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From Simple Mechanics to Complex Dynamics: A Dynamical Systems Science of Mindfulness and Meditation

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Mindfulness meditation is a robust and rapidly growing area of inquiry in the psychological sciences. However, core questions remain about how mindfulness develops, how it exerts its effects, and what conditions amplify or attenuate these effects. We argue that empirical research on mindfulness has predominantly relied on reductionist decomposition—a foundational scientific approach that isolates and analyzes discrete components and mechanisms of a system, its mechanics. While valuable, this approach is poorly suited to capturing how change and development emerge from continuous, nonlinear, and recursive interactions unfolding across multiple timescales—its dynamics. To address this gap, we propose that dynamical systems (DS) theory and methods provide a powerful framework for advancing the science of mindfulness and meditation. We introduce a DS organizational framework for mindfulness and meditation science structured around three multifaceted dimensions: complex interaction dynamics, nonlinear causality, and multiscale temporal dynamics. We illustrate how this framework can inform theory building, empirical research, and intervention science in mindfulness and meditation. In turn, we examine how leading psychological and neuroscientific theories of mindfulness and meditation align with DS theory, in contrast to much of the empirical research, which remains rooted in reductionist component-based approaches. Finally, we outline actionable future directions, including the development of formal DS theory and computational models, study designs that collect high-dimensional multiscale data, as well as data analytic tools capable of modeling complex dynamical change.

Public Significance Statement
Mindfulness meditation is a widely practiced approach to enhance well-being, but many questions remain about how and for whom it works best. We propose that dynamical systems theory—a framework for understanding complex, changing processes—can help scientists better capture how mindfulness develops and produces its effects. This approach may improve how mindfulness-based programs are designed, personalized, and implemented by practitioners, clinicians, and policymakers.

Keywords: complex interaction dynamics, dynamical systems, mindfulness meditation, multiscale temporal dynamics, nonlinear causality

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continued



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Mindfulness meditation is an exponentially growing focus of the psychological sciences (Baminiwatta & Solangaarachchi, 2021; Bernstein, Vago, & Barnhofer, 2019). The term *mindfulness* refers to a family of mental states and forms of mental training such as meditation, characterized by present-moment attention and awareness and a particular set of attitudes toward experience such as nonjudging, acceptance, and curiosity (Anālayo, 2019; Dunne, 2015; Gethin, 2011; Nilsson & Kazemi, 2016). Research to date has documented the salutary effects of mindfulness on well-being, mental health, and prosociality (Donald et al., 2019; Goldberg et al., 2022; Guendelman et al., 2017; Hadash et al., in press). Research has also documented limited or null effects on these outcomes (Berry et al., 2020; Goldberg et al., 2017; Kuyken et al., 2022; Whitfield et al., 2022) and even some evidence of adverse effects (Britton, 2019; Britton et al., 2021; Van Dam et al., 2025). However, fundamental questions remain about the dynamics of its development, mechanisms of action, and conditions that contribute to its effects. For example, how do altered mindful traits emerge, over time, from repeated mindful states during meditation training? Or when and how salutary or adverse outcomes emerge from mindfulness training, and what conditions may amplify or mitigate these effects?

To help answer these types of fundamental questions, we propose that mindfulness and meditation may be re-conceptualized and studied through dynamical systems (DS) theory. We also propose that DS theory may guide the design and application of methodological approaches critical to answering fundamental questions in mindfulness and meditation science. Moreover, we speculate that advancing our understanding of mindfulness and meditation through DS theory and methods could also help guide the optimization and personalization of meditation training.

But why DS theory and methods specifically? As with any nascent scientific field studying complex, dynamical phenomena, foundational stages often emphasize reductionist *decomposition*—the identification, classification, and investigation of constituent parts (Kelso, 1995; Lewis, 2005; Prigogine & Stengers, 2018). Even in the study of inherently complex systems, such as ecological networks, early research frequently centers on analyzing interrelations among collections of discrete components (e.g., individual species within their environments). However, as scientific fields mature, they often progress toward studying the dynamic interdependence, reciprocal causality, and emergent properties of these components. Indeed, scholars across disciplines have observed that scientific progress often involves a transition from early-stage reductionism—the decomposition and classification of system parts—to later-stage scientific development focused on dynamical complexity, or the recomposition of those parts into an integrated, interacting whole (Mitchell, 2009; Prigogine & Stengers, 2018; Simon, 1969).

We argue that the science of mindfulness and meditation has reached such a point of maturity. Indeed, over the past 2 decades, substantial progress has been made in identifying, classifying, and characterizing the modular components and mechanisms associated with mindfulness and meditation (Baminiwatta & Solangaarachchi, 2021; Bernstein, Vago, & Barnhofer, 2019; Goldberg & Davidson, 2024). This foundational work provides a necessary basis for the field to now embrace methods that examine how these components interact over time, across nested timescales, and within dynamic contexts. Accordingly, we propose that DS theory and methods offer a timely and generative framework for advancing the science of mindfulness and meditation, enabling the field to move beyond the isolated examination of components toward understanding how mindfulness and meditation unfold dynamically within individuals, over time, and across contexts. In other words, DS can help advance mindfulness and meditation science from simple modular albeit foundational mechanics to more complex interdependent dynamics.

Importantly, the reductionist paradigm of decomposition was and remains critical to establishing the foundational science of mindfulness and meditation. Moreover, it remains

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vital to the ongoing study of mindfulness and meditation, particularly in efforts to identify, classify, or characterize modular components of the phenomena of mindfulness and meditation. Indeed, prior to modeling complex and dynamical interrelations between system parts, we must first have a strong taxonomy of those modular parts, their properties, and functions (Bechtel & Richardson, 2010).

Article Overview

Accordingly, our aim in this article was to illustrate DS concepts and methods that we believe may help build on, complement, and advance the foundational science of mindfulness and meditation. We do so by illustrating these concepts and methods through a range of exemplar applications and implications and in turn invite scholars and scientists to apply these concepts and methods to their own mindfulness and meditation research.

Specifically, we first offer an organizing framework of DS features to help guide the application of DS theory and methods to mindfulness and meditation research (see Figure 1). We then use exemplars central to mindfulness and meditation science to both explain the key DS features so that scholars and scientists can apply them and illustrate how DS features might help scholars reconceptualize key questions and hypotheses about mindfulness and meditation. Second, to illustrate how some scholars already conceptualize these phenomena in ways aligned with DS theory, we review DS features in existing contemporary psychological and neuroscientific theories of mindfulness and meditation. Third, in contrast to contemporary mindfulness and meditation theory, we briefly outline the reductionist paradigm of decomposition that has characterized extant foundational mindfulness and meditation empirical research. Finally, we propose three broad, actionable future directions to advance mindfulness and meditation science through DS theory and methods. These include formalized DS theory and computational modeling, DS-aligned research designs and methods, and data analytic approaches to quantify dynamical complexity.

DS: A Framework for Mindfulness and Meditation Science

There are growing efforts to apply DS to a variety of phenomena in the psychological sciences (Fogel, 2011; Fried & Cramer, 2017; Kelso, 1995; Lewis, 2005; Nelson et al., 2017; Scheffer et al., 2024; Spencer et al., 2011; van Geert, 2011) and several good introductions to the DS approach for the study of brain and behavior (Beer, 2000; Kelso, 1995; Lewis, 2005; Thelen & Smith, 2006). Drawing on this literature, we highlight three interrelated domains of DS features that we propose could advance mindfulness and meditation theory and research. See Figure 1 for a visual overview of the framework.

Complex Interaction Dynamics

Interaction-Dominant Dynamics

DS entail interaction-dominant dynamics rather than component-dominant dynamics. In component-dominant dynamics, outcomes are the result of independent components contributing in an additive way, with each component acting separately. Likewise, system components interact but maintain their independence—they influence each other without fundamentally changing the structure or function of one another. In other words, in component-dominant systems, each component retains its distinct, stable structural or functional properties across interactions.[1] By contrast, in interaction-dominant dynamics, outcomes emerge from the continuous, reciprocal interactions between system components (Sameroff, 2009; Van Orden et al., 2003). Importantly, in DS the structure and function of system components may change as a result of their ongoing interactions. As a result, in phenomena characterized by interaction-dominant dynamics, it is very challenging and sometimes not possible to meaningfully disentangle the separate contribution of individual system components (see Figure 2A; Den Hartigh et al., 2017; Van Orden et al., 2003).

Exemplar: Mindfulness Mechanisms of Action. In a system characterized by component-dominant dynamics, a theorized mechanism of action such as decentering,

[1] Structure refers to the configuration or properties of a system component—such as its form, organization, or its stable traits (e.g., architecture of a neural circuit or cognitive process such as working memory). Function refers to how a component behaves or operates within the system—what it does, its role, or its contribution to the system's output (e.g., computations performed by a neural circuit or the role of working memory in shaping conscious experience).



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acceptance, or emotional tranquility might partially mediate the effects of mindfulness training on well-being. This is how the large majority of extant mindfulness and meditation science has studied mechanisms of action (e.g., Alsubaie et al., 2017; Gu et al., 2015; Hölzel et al., 2011; van der Velden et al., 2015). By contrast, in a system characterized by interaction-dominant dynamics, no single system component has causal priority, such that the system's behavior results from the multicausal interactions between its components. Indeed, each system component—mindfulness training, its putative mechanisms (e.g., acceptance), and its salutary outcomes (e.g., mental health)—affects the others reciprocally, and each component affects its own value in the system's next state in time. For instance, the development of decentering during mindfulness training may be characterized by interaction-dominant dynamics, in which three metacognitive processes—meta-awareness, disidentification from internal experience, and reduced reactivity to thought content—continuously and reciprocally reinforce one another and themselves (Bernstein et al., 2015). Moreover, the structure and function of these metacognitive processes may change over repeated interactions, such as when meta-awareness becomes sustained and nonpropositional, and reduced reactivity to thought content is transformed into dereification of thought content (Dunne et al., 2019).

Utility and Implications. From a DS perspective, a component-dominant dynamics approach to even fundamental mechanisms—phenomenological (e.g., tranquility), neural (e.g., altered functional connectivity), cognitive (e.g., internal attentional control), or behavioral (e.g., avoidance behavior)—may only partially explain the effects of mindfulness meditation on salutary outcomes. Instead, from a DS perspective, interaction-dominant dynamics might help us reconceptualize and thereby study mindfulness mechanisms as dynamic, reciprocal, and recursive interrelations between factors and outcomes in time. This approach may be critical to improve our understanding of mindfulness mechanisms and developing approaches to more effectively target and engage salutary mechanisms of action (e.g., by enhancing or mitigating system interactions that amplify salutary effects).

Emergence

Emergence in DS refers to the phenomenon wherein complex patterns, behaviors, or system properties arise from the *interactions* of system components. In other words, interaction-dominant dynamics generate emergence. As a result, emergent properties of DS cannot be readily predicted or explained solely by understanding the system's individual components. Likewise, emergent phenomena in DS are more than the additive sum of their parts (see Figure 2B).

Exemplar: Mindful Awareness as an Emergent Phenomenon. One way to conceptualize mindful states is as emerging from the interaction between a set of active neurocognitive processes. For example, Kabat-Zinn (2013), one of the founders of the field of mindfulness science, conceptualized mindfulness as an awareness that emerges through paying attention to unfolding experience on purpose, in the present moment, and nonjudgmentally. Accordingly, from a DS perspective, mindful states may emerge from the interaction between maintenance of a cognitive set in procedural working memory to attend to present-moment experience with acceptance and curiosity, sustained internal attentional selection of present-moment experience, monitoring for distractions, and repeated attentional disengagement from mind wandering (Hadash et al., in press).

Utility and Implications. More broadly, DS emergence may help scholars and scientists to reconceptualize mental states that we seek to understand, such as mindful awareness or related meditation states (e.g., nondual states, equanimity; Desbordes et al., 2015). Indeed, these states may be best conceptualized, and later studied empirically, through the interaction of system components that subserve them. Accordingly, DS emergence may help inform ongoing efforts to define and measure mindfulness, and closely related phenomena (e.g., compassion, insight), by characterizing the interaction-dominant dynamics of possible system components that may give rise to these states and qualities of mind.

Self-Organization

DS also exhibit distributed control, wherein no single component, guiding entity, or executive controller (i.e., homunculus) dictates or controls the systems' behavior. Instead, ordered patterns of system behavior spontaneously emerge from the complex interaction of system components. This feature of DS has important utility for system functioning, maintenance, and development. For example, systemic self-organization facilitates learning and adaptation to changing



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internal and external conditions. DS self-organization ensures a capacity to recursively attune itself, again and again, through interaction of its components, despite and in response to changing contextual demands. Accordingly, DS self-organization enables system flexibility, responsiveness, and resilience (see Figure 2C). Critically, this same feature of self-organization can also contribute to maladaptation under certain conditions. Depending on the patterns of interaction among system components and the contextual constraints acting on the system, dysfunctional or maladaptive patterns can become stabilized, resulting in persistent states that are resistant to change. Thus, while self-organization underlies system flexibility and resilience, it can also give rise to stable yet maladaptive states that perpetuate suffering or dysfunction.

Exemplar: Sustained Mindful Awareness Despite Difficulties. DS self-organization may help us reconceptualize how, in early mindfulness practice, mindful states are often unstable and frequently disturbed by states of mind wandering without meta-awareness or by cognitive and emotional reactivity to distressing experience (Malinowski, 2013). From a DS perspective, in early stages of mindfulness practice, the interactions between cognitive processes that enable the emergence and maintenance of mindful states may lack flexibility, responsiveness, and resilience. Accordingly, an episode of mind wandering may perpetuate without being detected because monitoring for distractions is not sufficiently reinforced, amplified, and maintained by other system components (Chu et al., 2023). Likewise, distressing experience may evoke judgmental thoughts and reactions that amplify distress because acceptance is not triggered by other system components in this context (S. C. Hayes et al., 1996). However, repeated mindfulness training may forge mutually reinforcing interactions among the cognitive processes that enable the system's capacity to sustain and reengage in mindful states. From a DS self-organization perspective, these capacities may contribute to greater flexibility, responsiveness, and resilience to perturbations such as mind wandering and distress. For example, attentional selection of interoceptive sensations, monitoring for distractions, and internally generated attitudes of acceptance may become mutually amplifying processes, facilitating a capacity to sustain and reengage in mindful states and thereby a more flexible and resilient responses to difficulties during meditation (Hadash et al., in press). More specifically, this self-organizing amplification process may lead to sustained acceptance and monitoring for distractions that persist during difficulties and thereby may reduce the proliferation of negative thoughts and negative reactivity to distress (Farb et al., 2015).

Utility and Implications. DS self-organization may help us reconceptualize the salutary developmental trajectories of mindfulness meditation. Consequently, efforts to therapeutically impact these developmental trajectories may need to target interactions among system components to foster more flexible and resilient forms of self-organization. Moreover, considering mindfulness meditation through the lens of DS self-organization may help generate novel research questions, such as how states like tranquility, equanimity, and insight can be understood as expressions of a system's capacity for adaptive self-organization. In turn, we may also explore how contemplative training might impact the flexibility, responsiveness, and resilience of these dynamic system states.

