Mindfulness and Cognitive Control: A review on their dual mode mechanisms

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Abstract

Recent years have seen a massive increase in research on mindfulness as both a therapeutic practice as well as a protective health factor. While many associations have been made between mindfulness and clinical outcomes, understanding of the underlying mechanistic processes is still in its infancy. In this review, associations between mindfulness and other established frameworks in cognitive control are explored—in particular the dual modes of control framework in cognitive control theory. Studies in mindfulness providing evidence towards a dual-mode mindfulness model are reviewed and compared with the proactive and reactive modes of cognitive control to identify common underlying principles. Studies involving cognitive testing, advanced neuroimaging, and neurotransmitter levels and their associations with proactive and reactive control are reviewed in the context of the dual modes of mindfulness. While evidence supporting relationships between proactive and reactive modes of mindfulness and cognitive control are preliminary, existing literature on mindfulness already supports the notion of two components of mindfulness and is in line with the hypothesis that cognitive control and mindfulness are closely related. Since preliminary evidence suggests that proactive forms of mindfulness are more associated with improvement in clinical outcomes, mindfulness programs could be modified to target proactive mindfulness practices to maximize outcomes. The implications of proactive and reactive mindfulness on therapy, limitations of the framework, and necessity of studies providing direct evidence are further discussed.

Dual mode mechanisms

Although mindfulness and cognitive control have a distinct history in regards to modern scientific inquiry, it shares many biological and psychological similarities. For the past few decades, cognitive control has been a focus area in cognitive neuroscience research and has resulted in well-accepted frameworks of which the dual mechanisms of control (DMC) has gained prominence[1,2]. DMC frames cognitive control as comprising of two components: one responsible for anticipatory priming of cognitive processes and another for conflict resolution and other stimulus-evoked processes. Subsequent studies have built upon this framework and tested it across several experimental conditions[3,4] and studied it in the context of pathology[5,6]. While it is known that mental training such as Mindfulness programs[7,8] are known to improve cognitive control[9], the similarities in the psychological and neural constructs are not well defined. Similar to the DMC framework, estimates of mindfulness also seem to reveal a two-dimensional construct[10–12] one being more aligned with focused-attention whereas the other being more aligned with open-monitoring. It is interesting to find that the two constructs of mindfulness observed in the mindfulness literature overlap with mechanisms of proactive[2,13] and reactive cognitive control[4] which does not contain mindfulness as one of its foundational theoretical drivers. Thus these two domains of cognition have been predominantly studied as separate fields though each is based on similar notions. While cognitive control theory has been a key focus area in the field of cognitive neuroscience and has been studied using advanced technological and mathematical methods, mindfulness though much older in its origin, has only gained popularity recently with fewer established theoretical frameworks. Furthermore, the overlap in the literature between these two fields is minimal. This review aims to highlight the overlap between these fields and identify the similarities in the theoretical underpinnings of mindfulness and cognitive control in the context of the dual mechanistic model. Aspects of cognitive control that influences mindfulness such as sustained attention[14] and the cortical associations in the brain using fMRI studies[15,16] and the sustained attention aspect of mindfulness[17,18] are explored. Similarly, the aspects of mindfulness that influence cognitive control such as training programs (mindfulness-based stress reduction program)[19,20] and intervention strategies (mindfulness-based cognitive therapy)[21,22] are reported. Specifically, the review focuses on the dual mechanistic model in the context of cognitive control and mindfulness.

Cognitive Control

While cognitive control was initially conceived as the ability to allocate cognitive resources, recent advancements focused on its participation in domain-specific processes such as attention[23], memory[24] and emotion[25]. Although cognitive control may seem unitary[26], prior research shows that it may comprise of intentional strategies as well as sub-conscious processes with interdependencies[27]. For strategy based reallocation of cognitive processes, attentional inhibition of external sensory stimulus acts as a good example[28]. Individuals who are unable to effectively perform this reallocation suffer loss in performance and leads to a decline in cognitive control[17,29,30]. Although this type of total sensory inhibition is one

