfulness meditation could exert its influences [2, 15].

Neurobiological mechanisms underlying emotion regulation—A second component of self-regulation is emotion regulation. Emotion regulation refers to strategies that can influence which emotions arise and when, how long they occur, and how these emotions are experienced and expressed [16]. Neuroimaging studies have shown that emotion regulation activates multiple PFC regions and limbic regions such as amygdala [17]. Enhanced emotion regulation has been suggested to underlie many of the beneficial effects of mindfulness meditation [18]. A range of implicit and explicit emotion regulation processes has been proposed [16, 19], and mindfulness-based emotion

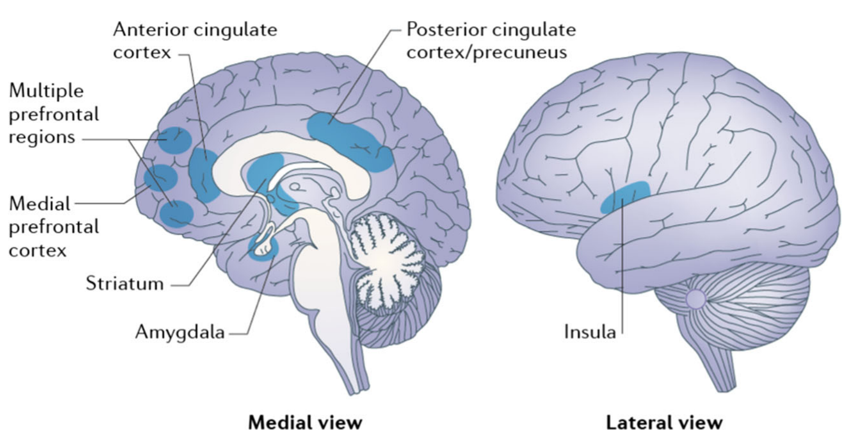

Fig. 2 | Brain regions involved in mindfulness meditation. Schematic view of the brain regions involved in attention control (the anterior cingulate cortex and the striatum), emotion regulation (multiple prefrontal regions, limbic regions, and the striatum), and self-awareness (insula, medial prefrontal cortex and posterior cingulate cortex, and precuneus). Cited from [2]

regulation may involve a mix of these processes, including attentional deployment (attending to mental processes, including emotions), cognitive change (altering typical patterns of appraisal regarding one's emotions), and response modulation (decreasing tonic levels of suppression) [2, 19].

Neurobiological mechanisms underlying self-awareness—Self-awareness is the third component of self-regulation that is hypothesized to be affected by mindfulness meditation. Self-awareness often refers to meta-awareness (making awareness itself an object of attention) in mindfulness meditation. Self-referential processing is one major component of self-awareness which concerns stimuli that are experienced as strongly related to one's own person. Typical examples are the way that we perceive pictures of ourselves or close friends versus pictures of completely unknown people or pictures of our houses where we spent our childhood versus pictures of any unknown house, etc. A meta-analysis of imaging studies indicated that self-referential processing is mediated by cortical midline structures [20]. In sum, self-awareness involves mPFC, the PCC, the precuneus, and insula [2].

THE EFFECTS OF MINDFULNESS MEDITATION ON BRAIN STRUCTURES AND SELF-REGULATORY OUTCOMES

A key test of our translational framework is whether mindfulness meditation interventions produce changes in the putative brain and behavioral self-regulatory mechanisms described in the preceding section. Type I translational prevention research is a useful method to address the question of whether there is evidence that mindfulness meditation leads to changes in the following: (1) the brain systems of ACC/PFC and striatum and the behavioral system of attention control; (2) the brain systems of the PFC and limbic areas and behavioral systems related to emotion regulation; and (3) the brain systems of the insula, mPFC, and PCC/precuneus and the behavioral system of self-awareness. Such evidence would provide full support for the hypothesized translational prevention framework shown in Fig. 1; support for only one or two of the three hypothesized pathways would provide partial support for this framework and would indicate that some re-examinations of the theoretical underpinning in the framework are necessary.

Numerous studies have been conducted using fMRI methods that each test individual component of our framework, that when examined as a whole body of evidence, can be synthesized to examine the full set of processes shown in Fig. 1. Table 1 presents a summary of these studies, and we provide a brief review of key studies in each area in this section (note that this is not a systematic review). As noted earlier, the brain systems and observed self-regulatory outcomes in our translational framework are inter-correlated, and thus, most studies have tested multiple components simultaneously, rather than testing each component individually. The first column of Table 1 indicates the specific brain structure and self-regulatory domain(s) targeted, the second column provides a brief overview of the study design, and the third column summarizes the key results.