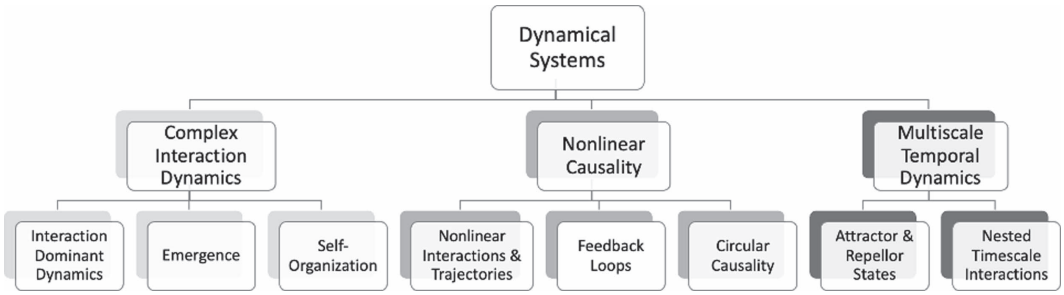
Critically, this same feature of self-organization might also help us with the rigidity and maladaptation within the developmental trajectories of mindfulness meditation. For example, depending on the patterns of interaction among cognitive, emotional, and somatic processes, and the contextual conditions in which meditation practice unfolds, maladaptive or rigid patterns of self-organization may stabilize, for example, persistent patterns of aversive reactivity, subtle striving, or dissociation during meditation. These patterns can become resistant to change, limiting the cultivation of flexibility, responsiveness, and resilience that mindfulness training aims to support. Thus, while self-organization underlies the adaptive development of mindfulness, it can also give rise to stable yet maladaptive trajectories that perpetuate distress or limit flourishing, underscoring the importance of understanding how contemplative training may disrupt these patterns to foster more adaptive forms of systemic self-organization.

Nonlinear Causality

Nonlinear Interactions and Trajectories

In DS, nonlinear and multidirectional interactions between system components lead to nonlinear trajectories of change over time. For example, in nonlinear systems, effects may follow exponential patterns, be sensitive to threshold effects, or be amplified or dampened by interactions with other system components. Likewise, nonlinear developmental trajectories

Figure 1
Dynamical Systems Theory Framework for Mindfulness and Meditation Science



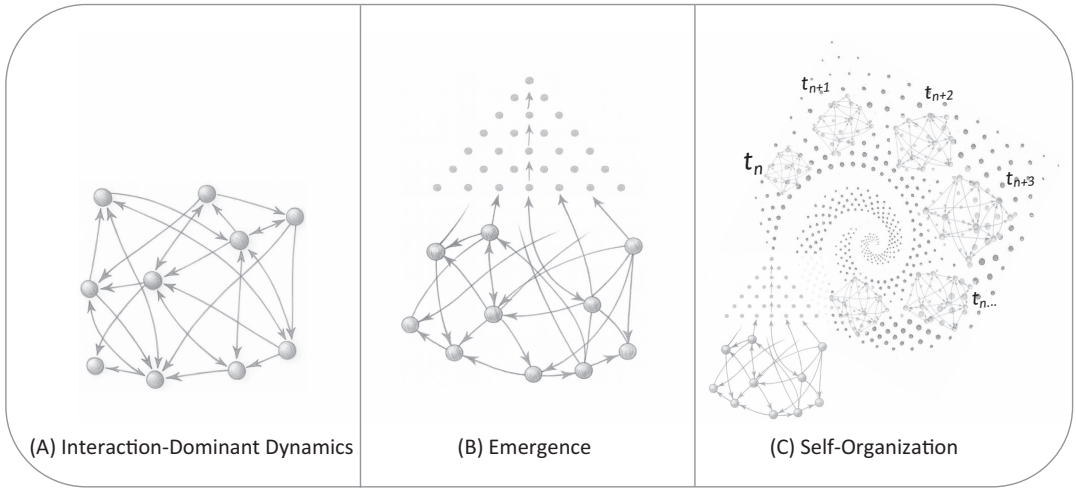
Complex Interaction Dynamics: Patterns of system behavior that arise from continuous, reciprocal interactions among components, producing emergent properties and self-organized order without central control. **a. Interaction-Dominant Dynamics:** System behavior emerges from continuous, reciprocal interactions among components, such that components influence and may transform each other, making it difficult to isolate their individual contributions. **b. Emergence:** Complex patterns or properties arise from interactions among system components and cannot be predicted or explained solely by examining the components in isolation. **c. Self-Organization:** The spontaneous emergence of ordered patterns in system behavior from local interactions among components, enabling flexibility and adaptation without a central controller, but which can also stabilize maladaptive patterns.	**Nonlinear Causality:** System change driven by multidirectional, recursive interactions that produce nonlinear trajectories, with feedback loops and circular causality shaping stability, transitions, and emergent patterns. **a. Nonlinear Interactions and Trajectories:** Multidirectional interactions among system components produce nonlinear change over time, with periods of stability punctuated by sudden transitions into new stable states. **b. Feedback Loops:** Reciprocal, recursive interactions in which system outputs influence future states, with positive loops accelerating change and negative loops decelerating change stabilizing the system, together shaping dynamic patterns and self-organization. **c. Circular Causality:** Bidirectional influences between fast-changing lower-level components and slower-changing higher-level structures, where each shapes and constrains the other through upward and downward causation.	**Multiscale Temporal Dynamics:** The unfolding of system behavior across time, where patterns of stability and change in attractor landscapes interact across fast (micro) and slow (macro) timescales to shape development. **b. State Space: Attractors and Repellers:** A representation of all possible system states, where attractors are stable states the system returns to, and repellers are unstable states the system moves away from, shaping system trajectories over time. **b. Nested Timescale Interactions:** Dynamic processes where short-term (micro-timescale) interactions shape long-term (macro-timescale) patterns, which in turn constrain and guide moment-to-moment system dynamics.

often entail periods of relative system stability between periods of change and are often characterized by sudden shifts between the stable states of the system. These sudden shifts, termed *phase transitions*, are often characterized by increased variability or fluctuations over time when the system becomes unstable. As the system self-organizes from this variability, a new stable state emerges. In this manner, development in DS is often characterized by temporarily stable states and abrupt transitions between these states, as opposed to linear trajectories of change (see Figure 3A).

Exemplar: Adaptive and Maladaptive Trajectories of Meditation. Various interacting components that subserve mindful states may change and develop slowly over time (Galante et al., 2023; Goleman & Davidson, 2017; Kiken et al., 2015). However, with repeated and sustained practice, sudden unusual or peak experiences may suddenly emerge (Hadash et al., 2024; Lindahl et al., 2017; Timmermann et al., 2023) as a result of the interaction between system components that evoke phase transitions to novel stable states. For example, interactions between system components during sustained

Figure 2

Complex Interaction Dynamics: Interaction-Dominant Dynamics, Emergence, and Self-Organization



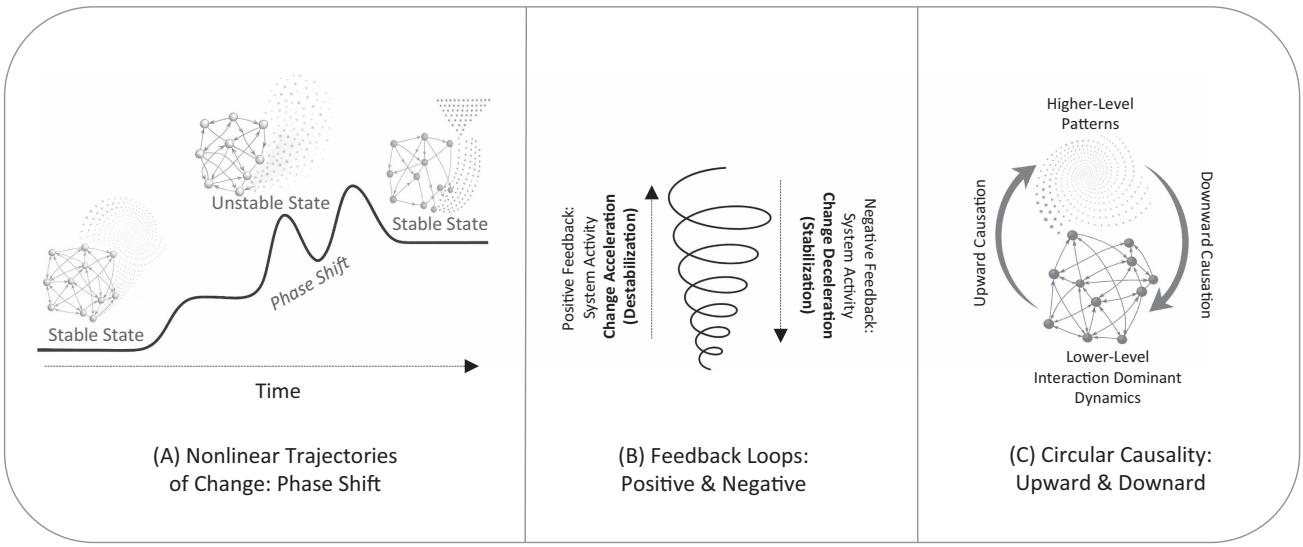
Note. Panel A illustrates interaction-dominant dynamics, where system behavior arises from continuous, reciprocal interactions among components rather than additive, independent contributions. Panel B depicts emergence, showing how higher order patterns and properties arise from these interactions and cannot be predicted well by analyzing components in isolation. Panel C illustrates self-organization, where emergent ordered patterns of system behavior spontaneously form from repeated local interaction-dominant dynamics in time, without centralized control, thereby enabling flexibility and resilience in the system as well as the potential for maladaptive patterns in the system.

mindfulness practice may lead a person to become disidentified from their internal experience (Bernstein et al., 2015). As a function of various internal or contextual conditions (e.g., metacognitive beliefs, cognitive appraisal, support from a teacher), that experience may lead to either a new adaptive mental state such as a decentered state of mind or to a maladaptive mental state characterized by dissociation and experiential avoidance (Britton, 2019; Hadash et al., 2023).

Utility and Implications. Initial research has documented nonlinear change trajectories of mindfulness-related

Figure 3

Nonlinear Causality: Nonlinear Interactions and Trajectories, Feedback Loops, and Circular Causality



Note. Panel A illustrates nonlinear interactions and trajectories, where interaction-dominant dynamics underpin multidirectional interactions that produce nonlinear patterns of change, including periods of state stability punctuated by sudden phase shift and state instability. Panel A also illustrates that such nonlinear change results from the perturbation of the interaction dynamics and respective emergent self-organization of an initial stable state into a new stable state characterized by a new pattern of interaction dynamics and respective emergent self-organization. Panel B depicts feedback loops, highlighting how positive loops can accelerate system change or destabilize a system, while negative loops decelerate system change or stabilize a system. Panel C shows circular causality, where lower level interaction-dominant dynamics and higher level emergent system patterns influence each other through upward and downward causation.

change processes (Abdoun et al., 2025; Britton et al., 2014; Shoham et al., 2017; Y.-Y. Tang et al., 2015). DS nonlinearity may help us reconceptualize and study these nonlinear developmental trajectories and the factors that may lead to adaptive and maladaptive outcomes of mindfulness meditation. For example, research could aim to characterize the interaction dynamics of practice type, dose, and timing that may be associated with phase transitions in mindfulness-related change processes (e.g., Abdoun et al., 2025). Relatedly, by better characterizing phase transitions, we may be better able to predict the likelihood of adaptive and maladaptive mental states from meditation practice. Such insights may help guide microinterventions to shape phase transition toward more adaptive trajectories. For example, we may be able to identify the conditions and timing that may facilitate positive change, make individuals more responsive to intervention, and facilitate the development of just-in-time adaptive meditation-based interventions (Butner et al., 2021; Collins et al., 2024; Schiepek et al., 2019).

Feedback Loops

Nonlinear relationships are often reciprocal, recursive, and multidirectional, meaning that system components influence each other through dynamic feedback loops. DS have two types of feedback loops—positive and negative feedback loops. In positive feedback loops, the system's output is fed back into the system in a way that amplifies change in the system. Positive feedback loops increase the system's activity by accelerating change, leading to a cycle of growing intensity, also called an upward spiral. Thus, even small changes in one part of the system may be amplified, causing large effects on the system's later states. This property of DS is referred to as sensitive dependence on initial conditions or the "butterfly effect." In negative feedback loops, the system's output is fed back into the system but in a way that mitigates further system change. Negative feedback loops thereby function to stabilize the system by counteracting or slowing down change. Thus, whereas positive feedback loops promote system change, negative feedback loops help stabilize the system through ongoing fluctuations. By balancing these opposing forces and establishing stable yet flexible patterns and structures, feedback loops are a key mechanism through which order or self-organization emerges in DS (see Figure 3B).

Exemplar: Salutary Mechanisms of Mindfulness Training. The coordinated forces of positive and negative feedback loops offer a novel approach to conceptualize and study various salutary or therapeutic mechanisms of mindfulness training. For example, distress (e.g., anxiety, pain) may be amplified through forms of emotional and cognitive reactivity such as negative repetitive thoughts ("I shouldn't be feeling this way"). These forms of reactivity contribute to a positive feedback loop that can intensify distress. By contrast, among experienced meditators, distress may cue states of meta-awareness and acceptance, which may function to reduce distress and emotional and cognitive reactivity (Lindsay & Creswell, 2017). Meta-awareness and acceptance of distress may thereby activate a negative feedback loop that mitigates the upward spirals in distress caused by the positive feedback loop of emotional and cognitive reactivity and thereby functions to stabilize the system.

Utility and Implications. DS feedback loops may be important to identify forces that shape nonlinear change as well as stabilization of mindful states and the salutary effects that might emerge from meditation (e.g., reduced distress, equanimity). Accordingly, efforts to characterize positive and negative feedback loops may become a promising focus of research on mindfulness and meditation. Moreover, DS feedback loops may also become promising potential targets of personalized or adaptive meditation-based intervention approaches to manage barriers and optimize growth and progress (Collins et al., 2024), for example, to help potentiate desired developmental outcomes of meditation or guard against the emergence of unwanted or adverse experiences of meditation.

Circular Causality

Similar to feedback loops, DS are also characterized by circular causality, wherein lower and higher levels of the system influence each other in a continuous loop. Unlike linear cause-and-effect relationships, circular causality involves self-regulating interactions between lower level components and higher level patterns of the DS. Lower level components are the fast-acting elements of a system (e.g., afferent interoceptive sensations, attentional shifts; returns to its attractor Berntson & Khalsa, 2021; Hadash et al., in press). By contrast, higher level structures are the slower changing patterns of the system (e.g., biases of interoceptive awareness, patterns of large-scale functional brain network coactivation; Giommi et al., 2023; Khalsa et al., 2018). Circular causality is the bidirectional relationship between these two levels of the DS through upward and downward causation. Upward causation occurs when lower level components of the system interact to give rise to higher level patterns. Downward causation occurs when higher level patterns influences how the lower level components work together by constraining or amplifying their interactions (see Figure 3C).

Exemplar: Mindfulness Change Mechanisms. The interaction between moment-to-moment interoceptive sensations (pain sensations), attentional shifts (attentional selection of pain sensations), cognitive (re)appraisals ("this pain isn't harmful"), and volitional states or attitudes (willingness to feel pain) may give rise, through upward causation, to a higher level mental state of equanimity (Desbordes et al., 2015). The emergent mental state of equanimity may then feedback downward to the lower level components, signaling the body to relax

and reducing unpleasant interoceptive sensations. This downward causation may also enhance a sense of psychological sense of safety, which diminishes automatic negative appraisals and habitual efforts to avoid unpleasant sensations. These types of impacts on the dynamics of lower level components may then further support the higher level mental state of equanimity, again, through upward causation pathways. In this manner, mental states of equanimity may be recursively enhanced through self-regulating pathways of circular causality.