form of cognitive control, selective inhibition also comes under the umbrella of cognitive control. For example, in Stroop tasks that contain conflicting stimuli of words and colors, the brain needs to selectively block a visual feature which in this case can be either the presented word or the font color of the word[31]. Furthermore, these forms of sustained task-specific allocation of resources are not the only forms of cognitive control. Another aspect of cognitive control and resource allocation is seen in task-switching paradigms such as the cued-version of the Stroop task[32]. In this case, cognitive control processes include the fast resource allocation and re-allocation in tasks with multiple instruction sets, and performance is measured as a function of both the instruction sets and the change between instruction sets. Often two cues (read the word, name the color) are used in the cued-Stroop where the correct response depends on the cue presented before the stimulus. The performance measures differ across the two cues due to varying difficulty associated with each cue. Additionally, switching between the cues during task also takes a toll on performance due to the resource re-allocation process. Given these varied forms of cognitive control, theoretical models have been developed to provide a framework of understanding, test new hypotheses, and predict outcomes. A well-accepted and widely tested framework is the dual mechanisms of control (DMC) framework, where the process of cognitive control has been broadly classified into two modes namely (i) proactive cognitive control and (2) reactive cognitive control[1].

Dual Mechanisms of Control (DMC): Proactive and Reactive

A series of experiments detailing the DMC framework gives an account of two distinct modes of cognitive control based on a temporal perspective[2,33]. These two modes are (1) Proactive control and (2) Reactive control. Whereas the proactive control is the process of resource allocation to efficiently perform a future task[34], reactive control comprises of the resource reallocation that occurs post-event to optimally respond to the event[35]. We can infer the engagement of these control modes in the case of the cued Stroop task, where the correct response to a presented stimulus depends upon a cue presented prior. Here proactive control gets engaged upon cue presentation to actively maintain goal-relevant information (cue) to bias attention, perception, and action systems until stimulus presentation. However, after stimulus presentation, reactive control gets engaged to recruit attention resources to attend to goal specific information in the stimuli and inhibit goal-irrelevant and conflicting information[36]. For example, if the presented stimulus is the word 'red' in blue font-color and the cue is 'name the color of the word', then the correct response would be blue and requires active inhibition of the prepotent response which is to read the word. This being a high interference task due to conflicting information, requires top-down goal-maintenance to remember the cue and priming of the visual attention system to attend to color (proactive control) and bottom-up conflict resolution after stimulus presentation (reactive control). Prior studies have shown that the pre-frontal cortex (PFC) plays a crucial role in the proactive control phase[37,38], whereas during reactive control the Anterior Cingulate Cortex (ACC) is engaged to resolve conflicts and reduce interference[39,40]. These findings suggest that while the proactive phase is a more top-down driven engagement of sustained attention and goal-directed cognitive

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orientation[13], the reactive phase is a more bottom-up stimulus-driven process of conflict resolution[41].

Mindfulness

While the concept of mindfulness in its classical sense has existed for centuries in the context of spiritual meditative practices, it has gained attention in the scientific community over the past three decades fueled by scientific reports and mass media coverage for its broad-spectrum benefits[42]. Its association with the practice of meditation, being more intuitive, resonates with individuals more than the cognitive control framework even though they share very similar concepts. However, cognitive control has mainstream adoption in research and clinical fields. Classical definitions of Mindfulness describe it as moment-by-moment awareness of sensations, perceptions, emotions, and thoughts[43] and is associated with better health outcomes in both mental and physical domains[44,45]. Similarly, cognitive control also deals with the goal-directed control of cognitive processes but the emphasis is on goal-directed attention - especially during a cognitive task such as memorization rather than a contemplative exercise which is the case in mindfulness. Although there exists a difference in the primary focus between cognitive control and mindfulness, the underlying cognitive processes share many similarities. The neuroscience underlying mindfulness also reveals similar process as that of cognitive control[46]. For example, the variability in Cognitive Control has been studied across states within individuals, across individuals and groups[1]. These differences have also been looked at in Mindfulness literature as state and trait mindfulness[47] where state mindfulness is the intentional and conscious practice of mindfulness whereas trait mindfulness reflects the predisposition to mindfulness daily. While these two aspects have been assessed independently, they overlap in their underlying constructs[12,48]. In practice, mindfulness training is primarily associated with a conscious change in mindfulness state which over time results in trait level changes. While these practices originated as a spiritual exercise, it has been secularized and standardized for use in clinical practice[20,49]. While state and trait mindfulness can be considered practice-related outcomes in the cognitive process, there are further differences in the way these cognitive processes are contextually engaged. Whereas in cognitive control this aspect has been formalized into the DMC framework, in Mindfulness literature such a distinction is not well studied.