Neuroscience research shows that the attention control network is heavily involved in mindfulness practice [2, 4, 6, 9] because attention control is required to stay engaged in the practice of mindfulness meditation. Studies examining the meditating role of attention control have reported that repeated practice leads to improvement [4, 6]. For example, in a cross-sectional study using Vipassana meditators versus controls, enhanced ACC activation during breath awareness (focused attention) meditation was found [21]. In a longitudinal mindfulness training versus active control, greater dorsolateral PFC activation during emotional Stroop executive processing was detected [22].

Mindful emotion regulation works by strengthening PFC cognitive control mechanisms and thus downregulating activity in regions relevant to affect processing, such as the amygdala. Present-moment awareness and non-judgmental acceptance through mindfulness meditation [4, 5] are thought to be crucial in promoting cognitive control because they increase sensitivity to affective cues that help to signal the need for control [23]. A frequently reported finding is that mindfulness practice is associated with a diminished activation of the amygdala in response to emotional stimuli during mindful states [24, 25]. For instance, in a longitudinal and uncontrolled study, patients with social anxiety disorder before and after MBSR showed diminished right dorsal amygdala activity during reacting to negative self-belief statements [24]. In a cross-sectional study, downregulation of the left amygdala was detected when viewing emotional pictures in a mindful state in beginner but not expert Zen meditators [25].

Recent studies seem to suggest that brain structures such as insula, mPFC, and PCC/precuneus supporting self-referential processing might be affected by mindfulness meditation [26, 27]. Mindfulness practitioners often report that the practice of attending to present-moment body sensations leads to an enhanced awareness of bodily states and greater perceptual clarity of subtle interoception. Thus, evaluative self-referential processing is assumed to decrease as an effect of mindfulness meditation, whereas awareness of present-moment experiences is thought to be enhanced [2, 4]. Recent studies have shown that mindfulness meditation improves self-awareness that is deficit in substance use and addiction [28, 29].

Functional imaging research has indicated that mindfulness meditation induces changes at resting and task implementation (attention, emotion, and self-referential tasks) that are associated with diverse brain networks such as ACC, PFC, PCC, striatum, amygdala, and insula [4]. Studies also show structural alteration in the brain associated with mindfulness meditation or diverse meditation traditions [2, 4, 30]. Across the functional and structural MRI studies that

Table 1 | Changes in the core brain regions after mindfulness meditation

Function/Brain region	Study design	Findings	Refs
Attention control			
ACC	Cross-sectional, Vipassana meditators (N=15) versus controls (N=15)	Enhanced ACC activation during breath awareness (focused attention) meditation	[21]
Striatum	Longitudinal, IBMT versus active control (relaxation training) (N=23 each group)	Enhanced ACC activity in resting state	[34]
	Longitudinal, IBMT, active control (relaxation training) (N=23 each group)	Enhanced caudate and putamen activity at resting state	[34]
PFC	Longitudinal, mindfulness training (N=30) versus active control (N=31)	Greater dorsolateral PFC activation during emotional Stroop executive processing	[22]
Emotion regulation			
ACC/PFC/striatum/insula			
Amygdala	Longitudinal, mindful attention training (N=12), compassion training (N=12), and active control (N=12)	Decreased activation in right amygdala in response to emotional pictures in a non-meditative state	[58]
	Longitudinal, uncontrolled, patients with social anxiety disorder before and after MBSR (N=14)	Diminished right dorsal amygdala activity during reacting to negative self-belief statements	[28]
Self-awareness			
Insula	Longitudinal, IBMT, active control (relaxation training) (N=23 each group)	Enhanced left insula activity at resting state	[34]
	Cross-sectional, MBSR (N=20), and waiting list control (N=16)	Greater anterior insula activity and altered coupling between dmPFC and posterior insula during interoceptive attention to respiratory sensations	[23]
PCC	Longitudinal, IBMT, active control (relaxation training) (N=23 each group)	Enhanced right PCC activity at resting state	[34]
	Cross-sectional, expert meditators (N=12) versus controls (N=13)	PCC deactivation during different types of meditation, increased coupling with ACC and dorsolateral PFC	[24]

have been published to date, especially based on the longitudinal randomized controlled studies with active control groups and meta-analyses, the brain regions of ACC, PFC, PCC, insula, striatum (caudate, putamen), and amygdala seem to show relatively consistent changes associated with mindfulness meditation [2, 4].