Utility and Implications. Circular causality calls attention to the reciprocal relationships between different levels of the system that shape change in the mechanisms and outcomes of meditation. Accordingly, identifying upward and downward causation pathways involved in meditation training may offer a fruitful direction for future research. Additionally, strengthening salutary circular causality pathways may become targets of meditation-based interventions to help individuals overcome obstacles and support ongoing development. For example, we may examine whether and how certain meditation practices, such as focused attention on the breath or bodily sensations, can give rise to meta-awareness, reduced reactivity, or reduced identification with experiencing (i.e., decentering; upward causation) and whether and how those emergent states function to maintain sustained mindful awareness during focused attention meditation (downward causation; Dahl et al., 2015; Lutz et al., 2015).

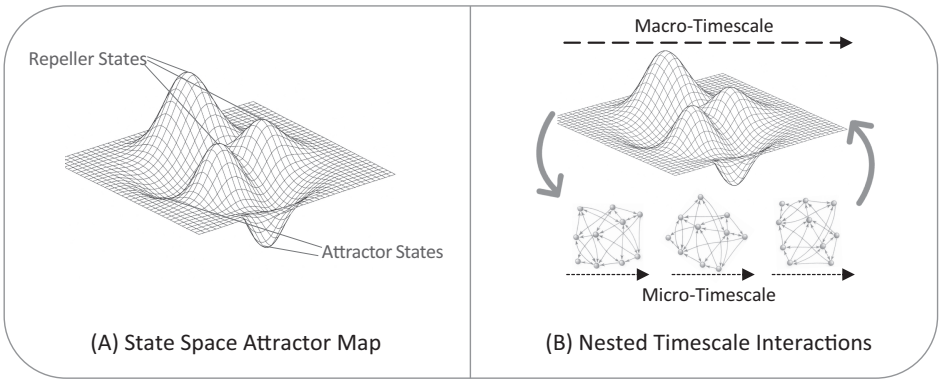
Multiscale Temporal Dynamics

State Space: Attractor and Repeller States

At any moment in time, a DS exists in a single state. A state space is a way of representing all possible states of a system (see Figure 4A). Each possible state is represented by a single point in this three-dimensional space, and as the system changes over time, it moves from one point to another, creating a path or trajectory. Nonlinear systems tend to stabilize over time in a specific subset of their potential states, called *attractor states*, and return to these states frequently. By contrast, *repeller states* reflect highly unstable or unlikely states that the system tends to not stay in for long and self-organize away from. Accordingly, attractors and repellers shape a system's state space. Attractors and repellers can be visualized as a 3D landscape with valleys representing attractors (stable states the system tends to settle into) and peaks representing repellers (unstable states the system moves away from). The system's state can be imagined as a ball rolling on this landscape: It naturally gravitates into valleys and away from peaks. Accordingly, a system's behavior can be visualized as a trajectory moving through the state space over time (see Figure 4A).

Exemplar: Impact of Mindfulness on Maladaptive Mental States. Repetitive negative thoughts can impair mental health because they tend to perpetuate and capture attention. Accordingly, they may be conceptualized as attractor states—stable states to which the system's trajectory repeatedly returns (Amir & Bernstein, 2022). Conversely, among perseverative thinkers, mindful states (characterized by regulated present-moment attention and acceptance) may be conceptualized as repeller states—disruptive unstable states the system moves away from. However, among perseverative thinkers, repeated mindfulness meditation training may enable more adaptive nonreactive awareness to distressing experience and sustained states of nonreactive awareness of present-moment experience (Blanke et al., 2020). In other words, meditation may transform the state space attractor landscape in individuals struggling with repetitive negative thinking. By repeatedly disrupting the habitual feedback loops and causal relations

Figure 4
Multiscale Temporal Dynamics: Attractor and Repeller States as Well as Nested Timescale Interactions



Note. Panel A illustrates state space attractor map and repeller states, where system behavior over time can be visualized as trajectories in a landscape shaped by stable attractor states (valleys) and unstable repeller states (peaks). Panel B depicts nested timescale interactions, showing how fast-changing (microtimescale) moment-to-moment system dynamics interact with and shape slower changing (macrotimescale) patterns over time, which in turn constrain and stabilize interaction-dominant dynamics and thereby system behavior.

between system components that underlie the state space and maladaptive attractor states (e.g., negative repetitive thinking), regular meditation practice may facilitate the development of new more adaptive mindful attractor states.

Utility and Implications. Attractor and repeller states offer a powerful way to reconceptualize and quantify change processes of meditation, (mal)adaptive habits that may be altered through meditation training, and barriers to meditation training. For example, we may seek to identify maladaptive attractor states that may be altered in meditation training (e.g., repetitive negative thoughts, experiential avoidance). We may likewise test whether different forms of meditation may alter the state space attractor landscape by creating novel adaptive attractor states (e.g., sustained self-compassion) that mitigate the "pull" of maladaptive attractors and sustain adaptive mental states. This approach may help us identify factors (e.g., habit loops, judgmental attitudes) and corresponding brain states (e.g., electroencephalogram [EEG] topography) that sustain strong maladaptive attractor states or hinder the development of novel adaptive attractor states despite mindfulness training. In these ways, attractor and repeller states may help us reconceptualize and characterize nonresponding to mindfulness-based interventions as well as difficulties sustaining meditation practice over time. Accordingly, individualized state space attractor maps may become promising candidate therapeutic target(s) for more personalized delivery of meditation training as well as a powerful means to quantify the therapeutic impact of such training (A. M. Hayes & Andrews, 2020).

Nested Timescale Interactions

The concept of attractors is also useful for understanding the principles that govern interactions between nested timescales over which we observe change and development. In the fast-changing short term (microtimescale), the system frequently returns to its attractor states. However, over the slower changing longer term (macrotimescale), these attractor states themselves evolve and dissolve, reshaping the system's development over time. DS theory explains bottom-up processes of change, where stable patterns in the macrotimescale emerge from the continuous interactions of system components in the microtimescale. Notably, these emergent changes in the state space attractor landscape in the macrotimescale then constrain, top-down, the real-time interactions between system components in the microtimescale (see Figure 4B).

Exemplar: Mindful States and Altered Traits. Mapping the interactions between processes that unfold over the micro- and the macrotimescales of mindfulness meditation may be key to understanding how mindful states and behaviors lead to altered traits (Goleman & Davidson, 2017). For example, repeated mindfulness training facilitates continuous interactions of system components in the microtimescale (e.g., reciprocal fluctuations in interoceptive attention, sustained monitoring of distractions) that create increasingly stable mindful states by altering the attractor and repeller state space landscape. Stable changes to the state space landscape may reflect altered traits at the macrotimescale. From this DS perspective, altered traits at the macrotimescale are emergent, stable dispositions or patterns in cognition, emotion, or behavior, such as increased attentional stability, enhanced interoceptive awareness, reduced cognitive reactivity, and a greater capacity for metacognitive insights (e.g., Alsubaie et al., 2017; Gu et al., 2015; Hölzel et al., 2011; van der Velden et al., 2015). Subsequently, these stable mindful traits at the macrotimescale may further constrain the moment-to-moment interactions of system components at the microtimescale, further acting to reinforce and maintain stability of these emergent dispositions or patterns (i.e., altered traits).

Utility and Implications. The DS concept of nested timescale interactions could drive new research questions and studies to investigate how mindfulness meditation practice and related mental states may facilitate a range of altered traits that have been tied to intensive long-term mindfulness meditation training. More broadly, nested timescale interactions invite us to try to distinguish and classify mental habits or behaviors central to mindfulness or meditation that unfold more slowly over macrotimescales from those that unfold more quickly from moment-to-moment at the microtimescale. In turn, we might thereby aim to identify and therapeutically target the microtimescale forms, qualities, or conditions of meditation practice (e.g., degree of effort, quality of attentional engagement, immediacy of reward or affective relief, identification with experience) that might facilitate or mitigate the emergent recurrence of (mal)adaptive behavioral or mental habits at the macrotimescale.

Summary: Synthesis of Proposed DS Theory Framework for Mindfulness and Meditation Science

In summary, we believe that the proposed features of DS theory—interaction-dominant dynamics, emergence, self-organization, nonlinear trajectories, feedback loops, circular causality, and multiscale temporal dynamics—offer a generative and integrative framework for advancing the science of mindfulness and meditation. Rather than isolating discrete mechanisms or assuming linear cause–effect pathways, this approach emphasizes dynamic interdependence, recursive feedback, and the complex temporal layering of change. Across interacting neural, neurocognitive, phenomenological, and behavioral processes and levels of analysis, we argue that mindfulness and meditation may be conceptualized and studied as DS characterized by recursive interactions, emergent mental states, evolving attractor landscapes, and nonlinear trajectories of change across nested timescales.

By foregrounding these principles, this perspective might also have implications for contemplative intervention

science. For example, it encourages scientific attention to within-person variability, nonlinear transitions, and the microtimescale dynamics that give rise to long-term change. Likewise, it invites a deeper investigation into why individuals may respond differently to similar practices, how states become traits, and how momentary qualities of practice shape long-term trajectories of well-being, mental health, and prosociality. In the next section, we try to build on this foundation by examining how seminal contemporary theoretical models of mindfulness and meditation are already aligned with many key features of DS theory.

DS Features in Mindfulness and Meditation Theory

Psychological Theories of Mindfulness and Meditation

The ideas that we propose here about ways that DS theory features may guide our conceptualization and study of mindfulness and meditation echo contemporary scientific theories of mindfulness that align with DS theory. We therefore briefly review exemplar theoretical models of mindfulness and meditation that are consistent with central features of DS.

One good illustration of DS features is found in mindfulness to meaning theory, which aims to explain how mindfulness promotes eudaimonic well-being (producing purpose and self-actualization) and emotional well-being in the face of stress (E. L. Garland, Farb, et al., 2015). Eudaimonic effects on well-being in the face of stress are theorized to emerge from the repeated reciprocal interactions over time between state mindfulness, decentering, attentional broadening, positive reappraisal, positive emotions, and savoring positive experience (i.e., DS interaction-dominant dynamics; E. Garland et al., 2009; E. L. Garland, Farb, et al., 2015; E. L. Garland et al., 2010). These interactions are theorized to lead to fluctuations and nonlinear growth in well-being due to disengagement and reengagement of positive feedback loops (termed "upward spirals" in mindfulness to meaning) between mindfulness mechanisms (i.e., DS nonlinear interactions and trajectories; E. L. Garland, Geschwind, et al., 2015). Furthermore, this theory proposes that, over time, repeated and sustained activation of these positive feedback loops results in altered traits such as greater meaning in life and eudemonic well-being (i.e., DS attractor states and nested timescales; E. L. Garland, Farb, et al., 2015). Thus, in line with central features of DS, the mindfulness to meaning theory conceptualizes mindfulness training as entailing nonlinear interactions between dynamic processes leading to a reconfiguration of attractor and repeller states and thereby to macrolevel nonlinear developmental changes.

Other contemporary psychological theories on mindfulness derived from Buddhist thought are also compatible with DS theory (Grabovac et al., 2011; P. Walpola et al., 2022; Williams & Kabat-Zinn, 2013). For example, contemporary scholars have argued that according to canonical Buddhist texts, recursive reactions of craving, attachment, and aversion to experience from moment to moment initiate and sustain mental proliferation—cascades of thoughts that have key roles in generating mental suffering (i.e., an attractor state; Grabovac et al., 2011; P. L. Walpola et al., 2017). By contrast, among individuals engaging in Buddhist mental training, continuous reciprocal interactions between mindfulness, insight, equanimity, attention regulation, and ethical practices are conceptualized to reduce craving, attachment, and aversion and thereby to diminish states of mental proliferation and mental suffering. Thus, in line with the proposed DS approach, contemporary scholars whose theoretical work is grounded in Buddhist thought traditions have conceptualized the salutary effects of mindfulness as a result of complex reciprocal interactions between several dynamical processes in time that lead to a reconfiguration of attractor and repeller states.

Similarly, the self-awareness, self-regulation, and self-transcendence framework sought to characterize the complex interactions between cognitive systems and processes in mindfulness meditation through the integration of Buddhist thought and contemporary neurocognitive science (Vago & Silbersweig, 2012). Specifically, Vago and Silbersweig (2012) described this process model depicting associations and feedback loops between cognitive systems (e.g., working memory, attention, response inhibition) and mindfulness mechanisms (e.g., decentering, equanimity) that subserve two key forms of mindfulness meditation—focused attention and open monitoring. This process model depicts how mental states such as engagement with an object of meditation, disengagement from objects of attention, and mental proliferation are produced by interactions and feedback loops between cognitive systems and processes (e.g., DS interaction-dominant dynamics and nonlinear interactions). Accordingly, while these models are not formulated using DS concepts explicitly, they are conceptually aligned with the DS interaction-dominant dynamics in which complex relationships between system components interact to produce system states.

Finally, the metacognitive processes model of decentering proposed that the interaction of three interrelated metacognitive processes—meta-awareness, disidentification from internal experience, and reduced reactivity to thought content—leads to an emergent salutary mechanism of mindfulness training (Bernstein, Hadash, & Fresco, 2019; Bernstein et al., 2015). In this model, these metacognitive processes interact via reciprocal causal pathways and positive and negative feedback loops, wherein decentering is an emergent property of these iterative interactions, from moment to moment in time. Accordingly, the model conceptualizes this key salutary mechanism of action of mindfulness training in a manner aligned well with the proposed DS theoretical perspective—multidirectional associations and feedback loops between metacognitive processes that lead to the emergence and stabilization of a new (decentered) attractor state.

Neuroscientific Theories of Mindfulness and Meditation

Furthermore, DS theory has also been fundamental to neuroscientific theory and study of neuronal activity to large-scale brain networks (Bassett & Sporns, 2017; Favela, 2021; Izhikevich, 2007). With respect to mindfulness and meditation, neuroscientific theory has argued that mindfulness practice engages multiple large-scale brain networks and specific activation or connectivity patterns rather than localized neuronal activity (Afonso et al., 2020; Fox et al., 2014; Giommi et al., 2023; Shen et al., 2020; Y.-Y. Tang et al., 2015, 2017). Accordingly, neural activity underlying mindfulness training cannot be readily disentangled into separate additive contributions of particular brain regions or circuits (i.e., component-dominant dynamics). Rather, it should be studied through the interactions and (a)synchronized activity within and between global brain networks, in line with the DS complex interaction dynamics (i.e., DS interaction-dominant dynamics; Bassett & Sporns, 2017; Bullmore & Sporns, 2009).

Second, brain networks are believed to self-organize through the complex, nonlinear interactions and coordination of activity across different brain regions, without the need for a central controller. This process involves a balance between flexibility to adapt to new information and stability to maintain structures necessary for consistent function (Giommi et al., 2023; Shine et al., 2016). The dynamic activity in large-scale, widely distributed brain areas involved in mindfulness training is thought to involve complex, nonlinear interactions, where different brain regions influence each other in a reciprocal, recursive manner (Chiel & Beer, 1997; Clark, 1999; Giommi et al., 2023; John et al., 2022; Thompson & Varela, 2001). The neural activity in these networks shifts between different functional states, with varying levels of stability, moving toward stable states (attractors) or away from unstable states (repellers; John et al., 2022; Shine et al., 2016).