Dual Mechanisms of Mindfulness (DMM)

While not explicitly conceptualized as dual-mode cognitive mechanisms, the fundamental tenets of mindfulness practice incorporate the dual mechanistic model. In mindfulness meditation, two general forms of practice are commonly employed - the first being 'focused attention' and the second being 'open monitoring'[50]. Beginners are first introduced to the focused attention aspect of mindfulness training. This is followed by activities to engage in open-monitoring which requires a stable skill level in focused attention. Whereas the first (focused attention) is a more intentional and action-oriented mode of mindfulness, the second (open monitoring) is more perception oriented mindfulness that is focused on

passive monitoring of events. Although the dual forms of mindfulness practices discussed prior are specific to state mindfulness, they also extend to trait mindfulness. For example, while initial factor analysis of the 39 item Five Facet Mindfulness Questionnaire (FFMQ)[51,52] resulted in five sub-scales, subsequent analysis has revealed the presence of a higher-order dual-factor structure of mindfulness[12,53] reminiscent of the DMC framework.

The first and predominant factor of mindfulness is loaded on the facets, acting with awareness, describing, and non-judging which focus on the aspect of mindfulness that involves focused attention and action-oriented cognitive processes[10,53]. Qualitative analysis of the FFMQ also reveals that the questions associated with these facets most appealed to non-meditators[52]. This may be the reason why focused attention based mindfulness training appeals to- and therefore is prescribed to- beginners of Mindfulness-Based Cognitive Therapy (MBCT). The second factor is loaded on the facets - observing and non-reactivity - and is more associated with perception oriented cognitive processes similar to the open-minded monitoring aspect of MBCT. The questions associated with these facets also appeal more to long-term practitioners of mindfulness[52] and is the second phase of mindfulness training programs typically prescribed to intermediate-to-advanced mindfulness practitioners. Furthermore, randomized controlled trials show that Acting with Awareness, Describing and Non-judging were most malleable to mindfulness training, whereas Observing and Non-reactivity were not[54] and further strengthen the evidence of the bi-factor model of mindfulness. The similarities between the reports on the two factors of mindfulness and the dual mechanisms of cognitive control suggest that the extensive literature on proactive and reactive control could also be applied to mindfulness. The following sections will explore the implications of these findings and explore the framework behind proactive and reactive aspects of mindfulness.

Proactive Mindfulness

Similar to the DMC framework where the term "proactive" reflects a state of anticipatory active cognitive engagement for a future event, in mindfulness, the proactive facet aligns well with the doing mode of mindfulness[55] and also with the first factor of trait mindfulness consisting of Acting with Awareness (AA), Describing (Des), Non-Judging (NJ)[10]. Whereas proactive cognitive control has been mainly studied in the context of focused attention during a task[56–58], proactive mindfulness is most discussed in the context of focused attention to general life events. For example, the FFMQ facets associated with proactive mindfulness estimate the individual's general disposition to pay attention to events, staying alert(Acting with Awareness) and being able to objectively articulate the environment (Describing, Non-Judging). These trait aspects of mindfulness are similar to proactive cognitive control processes where similar processes of focused attention, orientation and maintenance of goal directed cognitive processes leads to better performance[23,59].

Reactive Mindfulness

Similar to the DMC framework where the term "reactive" reflects the stimulus driven recruitment of cognitive resources, in mindfulness, the reactive facet aligns well with the

being mode of mindfulness[55] and also with the second factor of trait mindfulness consisting of Observing (Obs) and Non-Reactivity (NR)[10]. Whereas reactive cognitive control has been mainly studied in the context of inhibition of prepotent response to incoming external stimuli[60-62], reactive mindfulness emphasizes open monitoring. For example, the FFMQ facets associated with reactive mindfulness estimate the individual's general disposition to objectively monitor current experience (Observe) and disengage from the experience which involves a form of inhibition of the prepotent response (Non-Reactivity). These trait aspects of mindfulness are similar to the conflict resolution where the brain objectively responds by engaging resources to suppress irrelevant information[61,63,64].