An illustrative example: IBMT—One form of mindfulness meditation, integrative body–mind training (IBMT), has been shown in randomized controlled trials (RCTs) to lead to improvements in self-regulation (attention control, emotion regulation, and self-awareness). We here take IBMT as an example to further discuss the relationships among self-regulation, brain areas involved, and mindfulness meditation. IBMT originates from ancient Eastern contemplative traditions, including traditional Chinese medicine and Zen. IBMT stresses no effort or less effort to control thoughts and the achievement of a state of restful alertness that allows a high degree of awareness and balance of the body, mind, and environment. The meditation state is facilitated through training and trainer–group dynamics, harmony, and resonance. IBMT has been categorized in the literature as open-monitoring mindfulness meditation [2, 6, 31, 32].

In one study, Chinese undergraduates were randomly assigned to either an IBMT group (n=40) or to a relaxation control group (n=40) using a pre-study–post-study RCT design [6]. Analyses indicated that after 5 days of training, the IBMT group showed significantly greater improvement in attention control than did the control group. In addition, individuals in the IBMT condition had lower negative affect and fatigue and higher positive feelings on the emotion regulation [6]. In a second study, we randomly assigned 46 undergraduates to IBMT or relaxation groups and conducted brain imaging assessments before, during, and after 5 days (about 2 h) of IBMT vs. relaxation training [7]. Neuroimaging data demonstrated that individuals in the IBMT condition showed stronger subgenual and adjacent ventral ACC activity compared to individuals in the relaxation control condition. In a third study (n=23 IBMT; n=22 relaxation group), we acquired brain images from each participant at rest using MRI diffusion tensor imaging for analysis of white matter before and after training. Results showed that around 4 weeks (~10 h) of IBMT increased fractional anisotropy connecting ACC to other regions, indicating the white matter structural change following longer IBMT [32]. Because deficits in activation of the ACC have been associated with many disorders, including mood disorders and substance abuse, the ability to strengthen cingulate connectivity through training could provide a means for improving attention control and might serve as a possible therapy or prevention tool [2, 32]. These brain areas before-mentioned may be the core regions involved in self-regulation of attention, emotion, and awareness following mindfulness training, as shown in Table 1. However, we acknowledge that many other brain areas are also involved in mindfulness practice and warrant further investigation using rigorous RCT designs.

CLINICAL STUDIES AND IMPLICATIONS OF THE TRANSLATIONAL PREVENTION FRAMEWORK

As illustrated in Fig. 1, the distal outcome in our translational framework is the promotion of well-being and mental health. Improved mental health symptoms are hypothesized to be driven by changes in brain regulatory systems and structures that affect the self-regulation functions targeted by mindfulness meditation interventions. In this section, we draw from the field of prevention science to provide three examples of behavioral health outcomes that are hypothesized to be improved and avoided via mindfulness meditation interventions: attention-deficit hyperactivity disorder (ADHD), depression, and drug use [33]. Within each section, we propose next steps that neuroscience and prevention science researchers and practitioners can do moving forward to further the research rigor and expand dissemination efforts.

Attention-deficit hyperactivity disorder—ADHD is widely considered to comprise a deficit in self-regulation, which encompasses deficits in behavioral inhibitions, working memory, regulation of motivation, and motor control [34]. As such, it is a primary long-term outcome hypothesized to be reduced or prevented by mindfulness meditation interventions. Extant research has identified brain systems and structures that are differentially affected in individuals with and without ADHD. Specifically, functional and structural neuroimaging has identified brain abnormalities involved in ADHD. Hypofunction of the brain regions including the cingulo-frontal-parietal cognitive attention network has been consistently observed across studies [35]. A meta-analysis also showed a ventral-striatal hyporesponsiveness (decreased response) on reward anticipation in ADHD individuals compared to healthy individuals [36]. These are major components of neural systems related to attention and self-control networks, motor systems, and reward/feedback-based processing systems. The ADHD neuroimaging research related to these network dysfunctions is also associated with the core symptoms of inattention, impulsivity, and hyperactivity. However, these network abnormalities are not the only factors responsible for ADHD; instead, they are only part of the pathophysiology of ADHD [36]. In order to fully characterize the disorder, a next step for neuroscience researchers in this area is to expand their investigation beyond dysfunction of prefrontal-striatal circuitry, to consider the large-scale neural systems involved in ADHD including frontoparietal, dorsal attentional, motor, visual, and default networks [33, 37].