Finally, in light of the emphasis on interaction-dominant dynamics, neuroscientists have argued that the study of the salutary effects of mindfulness training should focus on changes in network dynamics (i.e., changes in the attractor landscape; Giommi et al., 2023; Mooneyham et al., 2016; Zhou et al., 2023). Indeed, there is evidence for changes in network structure and dynamics or connectivity patterns associated with mindfulness training (Afonso et al., 2020; Falcone & Jerram, 2018; Guidotti et al., 2021; Y.-Y. Tang et al., 2017; R. Tang et al., 2020, Vago, 2022; Young et al., 2018). Some of these changes also persist in resting state, potentially reflecting a functional reorganization of connectivity and brain plasticity. Moreover, systemic alterations in networks have been associated with more effective performance in cognitive tasks (Shine et al., 2016), suggesting that the changes in functional connectivity associated with mindfulness training may be linked to the salutary effects associated with practice. While the exact mechanisms behind these forms of brain plasticity are not yet fully understood, research suggests that the processes occurring at microtimescales during meditation practice contribute to the development of long-term, stable changes in network structure and function over the macrotimescale (Creswell et al., 2019; Gu et al., 2015; Y.-Y. Tang et al., 2015). This may reflect a form of temporal emergence across nested timescales that is central to DS wherein fast processes during practice scale up to influence slower, long-term developmental changes over time. Likewise, other studies have shown that long-term, stable changes in network structure and function in advanced meditators (e.g., enhanced prefrontal cortical control, increased gamma synchrony) subsequently influence moment-to-moment neural activity in and outside of meditation (Brewer et al., 2011; Lutz et al., 2004). These effects may reflect a form of top-down interaction or constraint between nested timescales.

It is also important to highlight Thompson and Varela's (2001) seminal enactive theory of cognition. The enactive approach is based on the idea that brain processes essential for consciousness involve reciprocal, circular causal relationships between local brain activity and conscious states that span across the brain, body, and environment (Chiel & Beer, 1997; Clark, 1999; Thompson & Varela, 2001). Accordingly, the enactive approach explores dynamical activity of large, widely distributed brain areas characterized by the soft assembly of emergent processes of consciousness (John et al., 2022; Melnychuk et al., 2018; Munn et al., 2021; Thompson & Varela, 2001). Soft assembly means that the components of consciousness are not rigid or fixed but flexible and adaptable. Importantly here, scholars have applied the enactive approach to understand and study complex mental states such as mindfulness (Clark, 1999; Lutz et al., 2025; Meling, 2022; Sandved-Smith et al., 2021; Thompson & Varela, 2001). From the enactive perspective, mindfulness has been conceptualized as a dynamical system made up of complex, interconnected, and changing mental processes. These processes emerge through the interactions of the mind, body, and environment, shaped by transient neurophysiological activity within global brain networks (Clark, 1999; Lutz et al., 2025; Meling, 2022; Sandved-Smith et al., 2021; Thompson & Varela, 2001).

Summary: DS Features Are Integral to Psychological and Neuroscientific Theory of Mindfulness and Meditation

Core principles that mirror those fundamental to DS theory are central to psychological and neuroscientific theories of mindfulness and meditation. Contemporary psychological models foreground interaction-dominant dynamics, recursive causal processes, and emergent states. While these models vary in scope and emphasis, they share a foundational view of mindfulness and meditation as dynamic, nonlinear, and developmentally unfolding processes. Likewise, neuroscientific theories of mindfulness—particularly those focused on functional brain network dynamics—have moved beyond modular and localization-based perspectives. They increasingly describe the effects of meditation in terms of large-scale, distributed, and

self-organizing network activity and entail changes in attractor landscapes, recursive feedback dynamics, and bidirectional causal pathways across nested timescales of neural and mental organization. Likewise, the enactive approach to cognition further integrates these ideas by explicitly grounding consciousness and mindfulness in embodied, embedded, and dynamic systems theory.

The observed alignment between these theoretical models and DS theory illustrates that the proposed DS framework is not an alternative or conceptual competitor to existing mindfulness theory or research. Instead, by making explicit the DS principles already central in these models, researchers may better conceptually and empirically characterize the dynamic processes underlying mindfulness and meditation. Moreover, to facilitate this process, it is important that we understand how to not only integrate DS into the science of mindfulness and meditation conceptually but also integrate DS empirically and methodologically. To help guide such efforts, we next review the dominant empirical paradigm through which mindfulness and meditation research has been conducted.

Review of the Reductionist Paradigm of Decomposition in Mindfulness and Meditation Research

As noted, the foundational beginnings or first-generation of nascent scientific fields of even complex and dynamical phenomena often begin with the decomposition of the phenomena—the identification and investigation of its constituent parts (Kelso, 1995; Lewis, 2005; Varela et al., 1991). Although our first-generation scientific study of mindfulness and meditation has been foundational, we argue that predominant empirical approaches are not well-suited to interrogate mindfulness and meditation as more complex and dynamical phenomena. To identify the domains in which mindfulness and meditation science may productively embrace dynamical complexity of recomposition, it is important that we first highlight exemplars and limitations of reductionist modularity of decomposition that has characterized the foundational science of mindfulness and meditation.

Component-Dominant Dynamics: Limited Study of Complex Interaction Dynamics

First, most empirical studies of mindfulness mechanisms to date have tested the contribution of individual, isolated mechanisms (e.g., mediation, moderation) and attempted to dismantle mindfulness practices and interventions into their components (e.g., Alsubaie et al., 2017; Gu et al., 2015; Hölzel et al., 2011; Lindsay et al., 2018; van der Velden et al., 2015). When we study individual, isolated mechanisms, to dismantle mindfulness practices and interventions into their components, we need to assume that mindfulness mechanisms are characterized by component-dominant additive dynamics, in which factors contribute separately and additively. However, if mindfulness and its underlying mechanisms function as complex and DS—where different factors continuously interact and shape each other to form coherent, organized patterns—then our understanding may remain systematically limited until we account for these dynamic interactions. Thus, field-wide reliance on this component-dominant paradigm could limit not only our understanding of how mindfulness develops but also our understanding of the dynamics of its development, mechanisms of action, and conditions that contribute to its salutary or putatively adverse effects.

Gradual, Continuous, and Linear: Limited Study of Nonlinear Causality

A large proportion of mindfulness and meditation studies to date have explored linear relationships and trajectories (Alsubaie et al., 2017; Goldberg et al., 2022; Gu et al., 2015; van der Velden et al., 2015). Importantly, nonlinear trajectories of change, characterized by phase shifts, may be masked by reliance on cross-sectional designs or longitudinal contrasts between two or three observations (i.e., pre- and postintervention designs). Likewise, although trajectories of change may vary meaningfully between individuals (Ietsugu et al., 2015; Isbel et al., 2020; Kiken et al., 2015), aggregating participant data may unintentionally mask such systematic variability. Moreover, commonly used trait self-report scales are not designed to capture the nonlinear dynamics that may characterize mindfulness states and training (Hadash & Bernstein, 2019). Likewise, even studies that use temporally intensive data (e.g., EEG) often aggregate static scores (e.g., mean score, peak frequency, frequency counts; Lee et al., 2018; Lomas et al., 2015). Notably, several exciting initial studies of DS nonlinearity in mindfulness and meditation are emerging using, for example, intensive longitudinal designs and methods to characterize nonlinear trajectories of change, nonlinear EEG metrics, massive time-series feature extraction of brain dynamics, and synchronous stability and time-varying graphs (Abdoun et al., 2025; Bailey et al., 2024; Panitz et al., 2025; Toutain et al., 2021; Vyšata et al., 2014).

Either Micro- or Macrotimescales: Limited Study of Multiscale Temporal Dynamics

Importantly, despite research on mindfulness and meditation along multiple timescales (e.g., during meditation, over the course of an intervention), few studies have sought to connect the processes that occur across nested timescales of mindfulness training (Isbel et al., 2020; Kiken et al., 2015). We speculate that the field is ripe for this type of DS study. Indeed, there are fast-growing interest and study, using experience sampling, behavioral assays, and neuroimaging (e.g., EEG, magnetoencephalography), to quantify moment-to-moment dynamics of mindfulness meditation and related states (e.g., meta-awareness; Berkovich-Ohana et al., 2020; Chu et al., 2023; E. L. Garland, Geschwind, et al., 2015;

Goldberg et al., 2020; Ruimi et al., 2018; Schooler et al., 2011; Timmermann et al., 2023). Likewise, through longitudinal and ecological momentary assessment designs, there is fast-growing interest and study of macrotimescale developmental trajectories of mindfulness (Enkema et al., 2020; Levi et al., 2021; Shoham et al., 2017). However, to understand the development and outcomes of mindfulness from a DS perspective, it is important to understand how, on the one hand, change and stability in trait-level affect, behavior, cognition, neural activity, and subjective experience (macrotimescale) emerge, bottom-up, from the real-time dynamics that occur during meditation and, on the other hand, how these trait affects, top-down, constrain the real-time dynamics (microtimescale) that occur during meditation (Goleman & Davidson, 2017; Granic, 2005; Richters, 1997).

Summary: Foundational Reductionist Decomposition Characterizing Mindfulness and Meditation Research

Extant scientific study of mindfulness and meditation has laid the essential groundwork by identifying and isolating key components, mechanisms, and outcomes. These foundational efforts reflect an indispensable phase in scientific development of mindfulness and meditation—the reductionist decomposition of complex phenomena into analyzable parts. We want to be explicit that our critique is not of this paradigm itself nor of the scientific contributions it has yielded. To the contrary, research grounded in the reductionist paradigm has been and continues to be crucial to establishing a taxonomy of core components, processes, and effects of mindfulness and meditation. Moreover, this paradigmatic work remains essential, particularly when the goal is to identify, classify, or characterize isolated constituent parts of these multifaceted practices and mental states. Indeed, robust modeling of complex systems depends on the careful delineation of the modular properties and functions of system parts (Bechtel & Richardson, 2010).

At the same time, we propose that various domains of mindfulness and meditation science have reached a level of maturity that affords a paradigmatic transition. While decomposition has been foundational, the component-dominant assumptions that underpin much existing research are increasingly inadequate for capturing how mindfulness functions as a complex, adaptive, and evolving system. Continued reliance on linear models and static measurement tools has constrained our ability to detect the nonlinear trajectories, phase transitions, and recursive feedback dynamics that may underlie developmental shifts or therapeutic outcomes. Similarly, the disconnection between analysis of micro- and macrotimescales has obscured the nested temporal dynamics through which momentary states of mindfulness give rise to enduring traits and vice versa. Together, these limitations underscore the need for a conceptual and methodological expansion of mindfulness meditation research through DS theory and methods. Thus, in the sections that follow, we describe how DS can help us reimagine the next generation of computational and empirical mindfulness and meditation science.

From Theory to Data: Emerging and Future Directions of a DS Science of Mindfulness and Meditation

Our intention here is to propose actionable ways forward to try to help advance mindfulness and meditation science through DS theory and methods. We highlight three promising directions for advancing mindfulness and meditation research: (a) the development of formalized theory and computational models to characterize mindfulness-related processes; (b) the use of study designs and methodological approaches capable of capturing the high-dimensional, multilevel data needed for DS modeling; and (c) the application of analytic techniques suited to modeling complex interactions, nonlinear causal relationships, and processes unfolding across multiple timescales.

DS Theories and Computational Modeling

First, we argue that developing formalized DS theories and computational models may be one productive step toward the application of DS in mindfulness and meditation research. In formal mathematical theory, computational modeling quantifies a formal account of psychological processes and their functions (Fried, 2020; Grahek et al., 2021). These models can be distinguished from conceptual theories common in the psychological sciences, and in mindfulness science more specifically, which are typically descriptions of broad principles or propositions (e.g., "mindfulness improves attentional control," "acceptance reduces distress") without mathematical formalization. Computational formalization can advance theory development by requiring the delineation of explicit assumptions about system components and relationships (Borsboom, van der Maas, et al., 2021; Epstein, 2008). Furthermore, formal DS computational modeling permits (experimental) simulations under various conditions, through mathematical manipulations of model parameters. Such modeling enables simulations of momentary states of the system, as well as temporal trajectories of the DS under various theoretical scenarios and parametric conditions, including those that are (very) difficult to test empirically (i.e., when the data lack the fine-grained temporal resolution, across domains or levels of analysis). Although specific states of a DS may not be readily predicted with precision, a large number of computational simulations may be used to fine-tune predictions of distribution(s) of later states and trajectories (Robinaugh et al., 2020). These predictions can be contrasted with empirical data. Insofar as formalized computational modeling may be important for understanding and predicting the behavior of DS, it may likewise be important in understanding and predicting the development of mindfulness and meditation outcomes.

For instance, computational modeling can simulate interaction-dominant dynamics, allowing researchers to examine how reciprocal interactions among mindfulness mechanisms (e.g., meta-awareness, acceptance, tranquility) coevolve over time and give rise to emergent states of mindful awareness. Similarly, DS models can model self-organization and feedback loops, enabling simulation of conditions under which mindfulness training fosters adaptive, flexible system trajectories versus conditions that stabilize maladaptive patterns. DS computational approaches also allow researchers to simulate nonlinear change trajectories and phase transitions—for example, how different meditation intensities, durations, and contexts interact to produce sudden shifts into new stable states, such as equanimity or insight, or, alternatively, transitions into maladaptive states. Finally, formal DS modeling can facilitate the construction of state space attractor landscapes—for example, testing how repeated mindfulness practice reshapes the stability and accessibility of maladaptive attractor states (e.g., repetitive negative thinking) and cultivates new adaptive attractors (e.g., sustained nonreactive awareness). By simulating these complex, multiscale dynamics and comparing model-generated predictions to empirical data, formalized DS computational modeling may be conceptually and practically useful. For example, such modeling can advance our understanding of the conditions under which mindfulness and meditation produce salutary outcomes, as well as support the development of more effective, personalized, and adaptive meditation-based interventions.

Scholars have begun to explore formal computational modeling of mindfulness and meditation (van Vugt et al., 2019). Initial efforts include a model of focused attention meditation and its transfer to a sustained attention task as well as a deep parametric active inference model of meta-awareness (Moye & van Vugt, 2021; Sandved-Smith et al., 2021). However, although these models provide an initial formalization of closely related phenomena, they are not DS models of the developmental trajectories or outcomes of mindfulness meditation. A related recent approach, the attention-to-thoughts model, proposed a formal DS theory and computational model of (mal)adaptive internally directed cognitive processes, with implications for mindfulness as a form of internally directed cognition (Amir & Bernstein, 2022). Nevertheless, a formalized DS theory and computational model of mindfulness development has yet to be developed and, we argue, could help guide efforts to develop a DS science of mindfulness and meditation.

DS Study Designs: Observation Frequency, Levels of Analysis, and Nested Timescales

Empirical DS mindfulness and meditation research will require sufficiently dense observation frequency across levels of analysis and timescales. These types of data are sometimes described as high-dimensional data. That is, time-series data, from multiple variables, needed to capture a complex dynamical system's state, interaction-dominant dynamics, emergent properties, various forms of nonlinear causality and feedback loops, and multiscale temporal dynamics. Consequently, a DS-aligned design could entail temporally intensive behavioral or physiological assays during mindfulness meditation (microtimescale) as well as frequent (e.g., weekly, daily, or more) measurements over the course of repeated practice sessions (macrotimescale; Hadash & Bernstein, 2019; Hadash et al., 2023). Such data permit study of interaction-dominant dynamics and developmental trajectories over the course of mindfulness training, efforts to bridge microtimescale psychological and neurophysiological changes that occur during meditation with the macrotimescale changes that occur over long-term practice or interventions, and efforts to characterize attractors and repellers of the mindfulness training state space. For example, this may entail integration of temporally intensive behavioral assays of attention and awareness metrics during mindfulness meditation as offered by tools such as the mindful awareness task (Hadash & Bernstein, 2019; Hadash et al., 2023; microtimescale) with experience sampling methods as well as mobile passive sensor data, over time and context (e.g., Mehl et al., 2024; macrotimescale).