Similarities and dissimilarities between the dual mechanisms within mindfulness and cognitive control

The proactive and reactive features of mindfulness aligns well with the two features that appear in most definitions of mindfulness (awareness and open monitoring) but have unique differences when compared with cognitive control. Where cognitive control is primarily discussed in the context of task related engagement of cognitive process, mindfulness is primary discussed in the context of disengagement of the self when attending to experiences. One of the definitions of mindfulness grounds attention and awareness in one's present moment experience[65-67]. It is important to note here that the proactive mindfulness (awareness, attention) discussed here focuses on a contemplative but intentional awareness to current situations. However, in cognitive control the focus is more on intentional but goal-directed prospective (future oriented) attention. Although, these two differ in their focus domains, the proactive aspects of the two are similar in that they both require intentional recruitment of cognitive process that orient awareness. The other conceptualization of mindfulness which posits the adoption of an attitude of disengaged and nonreactive monitoring[50,68] also termed "repreceiving"[69,70] is similar to the process of inhibition of a prepotent response which is a key aspect of reactive cognitive control. As observed here although the perspective and focus differs across the notions of mindfulness and cognitive control, the similarities between the proactive and reactive aspects of the two suggests that the cognitive processes engaged could have overlaps. Since cognitive control and executive function has been extensively studied, the findings from these studies could translate to mindfulness which only gained popularity in western medicine in recent years.

Cognitive control literature implications on Dual Mechanisms of Mindfulness

Compared to mindfulness, cognitive control has been studied more extensively in the past few decades using advanced methods such as quantitative behavioral assessment, electroencephalography, functional magnetic resonance imaging, and cellular level testing. The following sections provide a brief discussion of prior literature on the dual mechanisms of cognitive control and its implications on mindfulness across the different domains of assessment.

Behavioral Performance

Task-switching

Cognitive control studies typically include quantitative behavioral testing which has identified many sub-processes of higher-order control. One such process is task switching which is associated with proactive cognitive control. Although task-switching is well studied in the context of proactive cognitive control it is not commonly associated with proactive mindfulness. Since diminished task switching is associated with pathological conditions such as ADHD[71,72], sleep deprivation[73] and mTBI[74], it is possible that proactive mindfulness training could bring about targeted improvement in task-switching performance. While prior literature supports general mindfulness training as a means to improve task switching performance[75,76], it is not yet known whether the two forms of mindfulness have a differential effect on task-switching performance.

Memory

In memory encoding and retrieval, the involvement of dorsal and ventral neuronal pathways have been attributed to proactive and reactive cognitive control respectively in prior studies[77]. In mindfulness, however, such distinct neural pathways for different forms of mindfulness and consequently their impact on performance have not been systematically investigated. Since mindfulness has varying definitions[78,79] and differences in interpretation across contexts and cultures[80–83], developing a task that specifically engages the different mindfulness process would be necessary to identify their underlying neuronal substrates. In memory-related tasks such as the Working Memory task, the encoding (proactive) and retrieval (reactive) period are temporally well separated with distinct neural processes[84]. This enables precise assessment within each sub-process and has helped identify the involvement of the proactive dorsal pathway (eg: DLPFC) responsible for learning and context guided orientation and reactive ventral pathway (eg: cingulate, VLPFC) responsible for conflict detection and resolution[85–87]. Although mindfulness is known to engage components of the dorsal and ventral pathways, the relationships between proactive and reactive sub-processes are yet to be explored. Furthermore, mindfulness paradigms with temporally well separated proactive and reactive processes are not currently well established and needs to be developed to study these differences. While the dual mechanisms of mindfulness are not well studied in this context, its similarity with the dual-mode control framework suggests that different modes of mindfulness practice can differentially engage the dorsal and ventral pathways and consequently have differential performance outcomes.

