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From many to (n)one: Meditation and the plasticity of the predictive mind

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ABSTRACT

How profoundly can humans change their own minds? In this paper we offer a unifying account of deconstructive meditation under the predictive processing view. We start from simple axioms. First, the brain makes predictions based on past experience, both phylogenetic and ontogenetic. Second, deconstructive meditation brings one closer to the here and now by disengaging anticipatory processes. We propose that practicing meditation therefore gradually reduces counterfactual temporally deep cognition, until all conceptual processing falls away, unveiling a state of pure awareness. Our account also places three main styles of meditation (focused attention, open monitoring, and non-dual) on a single continuum, where each technique relinquishes increasingly engrained habits of prediction, including the predicted self. This deconstruction can also permit certain insights by making the above processes available to introspection. Our framework is consistent with the state of empirical and (neuro)phenomenological evidence and illuminates the top-down plasticity of the predictive mind. Experimental rigor, neurophenomenology, and no-report paradigms are needed to further understanding of how meditation affects predictive processing and the self.

1. Introduction

Thousands of meditation practitioners going back at least three millennia have reported accessing states far outside the ordinary mind. Meditators, even in laboratory settings, report that aspects of experience that we often take to be stable and unchanging, such as time, space, and self, can be modulated in profound ways (Ataria et al., 2015; Berkovich-Ohana et al., 2013; Dor-Ziderman et al., 2013, 2016; Fingelkurts et al., 2020; Travis and Pearson, 2000; Wahbeh et al., 2018). Moreover, according to many of these meditation traditions attaining such changes in experience are desirable and permit one to lead a happier and more compassionate life. Mindfulness meditation-based interventions are also now a conventional treatment for mental disorders in some countries (Rycroft-Malone et al., 2017) and downloads of mindfulness apps are well into the tens of millions. The scientific study of meditation is also growing exponentially (Van Dam et al., 2018). But as yet, there does not exist a unifying account of how meditation generates its manifold empirical and phenomenological effects. The lack of a general theory of meditation may be partly owing to a lack of a unifying scientific account of the mind, brain, and behavior, which has been missing until relatively recently.

Beginning with the simple axiom that an organism must resist entropy and the dissolution of its boundaries, Karl Friston's Free Energy Principle (2010) and predictive processing more broadly, is gaining scientific traction as an all-encompassing account of living organisms. It recharacterizes organisms as fundamentally anticipatory—as continuously inferring or predicting the outside world based on prior experience. This framework supposes to explain everything from the behavior and computations of unicellular organisms to the complex cognitive and emotional inner landscapes of homo sapiens, including the self (Apps and Tsakiris, 2014), through one and the same mechanism: free energy minimization (Bruineberg et al., 2018). Due to the fact that the brain lacks direct access to the external world, it must 'guess' or predict the hidden causes of sensory input based on past experience in order to adaptively interact with it. To improve its predictions, the brain is proposed to *minimize the difference* between its top-down predictions and the sensory input (i.e., free energy or prediction error). Prediction error minimization is proposed to operate at all levels of the neural hierarchy, including those detached from the present environment in service of future adaptive behavior. Thus, in this framework, perception, action and everything in between, are constructed through predictive models that have previously come to reliably reduce *errors* in prediction. Therefore, past experience is a pervasive factor underlying all mental activity (Bruineberg et al., 2018; Limanowski and Blankenburg, 2013).

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Obviously, having a mind that is constructed through past experiences is advantageous in many situations, as it is organized to align the individual's needs with the possibilities in its environment. Yet, a mind that is too restricted—that too often occupies habitual modes of thinking and feeling—and is not flexibly adapted to changing situations, can be maladaptive. Crucially, within the free energy framework, the brain does not simply undergo influences from the *outside*, but continuously generates its own model of the environment from *within* based on past experience, a reality that is continuously tested against the outside world. This also turns the typical notion of brain plasticity—the capacity to undergo change (Buonomano and Merzenich, 1998; Feldman, 2009)—on its head (Boonstra and Slagter, 2019). That is, plasticity is not simply the result of outside influences (or the capacity to *receive* form), but very much about the capacity to *produce* form from *within* (Boonstra and Slagter, 2019). This raises important questions about the plasticity of the predictive mind. If our inner mental landscape is determined by models that through past experience have come to reliably minimize uncertainty, to what extent are these models still plastic or capable of revision based on new experiences? In other words, are there ways of deconstructing and reconstructing the generative models that underwrite our predictive mind? And, if so, can we understand the ensuing deconstruction in terms of predictive processing?