In relation to mindfulness and meditation research, initial studies have sought to collect such data and to begin to examine the dynamical properties of these data, most notably in relation to the study of feedback loops between mindfulness and its salutary mechanisms and associated outcomes (Du et al., 2019; Gotink et al., 2016; Stuart-Edwards, 2023). For example, through longitudinal randomized control data, E. L. Garland, Geschwind, et al. (2015) examined the positive feedback loop between mindfulness and positive reappraisal central to mindfulness to meaning theory (G. Garland et al., 2011; E. L. Garland, Geschwind, et al., 2015; E. L. Garland et al., 2017; Hanley et al., 2021). Likewise, in daily diary data over 12 weeks of a mindfulness-based intervention, Goldberg et al. (2020) found that the relationship between mindfulness meditation practice dose (time) and salutary response to practice may be complex, recursive, and interdependent.

Data Analytic Methods: Quantifying Features of DS

Data analytic methods to facilitate study of DS have been developed, and comprehensive reviews of such methods are available (e.g., McGoff et al., 2015). We highlight exemplary data analytic approaches and explain how they may be applied to facilitate a DS science of mindfulness and meditation. Critically, such data analytic tools may only be applied to empirical data with sufficient high dimensionality and sample size. In other words, developing a DS science of mindfulness and meditation depends on designing studies and

organizing data from existing measurement assays that permit the application of these data analytic methods. Importantly, some empirical areas of mindfulness and meditation research may not yet be ready for the application of some of these data analytic tools. We nevertheless highlight these methods because understanding these tools and their capacity may help scholars design studies, and develop measurement assays, that will permit the utilization of these data analytic tools for DS study of mindfulness and meditation.

Network Analysis

In recent years, network modeling has been widely applied in the psychological sciences, for example, in the study of mental disorders (Fried, 2022; Fried et al., 2017; Robinaugh et al., 2020; Roefs et al., 2022). In network modeling, the interrelations between system components are quantified and visualized using a network graph containing nodes (i.e., components) and edges (i.e., relationships). In this manner, the complexity of the phenomenon is represented in the reciprocal interconnections between network components. Several cross-sectional network analyses have been conducted to explore the relationships between mindfulness facets and related processes (Heeren et al., 2021; Lecuona et al., 2021; Sala et al., 2023), trait mindfulness and symptoms (Barcaccia et al., 2020; Bronchain & Chabrol, 2020; Medvedev et al., 2021; Sala et al., 2022; Sun et al., 2022), and differences between meditators and meditation-naïve participants (Smith et al., 2021). Likewise, initial studies have begun to examine changes in network topology following mindfulness-based interventions (Aizik-Reebs et al., 2021; Roca et al., 2019). However, these network models are limited in their capacity to capture system temporal dynamics and are not designed to capture nonlinear relationships or trajectories, to characterize attractor or repeller states, or to connect processes between nested timescales (e.g., states and traits; Haslbeck et al., 2022).

Importantly, temporal network analysis methods, such as time-varying graphical least absolute shrinkage and selection operator, dynamic Bayesian networks, or network vector autoregression methods, quantify how network nodes and edges change over time to capture evolving system dependencies (Blonder et al., 2012; Borsboom, Deserno, et al., 2021). Briefly, temporal network analysis has been increasingly applied across psychological sciences (Borsboom, Deserno, et al., 2021) with particularly rapid growth and sophistication in the area of network neuroscience (Bassett & Sporns, 2017). For example, in relation to mindfulness and meditation, these methods have begun to reveal intriguing patterns of interconnectivity among large-scale brain networks (default mode network, salience network, central executive network) as well as dynamic shifts in deep brain regions, with a variety of implications, such as for understanding meditation-related neuroplasticity (Prakash et al., 2025).

Nonlinear Dynamics and Data-Driven Modeling

Second, a number of methods are well-suited to uncover patterns in complex and changing processes. These include analysis of chaos measures (e.g. Lyapunov exponents; Wolf et al., 1985), linearization of nonlinear systems (e.g. Hankel alternative view of Koopman analysis; Brunton et al., 2017), and dynamic structural equation modeling (Asparouhov et al., 2018). Chaos measures, such as Lyapunov exponents, can be used to quantify how small differences in initial conditions can lead to vastly different outcomes (i.e., butterfly effect), such as investigating how the quality, sustained focused attention, or salutary effects of mindfulness meditation may emerge from its initial conditions (e.g., physiological arousal, contents of working memory, meditation practice history). Other techniques, like Hankel alternative view of Koopman analysis, can be used to simplify nonlinear dynamics into linear components, making it easier to predict system behavior. For example, Hankel alternative view of Koopman analysis has been applied to various kinds of psychological, neurophysiological, and behavioral data (e.g., EEG, head motion during dyadic conversations) to quantify attractor topology and its dynamics (Brunton et al., 2017; Moulder et al., 2023). For example, in mindfulness meditation, this could involve identification of shared and differential attractor topology and dynamics in focused attention or open monitoring meditation. In this way, seemingly complex fluctuations of cognitive or neural processes may be distilled into ordered patterns needed to help researchers to phenotype, better understand, and predict (and thereby prevent or respond skillfully to) wanted and unwanted shifts in mental states during or following meditation. Likewise, dynamic structural equation modeling, designed to integrate structural equation and multilevel time-series modeling, may have a number of applications. It may be used to quantify individual variability in dynamical patterns (e.g., via random effects in autoregressive parameters), nonlinear transitions and trajectories (e.g., via time-varying parameters), as well as more and less stable patterns, feedback loops (e.g., via cross-lagged and recursive effects), as well as change processes in micro- and macrotimescales. Promising initial studies have begun to apply dynamical structural equation modeling to understand the effects and candidate mechanisms of mindfulness-based interventions (Bolzenkötter et al., 2025; Joss et al., 2024).

State Space Analyses

Various methods have been developed to visualize and quantify the range of possible states of a system—the state space—as well as track how the system shifts between them, revealing patterns of stability and change in behavior or mental processes. These methods include phase plot of time-series data (Bakeman & Gottman, 1997), state space grids (Lewis et al., 1999), and attractor reconstruction methods (Kantz & Schreiber, 2003). Broadly, these methods analyze system

behavior over time, facilitating the study of complex, nonlinear interactions and transitions, and enabling the detection, quantification, and visualization of recurring transitions and shifts (e.g., attractor states) that are integral to DS.

To characterize attractor and repeller dynamics, multiple state space methods may be employed. Phase plots provide a visual depiction of a system's trajectory through continuous state space, allowing researchers to detect stable points, cycles, and transitions. State space grids discretize system states into defined regions, enabling the quantification of dwell times, transitions, and return probabilities—approaches that can empirically characterize the strength and organization of attractor basins that influence system behavior. Attractor reconstruction methods use time-delayed embedding to reconstruct the state space from scalar time-series data, providing a means to visualize system trajectories and detect attractors. Together, these approaches offer complementary insights into the structure and evolution of mental states during mindfulness meditation.

With an emphasis on understanding, as opposed to prediction, these methods allow us to quantify changes in a dynamical system over time (Hollenstein, 2007). For instance, in developmental psychology, state space grid analysis has been applied to study effects of content (e.g., positive vs. negative) as well as structure (i.e., flexible vs. rigid) of dyadic interactions (e.g., parent–child, teacher–student; Hollenstein & Lewis, 2006; Lunkenheimer et al., 2011; Turner & Christensen, 2020). Such studies demonstrate the self-organizing emergence of stable interaction patterns, as well as help us to explore the role of variability (i.e., flexibility) in periods of phase transitions and its relation to adaptive outcomes. Likewise, psychotherapy research has explored the emergence of alternative self-narratives over the course of treatment, quantifying the role of variability (i.e., flexibility) in the facilitation of therapeutic change processes (Ribeiro et al., 2011).

We believe that state space analytic methods are particularly well-suited to address questions central to mindfulness and meditation research. However, to the best of our knowledge, these methods have not yet been applied in this domain. We propose that studies applying state space analyses to mindfulness practice and development, across nested timescales, could facilitate a deeper understanding of the change processes and trajectories through which altered traits emerge from repeated meditation practice. For example, such studies could empirically examine how repeated mindfulness practice transforms the state space landscape, reducing the stability of maladaptive attractor states (e.g., repetitive negative thinking, experiential avoidance) while supporting the emergence and stabilization of new, adaptive attractors (e.g., equanimity, compassion, nonreactive awareness). These methods could also help delineate the timing and conditions—such as the cultivation of meta-awareness or acceptance—under which phase transitions disrupt maladaptive attractors, allowing the system to settle into more adaptive states. Additionally, by mapping microtimescale fluctuations in mindful states and macrotimescale shifts in traits, state space analyses could reveal how moment-to-moment meditation practice iteratively shapes and is constrained by evolving attractor landscapes, providing a mechanistic understanding of how mindfulness practice fosters stable, adaptive dispositions over time. In these ways, state space analyses can complement and extend current approaches in mindfulness research, offering a rigorous framework for visualizing, quantifying, and ultimately shaping the dynamical landscapes through which mindfulness training promotes human flourishing.

Data-Driven Modeling Using Machine Learning

Machine learning algorithms have recently been applied to discover governing equations that describe the behavior of DS, offering powerful data-driven approaches to modeling temporal complexity (Brunton et al., 2016; Champion et al., 2019). Methods such as sparse identification of nonlinear dynamical systems, deep learning-based partial differential equation discovery (DeepMoD), and neural ordinary differential equations can, in principle, predict system behavior, visualize and analyze attractor structures, and characterize system predictability and stability. These methods require high-frequency, high-dimensional, nonlinear time-series data, which limit their current applicability to mindfulness and meditation research. However, as physiological and neural recording technologies become increasingly portable and scalable, and as experience sampling methods are integrated with high-resolution neural and physiological monitoring, these methods may become feasible in contemplative science contexts.

In the future, such approaches could be used to quantify the evolution of mental states during meditation, forecast transitions between adaptive and maladaptive states, and personalize meditation practice delivery by predicting the timing and conditions of these transitions. They may also be applied to map attractor landscapes in behavioral, physiological, or neural signals corresponding to mindful or unmindful states, enabling comparisons between experienced meditators and novices or characterizing patterns of therapeutic response and nonresponse to mindfulness-based interventions. Although these methods remain aspirational for contemporary mindfulness and meditation research, they represent a promising future direction for advancing a mechanistically precise, DS science of mindfulness and meditation.

Conclusions

In summary, in this article we argue that while foundational research grounded in reductionist decomposition has been foundational and remains vital, it is not well-suited to characterize the complex interaction dynamics, nonlinear causality, and multiscale temporal dynamics that may be integral to mindfulness and meditation practice and development.

Accordingly, we offer a DS framework to help advance the science of mindfulness and meditation from the study of simple mechanics to complex dynamics. We hope that this article and the proposed DS framework help inspire and assist scholars and scientists to study mindfulness meditation as an emergent, self-organizing process arising from contextualized, recursive interactions across systems (e.g., neural, phenomenological) and nested timescales.

References

Abdoun, O., Poublan-Couzardot, A., Offort, S., Pagnoni, G., & Lutz, A. (2025). Shedding light on changes in subjective experience during an intensive contemplative retreat: The Lyon Assessment of Meditation Phenomenology Questionnaire. *Biological Psychiatry Global Open Science*, *5*(4), Article 100474. https://doi.org/10.1016/j.bpsgos.2025.100474

Afonso, R. F., Kraft, I., Aratanha, M. A., & Kozasa, E. H. (2020). Neural correlates of meditation: A review of structural and functional MRI studies. *Frontiers in Bioscience*, *12*(1), 92–115. https://doi.org/10.2741/s542

Aizik-Reebs, A., Shoham, A., Hadash, Y., & Bernstein, A. (2021). A network modeling approach to mindfulness mechanisms: A proof-of-concept investigation. *Mindfulness*, *12*(5), 1115–1126. https://doi.org/10.1007/s12671-020-01580-7

Alsubaie, M., Abbott, R., Dunn, B., Dickens, C., Keil, T. F., Henley, W., & Kuyken, W. (2017). Mechanisms of Action in Mindfulness-Based Cognitive Therapy (MBCT) and Mindfulness-Based Stress Reduction (MBSR) in people with physical and/or psychological conditions: A systematic review. *Clinical Psychology Review*, *55*, 74–91. https://doi.org/10.1016/j.cpr.2017.04.008

Amir, I., & Bernstein, A. (2022). Dynamics of internal attention and internally-directed cognition: The Attention-to-Thoughts (A2T) model. *Psychological Inquiry*, *33*(4), 239–260. https://doi.org/10.1080/1047840X.2022.2141000

Anālayo, B. (2019). Adding historical depth to definitions of mindfulness. *Current Opinion in Psychology*, *28*, 11–14. https://doi.org/10.1016/j.copsyc.2018.09.013

Asparouhov, T., Hamaker, E. L., & Muthén, B. (2018). Dynamic structural equation models. *Structural Equation Modeling: A Multidisciplinary Journal*, *25*(3), 359–388. https://doi.org/10.1080/10705511.2017.1406803

Bailey, N. W., Fulcher, B. D., Caldwell, B., Hill, A. T., Fitzgibbon, B., van Dijk, H., & Fitzgerald, P. B. (2024). Uncovering a stability signature of brain dynamics associated with meditation experience using massive time-series feature extraction. *Neural Networks*, *171*, 171–185. https://doi.org/10.1016/j.neunet.2023.12.007

Bakeman, R., & Gottman, J. M. (1997). *Observing interaction: An introduction to sequential analysis*. Cambridge University Press. https://doi.org/10.1017/CBO9780511527685

Baminiwatta, A., & Solangaarachchi, I. (2021). Trends and developments in mindfulness research over 55 years: A bibliometric analysis of publications indexed in web of science. *Mindfulness*, *12*(9), 2099–2116. https://doi.org/10.1007/s12671-021-01681-x

Barcaccia, B., Cervin, M., Pozza, A., Medvedev, O. N., Baiocco, R., & Pallini, S. (2020). Mindfulness, self-compassion and attachment: A network analysis of psychopathology symptoms in adolescents. *Mindfulness*, *11*(11), 2531–2541. https://doi.org/10.1007/s12671-020-01466-8

Bassett, D. S., & Sporns, O. (2017). Network neuroscience. *Nature Neuroscience*, *20*(3), 353–364. https://doi.org/10.1038/nn.4502

Bechtel, W., & Richardson, R. C. (2010). *Discovering complexity: Decomposition and localization as strategies in scientific research*. Massachusetts Institute of Technology Press. https://doi.org/10.7551/mitpress/8328.001.0001

Beer, R. D. (2000). Dynamical approaches to cognitive science. *Trends in Cognitive Sciences*, *4*(3), 91–99. https://doi.org/10.1016/S1364-6613(99)01440-0

Berkovich-Ohana, A., Dor-Ziderman, Y., Trautwein, F.-M., Schweitzer, Y., Nave, O., Fulder, S., & Ataria, Y. (2020). The Hitchhiker's guide to neurophenomenology–The case of studying self boundaries with meditators. *Frontiers in Psychology*, *11*, Article 1680. https://doi.org/10.3389/fpsyg.2020.01680