Electroencephalography (EEG) and neurostimulation

Electroencephalography (EEG) is the process of acquiring electrical signatures of the brain. While it has been used extensively in cognitive control literature to demonstrate distinct neural with the two modes of cognitive control[88–92], it is increasingly being used in mindfulness literature[93,94]. Prior literature shows that there are distinct theta (3-7Hz)

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oscillatory networks for the proactive and reactive modes of control[95] and similar findings in alpha (8-12Hz) oscillatory frequency during working memory paradigms suggest distinct underlying neural substrates responsible for the two modes of cognitive control 84]. Since theta and alpha rhythms are also known to be associated with mindfulness[94], similar distinctions in neural representation between the two mechanisms of mindfulness practice may also exist and could explain the differences in outcomes associated with proactive and reactive mindfulness training[12,53]. Studies also suggest that these theta markers of proactive cognitive control can be enhanced using transcranial direct current stimulation thereby improving performance[96]. Such technological aids to improve cognitive control could also improve the effect of mindfulness training but have not been looked at in detail with current studies showing mixed results[97,98]. Interestingly, a prior study did show significant changes post tDCS treatment but only in Acting with Awareness facet of FFMQ which is a proactive facet of mindfulness[99] and aligns well with prior studies showing beneficial effects of tDCS in proactive cognitive control[96]. Further studies on the differential changes in EEG markers and tDCS outcomes across proactive and reactive mindfulness are needed to reveal the neural substrates of these two mindfulness mechanisms.

Functional Magnetic Resonance Imaging (fMRI)

While EEG findings do not provide high spatial information, fMRI provides greater resolution to spatially localize the neuronal substrates of distinct cognitive processes. In cognitive control tasks, the frontal cortex has been consistently shown to activate during task performance[100–103]. However, even within the frontal cortex, there are network-level differences in cortical activation during engagement of proactive and reactive modes of control[104–108]. Prior fMRI studies have also shown prefrontal involvement during mindfulness and are in line with fMRI studies of cognitive control, however, the distinctions between the proactive and reactive modes are yet to be explored[109]. A prior study did show different cortical associations across mindfulness facets such that - 'Acting with awareness' (proactive FFMQ facet) was associated with dorsomedial prefrontal cortex (DMPFC) activity during relaxation imagery, whereas 'observing' (reactive FFMQ facet) was associated with DMPFC and left amygdala activity during emotional imagery[110] - this finding although preliminary is in line with the dual mechanisms of mindfulness framework and suggests that the proactive and reactive mindfulness modes may be modulated by distinct neuronal substrates.

Heart Rate Variability (HRV)

Heart rate variability is associated with better overall health and also cognitive performance[111,112]. Although the variability in heart rate and its association with cognitive control in the context of the dual mechanistic framework has not been extensively studied, preliminary evidence suggests that proactive and reactive control may have differential effects on HRV[113] and while yet unexplored dual mechanisms of mindfulness could also have similar associations with HRV. Preliminary evidence does support this notion by showing how different forms of mindfulness such as open monitoring and engagement in

externally facing or community-centric activities (dialogue with other mindfulness practitioners, reading books, and writing mindfulness journals) have a differential effect on HRV[78]. A prior study showed that while stress-task induced changes in HRV were unrelated to cortisol increase, HRV changes due to anticipatory cognitive processes to a future stressful event seem to be related to cortisol changes[113]. Since cortisol levels reflect top-down regulatory mechanisms and pre-frontal cortex engagement[111,114] which are involved in proactive control, it suggests that proactive control may modulate HRV through changes in cortisol levels. This is in line with other studies showing components of proactive control such as top-down inhibition and task-switching being associated with increases in HRV[115,116].

Neuro transmitter association

Neurotransmitters are the chemical substrates underlying the operations of many cognitive processes and while specific functions have been associated with neurotransmitter systems, most behavioral actions require the involvement of multiple neurotransmitter systems. In mindfulness literature, although studies suggest a decrease in cortisol[117] and increases in dopamine, norepinephrine, and epinephrine[118–120] associations between proactive and reactive forms of mindfulness practice with specific neurotransmitter systems are not well studied. In contrast, distinct neurotransmitter systems (dopamine, acetylcholine, serotonin, etc.,) have been associated with proactive and reactive control[77]. Specifically, proactive control is linked to noradrenalin-driven locus coeruleus[121,122] and mediodorsal corticolimbic pathway which is involved in top-down goal-maintenance and context-aware priming which improves performance[90,123–126]. Furthermore, serotonin has also been suggested to be involved in proactive behavior[127,128]. In contrast, reactive control has been suggested to be mediated by acetylcholine during transient increases in vigilance to novel stimuli[129] and uncertainty of stimuli[130] where the optimal response is a function of stimulus-related features[131]. Given similar associations between neurotransmitters involved with cognitive control and mindfulness, distinctions between neurotransmitters between proactive and reactive cognitive control could translate to proactive and reactive mindfulness which could enable the development of neuro-biologically targeted mindfulness training programs.