In this paper, we argue that this new understanding of the brain as a predictive organ coincides well with meditation, which, in some cases, explicitly and in other cases implicitly aims at deconstructing the mind from within, in order to allow one to experience things anew, no longer wholly determined by acquired mental habits. Therefore, here we aim to, 1) provide a unifying account of empirical and phenomenological effects of intensive deconstructive meditation practice that is grounded in predictive processing, and 2) to demonstrate how scientific research on meditation can reveal novel insights into the plasticity of the predictive mind.

Here we use Buddhist meditation techniques as a paradigmatic framework. Moreover, given the rich variety of Buddhist meditation traditions and practices, for the sake of scope, we focus on three styles of meditation that are widely practiced within the major Buddhist traditions (Zen, Theravada, Tibetan Buddhism), and that so far have received the most scientific attention: focused attention (FA), open monitoring (OM), and non-dual (ND) meditation (Josipovic, 2010; Lutz et al., 2008, 2015). We also focus on these meditation techniques because our account makes the novel neurobiologically informed (Cahn and Polich, 2006) proposal that there is a single mechanism which puts each of these practices clearly on a continuum. In this sense our model is about the practices and associated states and not about the ultimate goals of meditation, which can greatly vary across traditions. Our account also aims to capture the general structure underlying these meditation styles, and therefore necessarily cannot account for all the nuance of every individual FA, OM and ND meditation techniques.

The essence of our theory is quite simple. Our main contention is that FA, OM and ND meditation gradually bring the practitioner more and more into the present moment, thereby progressively abating hierarchically (i.e., temporally) deep predictive processing in the brain. We contend that this not only reduces temporally extended processes, such as episodic future thinking and decision making, but can also explain more unusual kinds of experiences reported by meditators, including loss of self-other distinction and the cessation of time as in non-dual awareness (Josipovic, 2010; Lindahl and Britton, 2019). That is, if awareness rests in the here and now, all mental processes that involve abstract and temporally deep processing should logically fall away, including sense of self, time, space, and body representation (Fingelkurts et al., 2020). Even seemingly direct experiences, like that of a teacup, demand a complex process of construction from past experience and include anticipation of possible changes in sensory input (e.g., proprioceptive and sensory changes related to drinking from the cup). Moreover, experience is inherently enactive, to experience something is to respond to its affordances, as an agent of that response. Thus, if awareness rests in the here and now, all conceptualization including the sense of agency should also dissipate, which ultimately is said to reveal a "pure awareness" that contains no phenomenological model of either self or world (Metzinger, 2020). And finally, the broad-scale emphasis on 'stillness' in body and mind may set the scene for pruning of counterfactual models that elicit insights through what is known as 'fact free learning' (Friston et al., 2017).

This paper is organized in the following way: we will begin with an outline of predictive processing and its key components, including views on the nature of self, insight, and fact free learning (Friston, 2018; Friston et al., 2017). We then describe the three meditation styles: focused attention, open monitoring, and non-dual meditation (Josipovic, 2010; Lutz et al., 2008, 2015). We next put forward the novel neurobiologically informed proposal that there is a single mechanism which puts each of these practices clearly on a continuum. That is, *each practice gradually reduces temporally deep processing in the brain*. We will then reformulate the different meditation techniques, and associated changes in phenomenology, and key neural and cognitive effects of meditation in terms of our model. This will cast some seminal findings in a new light, as we also discuss. Finally, we will make several testable predictions that derive from our novel account and outline important avenues for future research. For example, we make state-specific and technique-specific predictions about how meditation may affect habitual responding, learning, and the sense of self.

For our theory, we have chosen the name *many-to-(n)one* to depict the reduction in *counterfactual or temporal depth*[1] (Corcoran et al., 2019)—the tendency to abstract away from the present moment (Gilead et al., 2019)—that occurs during meditation. There is widespread agreement that information is represented hierarchically in the brain, with early levels of the hierarchy being more temporally precise and concrete, and higher levels being more temporally thick and abstract (Fingelkurts et al., 2010;Friston, 2008; Huntenburg et al., 2018). The quintessence of many meditation styles is also being in the present moment to the degree possible at any given time. Thus, as a heuristic version of our model, we suggest that meditation reins in the mind's habitual tendency to abstract (*many*) away from the here and now until all phenomenological distinctions stop (*(n)one*).[2] Metaphorically, we suggest that meditation *prunes*[3] *the counterfactual tree* (see Fig. 1).