Bernstein, A., Hadash, Y., & Fresco, D. M. (2019). Metacognitive processes model of decentering: Emerging methods and insights. *Current Opinion in Psychology*, *28*, 245–251. https://doi.org/10.1016/j.copsyc.2019.01.019

Bernstein, A., Hadash, Y., Lichtash, Y., Tanay, G., Shepherd, K., & Fresco, D. M. (2015). Decentering and related constructs: A critical review and metacognitive processes model. *Perspectives on Psychological Science*, *10*(5), 599–617. https://doi.org/10.1177/1745691615594577

Bernstein, A., Vago, D. R., & Barnhofer, T. (2019). Understanding mindfulness, one moment at a time: An introduction to the special issue. *Current Opinion in Psychology*, *28*, vi–x. https://doi.org/10.1016/j.copsyc.2019.08.001

Berntson, G. G., & Khalsa, S. S. (2021). Neural circuits of interoception. *Trends in Neurosciences*, *44*(1), 17–28. https://doi.org/10.1016/j.tins.2020.09.011

Berry, D. R., Hoerr, J. P., Cesko, S., Alayoubi, A., Carpio, K., Zirzow, H., Walters, W., Scram, G., Rodriguez, K., & Beaver, V. (2020). Does mindfulness training without explicit ethics-based instruction promote prosocial behaviors? A meta-analysis. *Personality and Social Psychology Bulletin*, *46*(8), 1247–1269. https://doi.org/10.1177/0146167219900418

Blanke, E. S., Schmidt, M. J., Riediger, M., & Brose, A. (2020). Thinking mindfully: How mindfulness relates to rumination and reflection in daily life. *Emotion*, *20*(8), 1369–1381. https://doi.org/10.1037/emo0000659

Blonder, B., Wey, T. W., Dornhaus, A., James, R., & Sih, A. (2012). Temporal dynamics and network analysis. *Methods in Ecology and Evolution*, *3*(6), 958–972. https://doi.org/10.1111/j.2041-210X.2012.00236.x

Bolzenkötter, T., Neubauer, A. B., & Koval, P. (2025). Impact of a momentary mindfulness intervention on rumination, negative affect, and their dynamics in daily life. *Affective Science*, *6*(2), 259–271. https://doi.org/10.1007/s42761-024-00291-9

Borsboom, D., Deserno, M. K., Rhemtulla, M., Epskamp, S., Fried, E. I., McNally, R. J., Robinaugh, D. J., Perugini, M., Dalege, J., Costantini, G., Isvoranu, A.-M., Wysocki, A. C., van Borkulo, C. D., van Bork, R., & Waldorp, L. J. (2021). Network analysis of multivariate data in psychological science. *Nature Reviews Methods Primers*, *1*(1), Article 58. https://doi.org/10.1038/s43586-021-00055-w

Borsboom, D., van der Maas, H. L. J., Dalege, J., Kievit, R. A., & Haig, B. D. (2021). Theory construction methodology: A practical framework for building theories in psychology. *Perspectives on Psychological Science*, *16*(4), 756–766. https://doi.org/10.1177/1745691620969647

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 of the United States of America*, *108*(50), 20254–20259. https://doi.org/10.1073/pnas.1112029108

Britton, W. B. (2019). Can mindfulness be too much of a good thing? The value of a middle way. *Current Opinion in Psychology*, *28*, 159–165. https://doi.org/10.1016/j.copsyc.2018.12.011

Britton, W. B., Lindahl, J. R., Cahn, B. R., Davis, J. H., & Goldman, R. E. (2014). Awakening is not a metaphor: The effects of Buddhist meditation practices on basic wakefulness. *Annals of the New York Academy of Sciences*, *1307*(1), 64–81. https://doi.org/10.1111/nyas.12279

Britton, W. B., Lindahl, J. R., Cooper, D. J., Canby, N. K., & Palitsky, R. (2021). Defining and measuring meditation-related adverse effects in mindfulness-based programs. *Clinical Psychological Science*, *9*(6), 1185–1204. https://doi.org/10.1177/2167702621996340

Bronchain, J., & Chabrol, H. (2020). Exploring the relationship between Schizotypal traits and dispositional mindfulness from a network perspective. *Journal of Nervous and Mental Disease*, *208*(8), 608–612. https://doi.org/10.1097/NMD.0000000000001169

Brunton, S. L., Brunton, B. W., Proctor, J. L., Kaiser, E., & Kutz, J. N. (2017). Chaos as an intermittently forced linear system. *Nature Communications*, *8*(1), Article 19. https://doi.org/10.1038/s41467-017-00030-8

Brunton, S. L., Proctor, J. L., & Kutz, J. N. (2016). Discovering governing equations from data by Sparse identification of nonlinear dynamical systems. *Proceedings of the National Academy of Sciences*, *113*(15), 3932–3937. https://doi.org/10.1073/pnas.1517384113

Bullmore, E., & Sporns, O. (2009). Complex brain networks: Graph theoretical analysis of structural and functional systems. *Nature Reviews Neuroscience*, *10*(3), 186–198. https://doi.org/10.1038/nrn2575

Butner, J. E., Bryan, C. J., Munion, A. K., & Tabares, J. V. (2021). A dynamical systems approach to examining the efficacy of suicide-focused interventions. *Suicide and Life-Threatening Behavior*, *51*(1), 97–114. https://doi.org/10.1111/sltb.12675

Champion, K., Lusch, B., Kutz, J. N., & Brunton, S. L. (2019). Data-driven discovery of coordinates and governing equations. *Proceedings of the National Academy of Sciences*, *116*(45) 22445–22451. https://doi.org/10.1073/pnas.1906995116

Chiel, H. J., & Beer, R. D. (1997). The brain has a body: Adaptive behavior emerges from interactions of nervous system, body and environment. *Trends in Neurosciences*, *20*(12), 553–557. https://doi.org/10.1016/S0166-2236(97)01149-1

Chu, M. T., Marks, E., Smith, C. L., & Chadwick, P. (2023). Self-caught methodologies for measuring mind wandering with meta-awareness: A systematic review. *Consciousness and Cognition*, *108*, Article 103463. https://doi.org/10.1016/j.concog.2022.103463

Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences*, *3*(9), 345–351. https://doi.org/10.1016/S1364-6613(99)01361-3

Collins, L. M., Nahum-Shani, I., Guastaferro, K., Strayhorn, J. C., Vanness, D. J., & Murphy, S. A. (2024). Intervention optimization: A paradigm shift and its potential implications for clinical psychology. *Annual Review of Clinical Psychology*, *20*(1), 21–47. https://doi.org/10.1146/annurev-clinpsy-080822-051119

Creswell, J. D., Lindsay, E. K., Villalba, D. K., & Chin, B. (2019). Mindfulness training and physical health: Mechanisms and outcomes. *Psychosomatic Medicine*, *81*(3), 224–232. https://doi.org/10.1097/PSY.0000000000000675

Dahl, C. J., Lutz, A., & Davidson, R. J. (2015). Reconstructing and deconstructing the self: Cognitive mechanisms in meditation practice. *Trends in Cognitive Sciences*, *19*(9), 515–523. https://doi.org/10.1016/j.tics.2015.07.001

Den Hartigh, R. J. R., Cox, R. F. A., & Van Geert, P. L. C. (2017). Complex versus complicated models of cognition. In L. Magnani & T. Bertolotti (Eds.), *Springer handbook of model-based science* (pp. 657–669). Springer. https://doi.org/10.1007/978-3-319-30526-4_30

Desbordes, G., Gard, T., Hoge, E. A., Hölzel, B. K., Kerr, C., Lazar, S. W., Olendzki, A., & Vago, D. R. (2015). Moving beyond mindfulness: Defining equanimity as an outcome measure in meditation and contemplative research. *Mindfulness*, *6*(2), 356–372. https://doi.org/10.1007/s12671-013-0269-8

Donald, J. N., Sahdra, B. K., Van Zanden, B., Duineveld, J. J., Atkins, P. W. B., Marshall, S. L., & Ciarrochi, J. (2019). Does your mindfulness benefit others? A systematic review and meta-analysis of the link between mindfulness and prosocial behaviour. *British Journal of Psychology*, *110*(1), 101–125. https://doi.org/10.1111/bjop.12338

Du, J., An, Y., Ding, X., Zhang, Q., & Xu, W. (2019). State mindfulness and positive emotions in daily life: An upward spiral process. *Personality and Individual Differences*, *141*, 57–61. https://doi.org/10.1016/j.paid.2018.11.037

Dunne, J. D. (2015). Buddhist styles of mindfulness: A heuristic approach. In B. Ostafin, M. Robinson, & B. Meier (Eds.), *Handbook of mindfulness and self-regulation* (pp. 251–270). Springer. https://doi.org/10.1007/978-1-4939-2263-5_18

Dunne, J. D., Thompson, E., & Schooler, J. (2019). Mindful meta-awareness: Sustained and non-propositional. *Current Opinion in Psychology*, *28*, 307–311. https://doi.org/10.1016/j.copsyc.2019.07.003

Enkema, M. C., McClain, L., Bird, E. R., Halvorson, M. A., & Larimer, M. E. (2020). Associations between mindfulness and mental health outcomes: A systematic review of ecological momentary assessment research. *Mindfulness*, *11*(11), 2455–2469. https://doi.org/10.1007/s12671-020-01442-2

Epstein, J. M. (2008). Why model? *Journal of Artificial Societies and Social Simulation*, *11*(4), 12–16. https://www.jasss.org/11/4/12.html

Falcone, G., & Jerram, M. (2018). Brain activity in mindfulness depends on experience: A meta-analysis of fMRI studies. *Mindfulness*, *9*(5), 1319–1329. https://doi.org/10.1007/s12671-018-0884-5

Farb, N., Daubenmier, J., Price, C. J., Gard, T., Kerr, C., Dunn, B. D., Klein, A. C., Paulus, M. P., & Mehling, W. E. (2015). Interoception, contemplative practice, and health. *Frontiers in Psychology*, *6*, Article 763. https://doi.org/10.3389/fpsyg.2015.00763

Favela, L. H. (2021). The dynamical renaissance in neuroscience. *Synthese*, *199*(1), 2103–2127. https://doi.org/10.1007/s11229-020-02874-y

Fogel, A. (2011). Theoretical and applied dynamic systems research in developmental science. *Child Development Perspectives*, *5*(4), 267–272. https://doi.org/10.1111/j.1750-8606.2011.00174.x

Fox, K. C. R., Nijeboer, S., Dixon, M. L., Floman, J. L., Ellamil, M., Rumak, S. P., Sedlmeier, P., & Christoff, K. (2014). Is meditation associated with altered brain structure? A systematic review and meta-analysis of morphometric neuroimaging in meditation practitioners. *Neuroscience and Biobehavioral Reviews*, *43*, 48–73. https://doi.org/10.1016/j.neubiorev.2014.03.016

Fried, E. I. (2020). Lack of theory building and testing impedes progress in the factor and network literature. *Psychological Inquiry*, *31*(4), 271–288. https://doi.org/10.1080/1047840X.2020.1853461

Fried, E. I. (2022). Studying mental health problems as systems, not syndromes. *Current Directions in Psychological Science*, *31*(6), 500–508. https://doi.org/10.1177/09637214221114089

Fried, E. I., & Cramer, A. O. J. (2017). Moving forward: Challenges and directions for psychopathological network theory and methodology. *Perspectives on Psychological Science*, *12*(6), 999–1020. https://doi.org/10.1177/1745691617705892

Fried, E. I., van Borkulo, C. D., Cramer, A. O. J., Boschloo, L., Schoevers, R. A., & Borsboom, D. (2017). Mental disorders as networks of problems: A review of recent insights. *Social Psychiatry and Psychiatric Epidemiology*, *52*(1), 1–10. https://doi.org/10.1007/s00127-016-1319-z

Galante, J., Grabovac, A., Wright, M., Ingram, D. M., Van Dam, N. T., Sanguinetti, J. L., Sparby, T., van Lutterveld, R., & Sacchet, M. D. (2023). A framework for the empirical investigation of mindfulness meditative development. *Mindfulness*, *14*(5), 1054–1067. https://doi.org/10.1007/s12671-023-02113-8

Garland, E., Gaylord, S., & Park, J. (2009). The role of mindfulness in positive reappraisal. *EXPLORE: The Journal of Science and Healing*, *5*(1), 37–44. https://doi.org/10.1016/j.explore.2008.10.001

Garland, E. L., Farb, N. A., Goldin, P. R., & Fredrickson, B. L. (2015). Mindfulness broadens awareness and builds eudaimonic meaning: A process model of mindful positive emotion regulation. *Psychological Inquiry*, *26*(4), 293–314. https://doi.org/10.1080/1047840X.2015.1064294

Garland, E. L., Fredrickson, B., Kring, A. M., Johnson, D. P., Meyer, P. S., & Penn, D. L. (2010). Upward spirals of positive emotions counter downward spirals of negativity: Insights from the broaden-and-build theory and affective neuroscience on the treatment of emotion dysfunctions and deficits in psychopathology. *Clinical Psychology Review*, *30*(7), 849–864. https://doi.org/10.1016/j.cpr.2010.03.002

Garland, E. L., Geschwind, N., Peeters, F., & Wichers, M. (2015). Mindfulness training promotes upward spirals of positive affect and cognition: Multilevel and autoregressive latent trajectory modeling analyses. *Frontiers in Psychology*, *6*, Article 15. https://doi.org/10.3389/fpsyg.2015.00015

Garland, E. L., Kiken, L. G., Faurot, K., Palsson, O., & Gaylord, S. A. (2017). Upward spirals of mindfulness and reappraisal: Testing the mindfulness-to-meaning theory with autoregressive latent trajectory modeling. *Cognitive Therapy and Research*, *41*(3), 381–392. https://doi.org/10.1007/s10608-016-9768-y

Garland, G., Gaylord, S. A., & Fredrickson, B. L. (2011). Positive reappraisal mediates the stress-reductive effects of mindfulness: An upward spiral process. *Mindfulness*, *2*(1), 59–67. https://doi.org/10.1007/s12671-011-0043-8

Gethin, R. (2011). On some definitions of mindfulness. *Contemporary Buddhism*, *12*(1), 263–279. https://doi.org/10.1080/14639947.2011.564843

Giommi, F., Bauer, P. R., Berkovich-Ohana, A., Barendregt, H., Brown, K. W., Gallagher, S., Nyklíček, I., Ostafin, B., Raffone, A., Slagter, H. A., Trautwein, F. M., & Vago, D. R. (2023). The (In)flexible self: Psychopathology, mindfulness, and neuroscience. *International Journal of Clinical and Health Psychology*, *23*(4), Article 100381. https://doi.org/10.1016/j.ijchp.2023.100381

Goldberg, S. B., & Davidson, R. J. (2024). Contemplative science comes of age: Looking backward and forward 20 years after Baer (2003). *Clinical Psychology: Science and Practice*, *31*(1), 39–41. https://doi.org/10.1037/cps0000186

Goldberg, S. B., Hanley, A. W., Baldwin, S. A., Bernstein, A., & Garland, E. L. (2020). Does mindfulness practice promote psychological functioning or is it the other way around? A daily diary study. *Psychotherapy*, *57*(3), 310–322. https://doi.org/10.1037/pst0000286

Goldberg, S. B., Riordan, K. M., Sun, S., & Davidson, R. J. (2022). The empirical status of mindfulness-based interventions: A systematic review of 44 meta-analyses of randomized controlled trials. *Perspectives on Psychological Science*, *17*(1), 108–130. https://doi.org/10.1177/1745691620968771

Goldberg, S. B., Tucker, R. P., Greene, P. A., Simpson, T. L., Kearney, D. J., & Davidson, R. J. (2017). Is mindfulness research methodology improving over time? A systematic review. *PLOS ONE*, *12*(10), Article e0187298. https://doi.org/10.1371/journal.pone.0187298

Goleman, D., & Davidson, R. J. (2017). *Altered traits: Science reveals how meditation changes your mind, brain, and body*. Penguin.