As described earlier, mindfulness meditation includes at least three components that interact closely to constitute a process of enhanced self-regulation: enhanced attention control, improved emotion regulation, and altered self-awareness. As such, the core ADHD symptoms of inattention, impulsivity, and hyperactivity are targeted [2, 33]. Mindfulness meditation has been applied in children, adolescents, and adults with ADHD and primarily targets strengthening attention, managing emotions, and achieving goals [33, 38]. Overall, the results are promising and demonstrate feasibility of mindfulness meditation in ADHD populations and preliminary effectiveness of mindfulness meditation in the treatment of ADHD [39]. However, prior research in this area has been plagued by methodological issues such as small samples, a lack of active comparison groups, and short follow-up periods limiting generalizability [39]. We therefore recommend that neuroscientists and prevention scientists partner to conduct rigorous longitudinal studies using RCT designs, samples large enough to detect small effects, and type 1 method and measurement approaches [33]. This would lay the groundwork for type 2 translational efforts.

Depression—Although less studied than ADHD in the context of mindfulness meditation using RCT designs, there is some evidence that brain structures and emotional regulation processes related to depressive symptoms can also be improved through mindfulness meditation interventions. Emotion regulation activates multiple PFC and limbic regions such as the amygdala [2, 17, 18], and studies have reported various positive effects of mindfulness meditation on emotional processing, including a reduction in emotional interference by unpleasant stimuli [40], decreased physiological reactivity and facilitated return to emotional baseline after response to a stressor film [41], and decreased self-reported difficulties in emotion regulation [42]. Consequently, lowered intensity and frequency of negative affect [43, 44] and improved positive mood states [6, 44, 45] are reported to be associated with mindfulness meditation. Mindfulness-based cognitive therapy (MBCT) has been used for treatment of depression, and a systematic review showed that some studies found that alterations in mindfulness, rumination, worry, compassion, or meta-awareness were associated with predicted or mediated MBCT's effect on treatment outcome [46–48]. However, despite this preliminary type 1 translational work, researchers should conduct more rigorous designs that can assess the causal relationship among the brain, emotion, and depression.

A meta-analysis of 39 studies conducted across ten countries indicated that mindfulness meditation interventions were superior to standard care (behavioral and psychopharmacological treatment) in reducing depressive symptoms and preventing relapse, with effect sizes ranging from 0.11 to 1.65 [49]. A meta-analysis of cancer patients and survivors conducted during the same time found similarly sized effects on depressive symptoms [50]. However, most studies in these meta-analyses used single-group pretest–posttest quasi-experimental designs, convenience sampling, and self-reported questionnaires; therefore, more rigorous designs are needed that examine the effects of mindfulness meditation interventions on depressive symptoms.

The hypothesis that drives many of the studies focused on depression is that mindfulness-based emotion regulation works by strengthening PFC cognitive control mechanisms and downregulating activity in regions relevant to affect processing, such as the amygdala, ultimately reducing depressive symptoms [2]. However, to our knowledge, few studies have tested all aspects of the proposed translational framework related to depression outcomes simultaneously. Researchers should conduct additional type 1 work in this area in order to advance our understanding of the neurobiological mediators and pathways underlying mindfulness meditation changes in depression.

Substance use and addiction—Substance use and addiction are distal outcomes that are hypothesized to have connections to all three self-regulation domains in our translational model: attention control, emotion regulation, and self-awareness. For example, substance use can be seen as an addictive behavior in which impulses and behavior cannot be controlled, suggesting deficits in attention control. It can also be viewed as a method of "self-medication" to relieve symptoms of distress and change one's emotional state, suggestive of impairments in emotion regulation. Third, it is considered by some as intentional deception, and as such, "denial" might instead reflect dysfunction of brain networks subserving insight and self-awareness [28]. More than 80 % of addicted individuals fail to seek treatment, which might reflect impairments in recognition of severity of disorder [28, 29]. There is preliminary evidence that mindfulness meditation can reduce substance use, perhaps through one or more of these hypothesized pathways [51, 52]. For example, one study of mindfulness-naive smokers demonstrated reduced connectivity between craving-related brain regions during a mindfulness condition compared to passive viewing of smoking-related images during cigarette craving [53], suggesting a functional decoupling of involved regions.

A meta-analysis of 24 studies focused on mindfulness and substance use suggested that mindfulness meditation interventions can reduce the consumption of several substances including alcohol, cocaine, amphetamines, marijuana, cigarettes, and opiates to a significantly greater extent than waitlist controls, nonspecific educational support groups, and some specific control groups [54]. This meta-analysis also provided preliminary evidence that mindfulness meditation interventions are associated with a reduction in craving as well as increased mindfulness. There is preliminary evidence of gender differences in mindfulness meditation interventions in relation to substance use outcomes, with a meta-analysis reporting that several quasi-experimental studies and case series found that women gravitated more toward mindfulness meditation interventions or benefitted more from mindfulness interventions [55]. However, similar to the other studies linking mindfulness meditation interventions with clinical-level benefits in self-regulation, most of the studies were limited by small sample sizes, lack of methodological rigor, or lack of consistently replicated findings [56]. Neuroscientists and prevention scientists should collaborate to conduct more rigorous and larger randomized controlled studies in this area, to increase the conclusions that can be drawn from type 1 translational studies and move the field closer to being able to conduct type II studies.