Trait differences in dual mode mindfulness

Disposition to daily mindfulness has been shown to differ across individuals and has been validated as a trait level characteristic[47]. Although such trait measures of mindfulness (FFMQ) have been associated with specific neural processes[94], the differential neural engagement between proactive and reactive mindfulness facets is not well studied. While not extensively explored in the context of mindfulness, the notion of differential engagement across proactive and reactive cognitive control has been linked to individual personality traits[132–135] influenced by environments[136], neurotransmitters[137,138] and even genetics[1,139–141]. For example, individuals with high reward sensitivity personality traits performed better in tasks with monetary rewards which provides evidence to higher levels

of context-related proactive goal maintenance[133]. Such findings suggest that personality traits influence preference towards specific forms of cognitive control processes for an individual, and such influence may also extend to mindfulness[142]. These trait level differences may influence individuals to find certain forms of mindfulness training programs easier and would lead to higher program adherence. Conversely, it may be more difficult for certain individuals to adhere to certain mindfulness programs or certain phases of mindfulness programs (eg: Being phase and Doing phase of mindfulness as seen in MBCT). For example, individuals scoring high in dispositional proactive mindfulness might find it easier to undergo proactive mindfulness training. However, improvement in clinical outcomes might be marginal due to their already high proactive tendency (ceiling effect). Preliminary evidence towards this notion can be observed in studies that compare meditative experience between meditators and non-meditators[52]. Therefore for individuals with higher proactive tendencies with no prior mindfulness training, introducing them to the proactive phase first followed by the reactive phase may improve adherence and overall health outcomes.

Dual modes in personality theory

While personality theory is an extensive field of study on its own, personality traits have been shown to be associated with cognitive control[143–145] and consequently could also be associated with mindfulness. The two major personality theories are (i) Eysenck's "three-factor model" which suggested that personality is reducible to three traits namely "neuroticism, extraversion, and psychoticism"[146,147] and (ii) Big Five personality traits which suggest that personality is reducible to five factors namely "neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness"[148–153]. A qualitative look at the two theories suggests two common underlying factors: extraversion and neuroticism[154]. Furthermore, studies show that factor analysis of the Big Five model across multiple studies in adolescents and adults revealed the presence of two meta-traits: one being related to Extraversion and Intellect; while the other was related to Agreeableness, Conscientiousness, and Emotional Stability[155]. The dichotomy observed here is similar to the focused attention (proactive) and open monitoring (passive) facets of mindfulness. While the majority of mindfulness practices agree with a dualistic approach, some ideas of non-dual forms of mindfulness have been proposed[156]. The bi-factor models of personality are not specific to just the Big Five model, but also other assessments of personality[157,157] and have been assessed with serotonergic and dopaminergic systems (similar to studies in cognitive control)[158–160]. These findings further extend the notion of the dual mindfulness framework and suggest translatable findings from other fields such as cognitive control and personality theory.

Therapeutic implications of DMM

Mindfulness as a therapy has been shown to have broad-spectrum health benefits and is not restricted to the mental health domain[161–163]. While most Mindfulness-based training programs are prescribed primarily for general anxiety and management of other mental

health issues such as stress[164,165], it has also been shown to improve hormonal balance[166] and improve physical functioning[167]. While the underlying constructs of mindfulness seem to follow some general trends as discussed in this review, there are many variations in the types of practices as seen in the mindfulness literature[78,168,169] as well as in clinical practice[19,49] with no standardized studies on differences in effects across the different approaches. Additionally, there is no standardized way to prescribing different kinds of mindfulness programs based on symptom profile nor are the mechanistic models underlying the different mindfulness programs well studied. While literature from the cognitive control studies can provide limited insight into the mechanisms of specific forms of mindfulness training it is not conclusive. Direct associations between proactive and reactive mindfulness and health outcomes are needed to provide concrete evidence towards the development of guidelines for prescribing different phases of mindfulness programs based on symptom profiles or individual trait differences. Mindfulness programs such as the MBCT already categorize different modes of mindfulness practice into doing (proactive) and being (reactive) modes[55]. While this dichotomization aligns well with the dual-mode mindfulness framework, there are no standardized methods for prescribing specific phases of MBCT based on symptom profile or trait level factors. Future randomized controlled trials to test health outcomes by employing proactive and reactive mindfulness training methods could enable the development of targeted mindfulness therapies instead of a blanket program for mental health issues.