Gotink, R. A., Hermans, K. S. F. M., Geschwind, N., De Nooij, R., De Groot, W. T., & Speckens, A. E. M. (2016). Mindfulness and mood stimulate each other in an upward spiral: A mindful walking intervention using experience sampling. *Mindfulness*, *7*(5), 1114–1122. https://doi.org/10.1007/s12671-016-0550-8

Grabovac, A. D., Lau, M. A., & Willett, B. R. (2011). Mechanisms of mindfulness: A Buddhist psychological model. *Mindfulness*, *2*(3), 154–166. https://doi.org/10.1007/s12671-011-0054-5

Grahek, I., Schaller, M., & Tackett, J. L. (2021). Anatomy of a psychological theory: Integrating Construct-validation and computational-modeling methods to advance theorizing. *Perspectives on Psychological Science*, *16*(4), 803–815. https://doi.org/10.1177/1745691620966794

Granic, I. (2005). Timing is everything: Developmental psychopathology from a dynamic systems perspective. *Developmental Review*, *25*(3–4), 386–407. https://doi.org/10.1016/j.dr.2005.10.005

Gu, J., Strauss, C., Bond, R., & Cavanagh, K. (2015). How do mindfulness-based cognitive therapy and mindfulness-based stress reduction improve mental health and wellbeing? A systematic review and meta-analysis of mediation studies. *Clinical Psychology Review*, *37*, 1–12. https://doi.org/10.1016/j.cpr.2015.01.006

Guendelman, S., Medeiros, S., & Rampes, H. (2017). Mindfulness and emotion regulation: Insights from neurobiological, psychological, and clinical studies. *Frontiers in Psychology*, *8*, Article 220. https://doi.org/10.3389/fpsyg.2017.00220

Guidotti, R., Del Gratta, C., Perrucci, M. G., Romani, G. L., & Raffone, A. (2021). Neuroplasticity within and between functional brain networks in mental training based on long-term meditation. *Brain Sciences*, *11*(8), Article 1086. https://doi.org/10.3390/brainsci11081086

Hadash, Y., & Bernstein, A. (2019). Behavioral assessment of mindfulness: Defining features, organizing framework, and review of emerging methods. *Current Opinion in Psychology*, *28*, 229–237. https://doi.org/10.1016/j.copsyc.2019.01.008

Hadash, Y., Dar, O., Amir, I., Braver, T., & Bernstein, A. (in press). The Mindfulness Internal Attention (MIA) framework: Uncovering the attentional mechanisms of mindfulness training. *Annual Review of Psychology*.

Hadash, Y., Ruimi, L., & Bernstein, A. (2023). Looking inside the black box of mindfulness meditation: Investigating attention and awareness during meditation using the mindful awareness task (MAT). *Psychological Assessment*, *35*(3), 242–256. https://doi.org/10.1037/pas0001194

Hadash, Y., Veksler, T., Dar, O., Oren-Schwartz, R., & Bernstein, A. (2024). Peak experiences during insight mindfulness meditation retreats and their salutary and adverse impact: A prospective matched-controlled intervention study. *Journal of Consulting and Clinical Psychology*, *92*(4), 213–225. https://doi.org/10.1037/ccp0000875

Hanley, A. W., de Vibe, M., Solhaug, I., Farb, N., Goldin, P. R., Gross, J. J., & Garland, E. L. (2021). Modeling the mindfulness-to-meaning theory's mindful reappraisal hypothesis: Replication with longitudinal data from a Randomized Controlled Study. *Stress and Health*, *37*(4), 778–789. https://doi.org/10.1002/smi.3035

Haslbeck, J. M. B., Ryan, O., Robinaugh, D. J., Waldorp, L. J., & Borsboom, D. (2022). Modeling psychopathology: From data models to formal theories. *Psychological Methods*, *27*(6), 930–957. https://doi.org/10.1037/met0000303

Hayes, A. M., & Andrews, L. A. (2020). A complex systems approach to the study of change in psychotherapy. *BMC Medicine*, *18*(1), Article 197. https://doi.org/10.1186/s12916-020-01662-2

Hayes, S. C., Wilson, K. G., Gifford, E. V., Follette, V. M., & Strosahl, K. (1996). Experimental avoidance and behavioral disorders: A functional dimensional approach to diagnosis and treatment. *Journal of Consulting and Clinical Psychology*, *64*(6), 1152–1168. https://doi.org/10.1037/0022-006X.64.6.1152

Heeren, A., Lannoy, S., Coussement, C., Hoebeke, Y., Verschuren, A., Blanchard, M. A., Chakroun-Baggioni, N., Philippot, P., & Gierski, F. (2021). A network approach to the five-facet model of mindfulness. *Scientific Reports*, *11*(1), Article 15094. https://doi.org/10.1038/s41598-021-94151-2

Hollenstein, T. (2007). State space grids: Analyzing dynamics across development. *International Journal of Behavioral Development*, *31*(4), 384–396. https://doi.org/10.1177/0165025407077765

Hollenstein, T., & Lewis, M. D. (2006). A state space analysis of emotion and flexibility in parent–child interactions. *Emotion*, *6*(4), 656–662. https://doi.org/10.1037/1528-3542.6.4.656

Hölzel, B. K., Lazar, S. W., Gard, T., Schuman-Olivier, Z., Vago, D. R., & Ott, U. (2011). How does mindfulness meditation work? Proposing mechanisms of action from a conceptual and neural perspective. *Perspectives on Psychological Science*, *6*(6), 537–559. https://doi.org/10.1177/1745691611419671

Ietsugu, T., Crane, C., Hackmann, A., Brennan, K., Gross, M., Crane, R. S., Silverton, S., Radford, S., Eames, C., Fennell, M. J. V., Williams, J. M. G., & Barnhofer, T. (2015). Gradually getting better: Trajectories of change in rumination and anxious worry in mindfulness-based cognitive therapy for prevention of relapse to recurrent depression. *Mindfulness*, *6*(5), 1088–1094. https://doi.org/10.1007/s12671-014-0358-3

Isbel, B., Sysak, T., & Summers, M. J. (2020). A qualitative examination of the developmental trajectory of learning mindfulness across an 8-week

program. *Mindfulness*, *11*(12), 2741–2754. https://doi.org/10.1007/s12671-020-01484-6

Izhikevich, E. M. (2007). *Dynamical systems in neuroscience*. Massachusetts Institute of Technology Press.

John, Y. J., Sawyer, K. S., Srinivasan, K., Müller, E. J., Munn, B. R., & Shine, J. M. (2022). It's about time: Linking dynamical systems with human neuroimaging to understand the brain. *Network Neuroscience*, *6*(4), 960–979. https://doi.org/10.1162/netn_a_00230

Joss, D., Teicher, M. H., & Lazar, S. W. (2024). Temporal dynamics and long-term effects of a mindfulness-based intervention for young adults with adverse childhood experiences. *Mindfulness*, *15*(9), 2245–2261. https://doi.org/10.1007/s12671-024-02439-x

Kabat-Zinn, J. (2013). Some reflections on the origins of MBSR, skillful means, and the trouble with maps. In J. M. Williams & J. Kabat-Zinn (Eds.), *Mindfulness diverse perspectives on its meaning, origins and applications* (pp. 281–306). Routledge. https://doi.org/10.4324/9781315874586

Kantz, H., & Schreiber, T. (2003). *Nonlinear time series analysis*. Cambridge University Press. https://doi.org/10.1017/CBO9780511755798

Kelso, S. J. A. (1995). *Dynamic patterns: The self-organization of brain and behavior*. Massachusetts Institute of Technology Press.

Khalsa, S. S., Adolphs, R., Cameron, O. G., Critchley, H. D., Davenport, P. W., Feinstein, J. S., Feusner, J. D., Garfinkel, S. N., Lane, R. D., Mehling, W. E., Meuret, A. E., Nemeroff, C. B., Oppenheimer, S., Petzschner, F. H., Pollatos, O., Rhudy, J. L., Schramm, L. P., Simmons, W. K., Stein, M. B., … the Interoception Summit 2016 participants. (2018). Interoception and mental health: A roadmap. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *3*(6), 501–513. https://doi.org/10.1016/j.bpsc.2017.12.004

Kiken, L. G., Garland, E. L., Bluth, K., Palsson, O. S., & Gaylord, S. A. (2015). From a state to a trait: Trajectories of state mindfulness in meditation during intervention predict changes in trait mindfulness. *Personality and Individual Differences*, *81*, 41–46. https://doi.org/10.1016/j.paid.2014.12.044

Kuyken, W., Ball, S., Crane, C., Ganguli, P., Jones, B., Montero-Marin, J., Nuthall, E., Raja, A., Taylor, L., Tudor, K., Viner, R. M., Allwood, M., Aukland, L., Dunning, D., Casey, T., Dalrymple, N., De Wilde, K., Farley, E. R., Harper, J., … Williams, J. M. G. (2022). Effectiveness and cost-effectiveness of universal school-based mindfulness training compared with normal school provision in reducing risk of mental health problems and promoting well-being in adolescence: The MYRIAD cluster randomised controlled trial. *Evidence-Based Mental Health*, *25*(3), 99–109. https://doi.org/10.1136/ebmental-2021-300396

Lecuona, O., García-Rubio, C., de Rivas, S., Moreno-Jiménez, J. E., Meda-Lara, R. M., & Rodríguez-Carvajal, R. (2021). A network analysis of the Five Facets Mindfulness Questionnaire (FFMQ). *Mindfulness*, *12*(9), 2281–2294. https://doi.org/10.1007/s12671-021-01704-7

Lee, D. J., Kulubya, E., Goldin, P., Goodarzi, A., & Girgis, F. (2018). Review of the neural oscillations underlying meditation. *Frontiers in Neuroscience*, *12*, Article 178. https://doi.org/10.3389/fnins.2018.00178

Levi, K., Shoham, A., Amir, I., & Bernstein, A. (2021). The daily dose–response hypothesis of mindfulness meditation practice: An experience sampling study. *Psychosomatic Medicine*, *83*(6), 624–630. https://doi.org/10.1097/PSY.0000000000000912

Lewis, M. D. (2005). Bridging emotion theory and neurobiology through dynamic systems modeling. *Behavioral and Brain Sciences*, *28*(2), 169–194. https://doi.org/10.1017/S0140525X0500004X

Lewis, M. D., Lamey, A. V., & Douglas, L. (1999). A new dynamic systems method for the analysis of early socioemotional development. *Developmental Science*, *2*(4), 457–475. https://doi.org/10.1111/1467-7687.00090

Lindahl, J. R., Fisher, N. E., Cooper, D. J., Rosen, R. K., & Britton, W. B. (2017). The varieties of contemplative experience: A mixed-methods study of meditation-related challenges in Western Buddhists. *PLOS ONE*, *12*(5), Article e0176239. https://doi.org/10.1371/journal.pone.0176239

Lindsay, E. K., Chin, B., Greco, C. M., Young, S., Brown, K. W., Wright, A. G. C., Smyth, J. M., Burkett, D., & Creswell, J. D. (2018). How mindfulness training promotes positive emotions: Dismantling acceptance skills training in two randomized controlled trials. *Journal of Personality and Social Psychology*, *115*(6), 944–973. https://doi.org/10.1037/pspa0000134

Lindsay, E. K., & Creswell, J. D. (2017). Mechanisms of mindfulness training: Monitor and Acceptance Theory (MAT). *Clinical Psychology Review*, *51*, 48–59. https://doi.org/10.1016/j.cpr.2016.10.011

Lomas, T., Ivtzan, I., & Fu, C. H. Y. (2015). A systematic review of the neurophysiology of mindfulness on EEG oscillations. *Neuroscience and Biobehavioral Reviews*, *57*, 401–410. https://doi.org/10.1016/j.neubiorev.2015.09.018

Lunkenheimer, E. S., Olson, S. L., Hollenstein, T., Sameroff, A. J., & Winter, C. (2011). Dyadic flexibility and positive affect in parent–child coregulation and the development of child behavior problems. *Development and Psychopathology*, *23*(2), 577–591. https://doi.org/10.1017/S095457941100006X

Lutz, A., Abdoun, O., Dor-Ziderman, Y., Trautwein, F.-M., & Berkovich-Ohana, A. (2025). An overview of neurophenomenological approaches to meditation and their relevance to clinical research. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *10*(4), 411–424. https://doi.org/10.1016/j.bpsc.2024.11.008

Lutz, A., Greischar, L. L., Rawlings, N. B., Ricard, M., & Davidson, R. J. (2004). Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(46), 16369–16373. https://doi.org/10.1073/pnas.0407401101

Lutz, A., Jha, A. P., Dunne, J. D., & Saron, C. D. (2015). Investigating the phenomenological matrix of mindfulness-related practices from a neurocognitive perspective. *American Psychologist*, *70*(7), 632–658. https://doi.org/10.1037/a0039585

Malinowski, P. (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in Neuroscience*, *7*, Article 8. https://doi.org/10.3389/fnins.2013.00008

McGoff, K., Mukherjee, S., & Pillai, N. S. (2015). Statistical inference for dynamical systems: A review. *Statistics Surveys*, *9*, 209–252. https://doi.org/10.1214/15-SS111

Medvedev, O. N., Cervin, M., Barcaccia, B., Siegert, R. J., Roemer, A., & Krägeloh, C. U. (2021). Network analysis of mindfulness facets, affect, compassion, and distress. *Mindfulness*, *12*(4), 911–922. https://doi.org/10.1007/s12671-020-01555-8

Mehl, M. R., Eid, M., Wrzus, C., Harari, G. M., & Ebner-Priemer, U. W. (2024). Mobile sensing in psychology: Where we are and where we might go from here. In M. R. Mehl, M. Eid, C. Wrzus, G. M. Harari, & U. W. Ebner-Priemer (Eds.), *Mobile sensing in psychology: Methods and applications* (pp. 737–748). Guilford Press.