Recently, a few rigorous and randomized studies started to test the effect of mindfulness meditation on addiction [51, 52]. For example, compared to treatment as usual (12-step programming and psychoeducation), eight weekly group sessions of mindfulness-based relapse prevention resulted in significantly lower risk of relapse to substance use and heavy drinking among participants [51]. Similarly, a recent randomized study of IBMT tested whether this mindfulness intervention reduced smoking [52]. Participant recruitment was for stress reduction and not specifically related to the intention to quit smoking. Before training, smokers demonstrated reduced activity in ACC, PFC, and other areas during rest compared to non-smokers, consistent with the association between impaired self-control and addiction. Two weeks of IBMT (5 h in total) produced a significant reduction in smoking (60 %) and craving, whereas no reduction was found in the relaxation training control group. Resting-state MRI showed increased activity for the IBMT group in the ACC and mPFC, key brain areas for self-control, which were associated with a reduction in smoking behavior [52]. These results suggest that brief mindfulness meditation approaches can improve self-control capacity and reduce smoking, even without a conscious intention to do so [52, 57]. Practitioners should review the findings from these more recent and more rigorous RCT trials and partner with the research team to investigate whether these interventions are sufficiently manualized and portable to be able to be delivered as part of routine clinical practice.

CONCLUSIONS AND FUTURE DIRECTIONS

Interest in the behavioral and neurobiological investigation of mindfulness meditation has rapidly increased over the past two decades. However, knowledge of the mechanisms that underlie the effects of mindfulness meditation is still in its infancy, suggesting the need for more type 1 translational research in this area. The emerging evidence indicates that mindfulness meditation might cause neuroplasticity in the structure and function of brain regions involved in control of attention, emotion regulation, and self-awareness. Further, there is a growing body of evidence that mindfulness meditation interventions can be effective in reducing ADHD symptoms, depression, and substance use and addiction. However, there is limited evidence linking all components of the proposed translational framework to illustrate which brain systems are affected, what specific self-regulation outcomes are improved, and, ultimately, which clinical symptoms are prevented.

In this paper, we described a translational prevention framework that linked underlying neurobiological structures with observable self-regulatory behavior, united by change mechanisms associated with mindfulness meditation. Further, we hypothesized distal outcome improvements in clinical symptoms as a result of the intervention-driven changes in brain structure and observed self-regulatory skills. Neuroscientists and prevention scientists should partner to conduct additional type 1 research that employs longitudinal, randomized, and actively controlled research designs and larger sample sizes to advance the understanding of the mechanisms of mindfulness meditation in regard to the interactions of complex brain networks and to connect neurobiological findings with findings from behavioral studies. Simultaneous to these type 1 efforts, specific model components that have been verified via rigorous type 1 trials can advance into type 2 and type 3 translational research. Prevention scientists should leverage these findings to test the implementation and sustainability of mindfulness meditation interventions and examine the cost-benefits of such interventions.

One significant barrier in this translation is the generation of a qualified work force of interventionists who are trained to deliver mindfulness meditation interventions with fidelity and model adherence. As such, researchers and practitioners should advocate to policy makers for the need for funding to help spur the translation from type I research to type 2 and 3 implementation work. Researchers and practitioners should also ensure that they have developed intervention manuals or instructions and fidelity systems so that effective interventions can be delivered by others. Relatedly, researchers and practitioners need to ensure that systems are in place for training and certifying new interventionists. Further, methods for quantifying the fiscal costs of delivering a specific mindfulness meditation intervention are needed.

As evident in the literature summary above, existing mindfulness meditation interventions vary significantly in their length; what is the optimal length of services that will achieve benefits to individual yet minimize the costs of service delivery? As such, examination of dosage effects is warranted, both in terms of the overall intended length of the intervention as well as the number of sessions that an individual needs to receive in order to show benefit. If supported by additional rigorous type 1 research studies and extended into type 2 research and beyond, the practice of mindfulness meditation might be promising for the prevention of clinical disorders associated with deficits of self-regulation that could be more widely disseminated in schools and communities nationally and globally.

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Compliance of ethical standards

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