Current Trends

There is an increasing necessity for remote mental health interventions due to increasing ease of access and reduced cost made possible through technological advancements in telecommunication. Many mobile applications have emerged which validate mindfulness training efficacy even if delivered remotely[170,171] and automated without human-to-human interaction[172,173]. A prior study showed that Apple and Google Android ecosystems have about 700 mindfulness apps and covered many types of guided meditation practices[171]. Furthermore, these apps include other features such as community support and social networking to boost engagement in mindfulness practice. The study also found that while many applications were of sufficient quality the median quality metric was low for engagement and identified target areas for improvement. Despite a large number of mindfulness applications on the market, there are only a few randomized controlled trials examining the efficacy of such apps[174]. Most of the apps focus on general mindfulness practices rather than the individual differences across its user base to generate individualized training programs and could be a target area for improvement. In the context of the dual modes of mindfulness and potential differences in health outcomes/adherence, apps could have a brief personality trait assessment that can provide information on which training program would be best suited for the individual. These methods while novel needs to be validated for efficacy in comparison to a standard and more general mindfulness program.

Future Prospects

Current mindfulness training literature has documented a large variety of mindfulness practices with varying efficacies[19,49,78,168,169]. While this variability could lead to a lack of consistency in observed outcomes, it could also be used to prescribe personalized training programs that account for individual differences and aims to maximize outcomes. To this effect studies that show the mechanistic underpinnings of different mindfulness programs would help develop a protocol for identifying programs that best benefit an individual. As discussed in this review, the dual mechanistic model of mindfulness could act as one such model which is already a common underlying theme existing across diverse forms of mindfulness. While evidence suggesting differential health outcomes based on individual differences in specific mindfulness facets (FFMQ) is preliminary, it supports the notion that mindfulness programs can be modified to suit the needs of the individual. Literature in cognitive control has shown that proactive and reactive cognitive processes are largely affected by individual traits[132-135] which adds to the notion that mindfulness programs that account for individual differences could boost overall effect of the program. On-site evaluation can characterize individuals using neurobehavioral[133] and neurobiological testing[1,139] to identify cognitive domains that need to be targetted for improvement which could then be used to prescribe either the doing (proactive) or being (reactive) phase of mindfulness programs.

While this notion is in line with existing literature in both mindfulness and cognitive control domains, studies showing direct evidence of differential effects of mindfulness programs on health outcomes are needed and will inform the development of evidence-based guidelines. For example, future studies could use assessments that evaluate working memory to categorize individuals with better encoding/retention capabilities (proactive) vs those with better retrieval capabilities and then quantify the effects of proactive and reactive mindfulness practices across groups for adherence and improvement in health outcomes[175]. Similarly, using personality assessments as used in prior studies to estimate reward sensitivity of individuals and then testing the effects of proactive and reactive mindfulness practice on high reward sensitive individuals (proactive) vs low reward sensitive individuals (reactive)[133] would provide practical solutions to developing individualized mindfulness program.

Summary

While cognitive control is essential to efficient behavioral functioning, mindfulness practices improve cognitive control processes which in turn improve health outcomes. This review explores the similarities between dual-mode mechanisms of cognitive control and the dual mechanisms of mindfulness. The proactive and reactive modes of cognitive control are well studied and have differential associations with health outcomes. Its similarity with the dual mechanisms of mindfulness suggests that such associations would also translate to the mindfulness domain. While preliminary evidence supports a dual-mechanistic mindfulness model, its association with health outcomes is not well explored. In this

context, future studies exploring the relationship between these two modes of mindfulness and how they affect health outcomes would enable the development of targetted mindfulness programs flexible enough to incorporate individual differences to maximize health outcomes.

Disclaimer

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