Meling, D. (2022). Knowing the knowing. Non-dual meditative practice from an enactive perspective. *Frontiers in Psychology*, *13*, Article 778817. https://doi.org/10.3389/fpsyg.2022.778817

Melnychuk, M. C., Dockree, P. M., O'Connell, R. G., Murphy, P. R., Balsters, J. H., & Robertson, I. H. (2018). Coupling of respiration and attention via the locus coeruleus: Effects of meditation and pranayama. *Psychophysiology*, *55*(9), Article e13091. https://doi.org/10.1111/psyp.13091

Mitchell, S. D. (2009). *Unsimple truths: Science, complexity, and policy*. University of Chicago Press. https://doi.org/10.7208/chicago/9780226532653.001.0001

Mooneyham, B. W., Mrazek, M. D., Mrazek, A. J., & Schooler, J. W. (2016). Signal or noise: Brain network interactions underlying the experience and training of mindfulness. *Annals of the New York Academy of Sciences*, *1369*(1), 240–256. https://doi.org/10.1111/nyas.13044

Moulder, R. G., Martynova, E., & Boker, S. M. (2023). Extracting nonlinear dynamics from psychological and behavioral time series through HAVOK analysis. *Multivariate Behavioral Research*, *58*(2), 441–465. https://doi.org/10.1080/00273171.2021.1994848

Moye, A. J., & van Vugt, M. K. (2021). A computational model of focused attention meditation and its transfer to a sustained attention task. *IEEE Transactions on Affective Computing*, *12*(2), 329–339. https://doi.org/10.1109/TAFFC.2019.2908172

Munn, B. R., Müller, E. J., Wainstein, G., & Shine, J. M. (2021). The ascending arousal system shapes neural dynamics to mediate awareness of cognitive states. *Nature Communications*, *12*, Article 6016. https://doi.org/10.1038/s41467-021-26268-x

Nelson, B., McGorry, P. D., Wichers, M., Wigman, J. T. W., & Hartmann, J. A. (2017). Moving from static to dynamic models of the onset of mental disorder: A review. *JAMA Psychiatry*, *74*(5), 528–534. https://doi.org/10.1001/jamapsychiatry.2017.0001

Nilsson, H., & Kazemi, A. (2016). Reconciling and thematizing definitions of mindfulness: The big five of mindfulness. *Review of General Psychology*, *20*(2), 183–193. https://doi.org/10.1037/gpr0000074

Panitz, D. Y., Mendelsohn, A., Cabral, J., & Berkovich-Ohana, A. (2025). Long-term mindfulness meditation increases occurrence of sensory and attention brain states. *Frontiers in Human Neuroscience*, *18*, Article 1482353. https://doi.org/10.3389/fnhum.2024.1482353

Prakash, R. S., Shankar, A., Tripathi, V., Yang, W. F., Fisher, M., Bauer, C. C., Betzel, R., & Sacchet, M. D. (2025). Mindfulness meditation and network neuroscience: Review, synthesis, and future directions. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *10*(4), 350–358. https://doi.org/10.1016/j.bpsc.2024.11.005

Prigogine, I., & Stengers, I. (2018). *Order out of chaos: Man's new dialogue with nature*. Verso Books.

Ribeiro, A. P., Bento, T., Salgado, J., Stiles, W. B., & Gonçalves, M. M. (2011). A dynamic look at narrative change in psychotherapy: A case study tracking innovative moments and protonarratives using state space grids. *Psychotherapy Research*, *21*(1), 54–69. https://doi.org/10.1080/10503307.2010.504241

Richters, J. E. (1997). The Hubble hypothesis and the developmentalist's dilemma. *Development and Psychopathology*, *9*(2), 193–229. https://doi.org/10.1017/S0954579497002022

Robinaugh, D. J., Hoekstra, R. H. A., Toner, E. R., & Borsboom, D. (2020). The network approach to psychopathology: A review of the literature 2008–2018 and an agenda for future research. *Psychological Medicine*, *50*(3), 353–366. https://doi.org/10.1017/S0033291719003404

Roca, P., Diez, G. G., Castellanos, N., & Vazquez, C. (2019). Does mindfulness change the mind? A novel psychonectome perspective based on network analysis. *PLOS ONE*, *14*(7), Article e0219793. https://doi.org/10.1371/journal.pone.0219793

Roefs, A., Fried, E. I., Kindt, M., Martijn, C., Elzinga, B., Evers, A. W. M., Wiers, R. W., Borsboom, D., & Jansen, A. (2022). A new science of mental disorders: Using personalised, transdiagnostic, dynamical systems to understand, model, diagnose and treat psychopathology. *Behaviour Research and Therapy*, *153*, Article 104096. https://doi.org/10.1016/j.brat.2022.104096

Ruimi, L., Hadash, Y., Zvielli, A., Amir, I., Goldstein, P., & Bernstein, A. (2018). Meta-awareness of dysregulated emotional attention. *Clinical Psychological Science*, *6*(5), 658–670. https://doi.org/10.1177/2167702618776948

Sala, M., Aslan, M., Gueorguieva, R., Schupak, M., & Garrison, K. A. (2023). A network investigation of core mindfulness processes. *Mindfulness*, *14*(4), 992–1004. https://doi.org/10.1007/s12671-023-02109-4

Sala, M., Vanzhula, I., Roos, C. R., & Levinson, C. A. (2022). Mindfulness and eating disorders: A network analysis. *Behavior Therapy*, *53*(2), 224–239. https://doi.org/10.1016/j.beth.2021.07.002

Sameroff, A. (2009). The transactional model. In A. Sameroff (Ed.), *The transactional model of development: How children and contexts shape each other* (pp. 3–21). American Psychological Association. https://doi.org/10.1037/11877-001

Sandved-Smith, L., Hesp, C., Mattout, J., Friston, K., Lutz, A., & Ramstead, M. J. D. (2021). Towards a computational phenomenology of mental action: Modelling meta-awareness and attentional control with deep parametric active inference. *Neuroscience of Consciousness*, *2021*(1), Article niab018. https://doi.org/10.1093/nc/niab018

Scheffer, M., Bockting, C. L., Borsboom, D., Cools, R., Delecroix, C., Hartmann, J. A., Kendler, K. S., van de Leemput, I., van der Maas, H. L. J., van Nes, E., Mattson, M., McGorry, P. D., & Nelson, B. (2024). A dynamical systems view of psychiatric disorders—Theory: A review. *JAMA Psychiatry*, *81*(6), 618–623. https://doi.org/10.1001/jamapsychiatry.2024.0215

Schiepek, G., Schöller, H., Carl, R., Aichhorn, W., & Lichtwarck-Aschoff, A. (2019). A nonlinear dynamic systems approach to psychological interventions 1. In E. Saskia Kunnen, N. M. P. Ruiter, B. F. Jeronimus, & M. A. E. Gaag (Eds.), *Psychosocial development in adolescence: Insights from the dynamic systems approach* (pp. 51–68). Routledge. https://doi.org/10.4324/9781315165844-4

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. https://doi.org/10.1016/j.tics.2011.05.006

Shen, Y.-Q., Zhou, H.-X., Chen, X., Castellanos, F. X., & Yan, C.-G. (2020). Meditation effect in changing functional integrations across large-scale brain networks: Preliminary evidence from a meta-analysis of seed-based functional connectivity. *Journal of Pacific Rim Psychology*, *14*, Article e10. https://doi.org/10.1017/prp.2020.1

Shine, J. M., Bissett, P. G., Bell, P. T., Koyejo, O., Balsters, J. H., Gorgolewski, K. J., Moodie, C. A., & Poldrack, R. A. (2016). The dynamics of functional brain networks: Integrated network states during cognitive task performance. *Neuron*, *92*(2), 544–554. https://doi.org/10.1016/j.neuron.2016.09.018

Shoham, A., Goldstein, P., Oren, R., Spivak, D., & Bernstein, A. (2017). Decentering in the process of cultivating mindfulness: An experience-sampling study in time and context. *Journal of Consulting and Clinical Psychology*, *85*(2), 123–134. https://doi.org/10.1037/ccp0000154

Simon, H. A. (1969). *The sciences of the artificial*. Massachusetts Institute of Technology Press.

Smith, J., Kempton, H., Williams, M., & van Ommen, C. (2021). Mindfulness as practice: A network analysis of FMI data. *Counselling & Psychotherapy Research*, *21*(4), 899–909. https://doi.org/10.1002/capr.12400

Spencer, J. P., Perone, S., & Buss, A. T. (2011). Twenty years and going strong: A dynamic systems revolution in motor and cognitive development. *Child Development Perspectives*, *5*(4), 260–266. https://doi.org/10.1111/j.1750-8606.2011.00194.x

Stuart-Edwards, A. (2023). Good begets good? Reciprocal relationships between mindfulness, approach coping, and subjective vitality. *Personality and Individual Differences*, *202*, Article 111970. https://doi.org/10.1016/j.paid.2022.111970

Sun, Y., Chen, Q., Li, Y., Wang, J., Bazzano, A. N., & Cao, F. (2022). Prenatal symptom cluster of psychopathology and associations with mindfulness and rumination: A network analysis. *Journal of Nervous and Mental Disease*, *210*(7), 515–524. https://doi.org/10.1097/NMD.0000000000001485

Tang, R., Friston, K. J., & Tang, Y. Y. (2020). Brief mindfulness meditation induces gray matter changes in a brain hub. *Neural Plasticity*, *2020*, Article 8830005. https://doi.org/10.1155/2020/8830005

Tang, Y.-Y., Hölzel, B. K., & Posner, M. I. (2015). The neuroscience of mindfulness meditation. *Nature Reviews Neuroscience*, *16*(4), 213–225. https://doi.org/10.1038/nrn3916

Tang, Y.-Y., Tang, Y., Tang, R., & Lewis-Peacock, J. A. (2017). Brief Mental Training Reorganizes Large-Scale brain networks. *Frontiers in Systems Neuroscience*, *11*, Article 6. https://doi.org/10.3389/fnsys.2017.00006

Thelen, E., & Smith, L. B. (2006). Dynamic systems theories. In R. M. Lerner (Ed.), *Handbook of child psychology* (Vol. 1, pp. 258–312). Wiley.

Thompson, E., & Varela, F. J. (2001). Radical embodiment: Neural dynamics and consciousness. *Trends in Cognitive Sciences*, *5*(10), 418–425. https://doi.org/10.1016/S1364-6613(00)01750-2

Timmermann, C., Bauer, P. R., Gosseries, O., Vanhaudenhuyse, A., Vollenweider, F., Laureys, S., Singer, T., Antonova, E., Lutz, A., & the Mind and Life Europe ENCECON Research Group. (2023). A neurophenomenological approach to non-ordinary states of consciousness: Hypnosis, meditation, and psychedelics. *Trends in Cognitive Sciences*, *27*(2), 139–159. https://doi.org/10.1016/j.tics.2022.11.006

Toutain, T. G., Baptista, A. F., Japyassu, H. F., Rosario, R. S., Porto, J. A., Campbell, F. Q., & Miranda, J. G. V. (2021). Does meditation lead to a stable mind? Synchronous stability and time-varying graphs in meditators. *Journal of Complex Networks*, *8*(6), Article cnaa049. https://doi.org/10.1093/comnet/cnaa049

Turner, J. C., & Christensen, A. L. (2020). Using state space grids to analyze teacher–student interaction over time. *Educational Psychologist*, *55*(4), 256–266. https://doi.org/10.1080/00461520.2020.1793763

Vago, D. R. (2022). How meditation changes the brain: A neurophilosophical and pragmatic account. In R. Repetti (Ed.), *Routledge handbook on the philosophy of meditation* (174–191). Routledge. https://doi.org/10.4324/9781003127253

Vago, D. R., & Silbersweig, D. A. (2012). Self-awareness, self-regulation, and self-transcendence (S-ART): A framework for understanding the neurobiological mechanisms of mindfulness. *Frontiers in Human Neuroscience*, *6*, Article 296. https://doi.org/10.3389/fnhum.2012.00296

Van Dam, N. T., Targett, J., Davies, J. N., Burger, A., & Galante, J. (2025). Incidence and predictors of meditation-related unusual experiences and adverse effects in a representative sample of meditators in the United States. *Clinical Psychological Science*, *13*(3), 632–648. https://doi.org/10.1177/21677026241298269

van der Velden, A. M., Kuyken, W., Wattar, U., Crane, C., Pallesen, K. J., Dahlgaard, J., Fjorback, L. O., & Piet, J. (2015). A systematic review of mechanisms of change in mindfulness-based cognitive therapy in the treatment of recurrent major depressive disorder. *Clinical Psychology Review*, *37*, 26–39. https://doi.org/10.1016/j.cpr.2015.02.001

van Geert, P. (2011). The contribution of complex dynamic systems to development. *Child Development Perspectives*, *5*(4), 273–278. https://doi.org/10.1111/j.1750-8606.2011.00197.x

Van Orden, G. C., Holden, J. G., & Turvey, M. T. (2003). Self-organization of cognitive performance. *Journal of Experimental Psychology: General*, *132*(3), 331–350. https://doi.org/10.1037/0096-3445.132.3.331

van Vugt, M., Moye, A., & Sivakumar, S. (2019). Computational modelling approaches to meditation research: Why should we care? *Current Opinion in Psychology*, *28*, 49–53. https://doi.org/10.1016/j.copsyc.2018.10.011

Varela, F. J., Evan, T., & Eleanor, R. (1991). *The embodied mind: Cognitive science and human experience*. Massachusetts Institute of Technology Press. https://doi.org/10.7551/mitpress/6730.001.0001

Vyšata, O., Schätz, M., Kopal, J., Burian, J., Procházka, A., Jiří, K., Hort, J., & Vališ, M. (2014). Non-linear EEG measures in meditation. *Journal of Biomedical Science and Engineering*, *7*(9), 731–738. https://doi.org/10.4236/jbise.2014.79072

Walpola, P., Walpola, I., & Toneatto, T. (2022). A contemporary model for right mindfulness based on Theravada Buddhist texts. *Mindfulness*, *13*(11), 2714–2728. https://doi.org/10.1007/s12671-022-01988-3

Walpola, P. L., Walpola, D. Y., Walpola, I. C., & Toneatto, T. (2017). Mapping the mind: A model based on Theravada Buddhist texts and practices. *Contemporary Buddhism*, *18*(1), 140–164. https://doi.org/10.1080/14639947.2017.1307575

Whitfield, T., Barnhofer, T., Acabchuk, R., Cohen, A., Lee, M., Schlosser, M., Arenaza-Urquijo, E. M., Böttcher, A., Britton, W., Coll-Padros, N., Collette, F., Chételat, G., Dautricourt, S., Demnitz-King, H., Dumais, T., Klimecki, O., Meiberth, D., Moulinet, I., Müller, T., … Marchant, N. L. (2022). The effect of mindfulness-based programs on cognitive function in adults: A systematic review and meta-analysis. *Neuropsychology Review*, *32*(3), 677–702. https://doi.org/10.1007/s11065-021-09519-y

Williams, J. M. G., & Kabat-Zinn, J. (Eds.). (2013). *Mindfulness: Diverse perspectives on its meaning, origins, and multiple applications at the intersection of science and dharma*. Routledge. https://doi.org/10.4324/9781315874586

Wolf, A., Swift, J. B., Swinney, H. L., & Vastano, J. A. (1985). Determining Lyapunov exponents from a time series. *Physica D: Nonlinear Phenomena*, *16*(3), 285–317. https://doi.org/10.1016/0167-2789(85)90011-9

Young, K. S., van der Velden, A. M., Craske, M. G., Pallesen, K. J., Fjorback, L., Roepstorff, A., & Parsons, C. E. (2018). The impact of mindfulness-based interventions on brain activity: A systematic review of functional magnetic resonance imaging studies. *Neuroscience and Biobehavioral Reviews*, *84*, 424–433. https://doi.org/10.1016/j.neubiorev.2017.08.003

Zhou, D., Kang, Y., Cosme, D., Jovanova, M., He, X., Mahadevan, A., Ahn, J., Stanoi, O., Brynildsen, J. K., Cooper, N., Cornblath, E. J., Parkes, L., Mucha, P. J., Ochsner, K. N., Lydon-Staley, D. M., Falk, E. B., & Bassett, D. S. (2023). Mindful attention promotes control of brain network dynamics for self-regulation and discontinues the past from the present. *Proceedings of the National Academy of Sciences of the United States of America*, *120*(2), Article e2201074119. https://doi.org/10.1073/pnas.2201074119

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