2. Predictive processing

What does the brain do? What is the basic imperative of a living organism? Evolution and gene selection theory were able to provide answers to core questions at the level of biology, explaining how life can emerge and adapt over time through natural selection (Ashburner et al., 2000). However, a unifying account of life *within the living* has yet to take hold. Organisms in their relatively short life spans also change, adapt, behave, think, and feel and seem to possess some inner imperative to survive beyond procreation. What is at the heart of this compulsion? According to the free energy principle (Friston, 2010), the basic imperative is not pleasure seeking, or any kind of simple reinforcement scheme. The imperative is to maintain a boundary between oneself and the world, or in other words, to resist the second law of thermodynamics (i.e., the tendency for isolated systems, including the human organism, to become more entropic over time). If an organism loses its boundaries, it becomes more entropic as its constitution and the world become

[1] Throughout this paper we use temporal depth, counterfactual depth, and abstraction, rather interchangeably. They are each different characteristics of hierarchically deep processing, and are often used interchangeably in the literature.

[2] Here 'one' should be understood as 'not-two', or non-dual (i.e., one without the concept of one).

[3] As the horticulturist shears away overgrown branches, meditation trims away the habitual conceptualization of experiences.

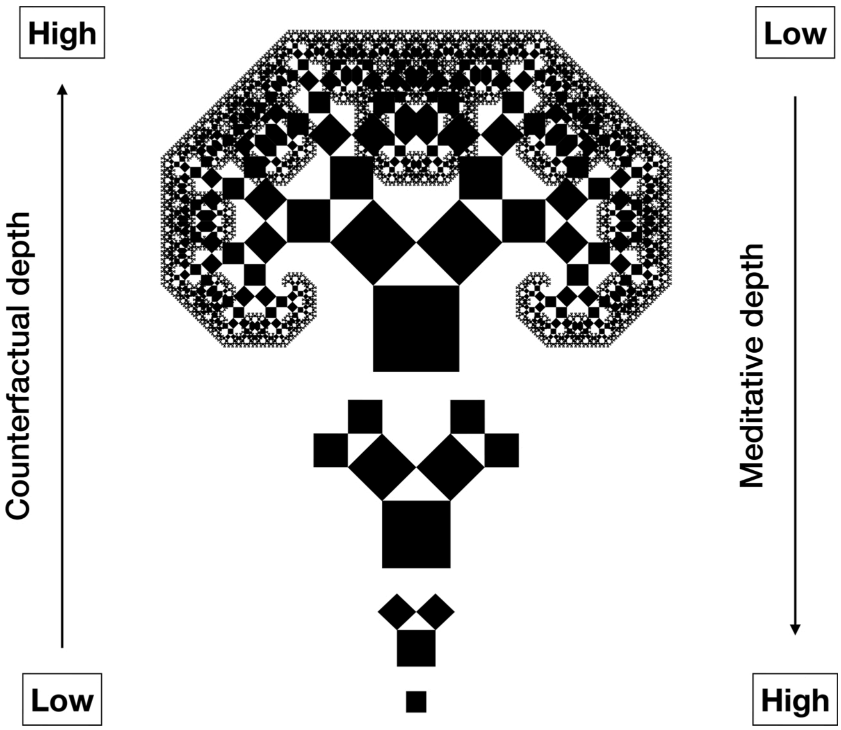

Fig. 1. Here we use the Pythagoras Tree to provide an intuitive illustration of how organisms represent the world with increasing counterfactual depth or abstraction.[24] The tree is constructed using squares that are scaled down by $\sqrt{2}/2$ and placed such that the corners of the squares meet and form a triangle between them, recursively. Analogously, the brain constructs experience from temporally precise and unimodal models of present-moment sensory representations and input (e.g., pixels on a screen), into ever more abstract, transmodal, and temporally deep models (e.g., a theory paper). Meditation brings one increasingly into the present moment, thus reducing the tendency to conceptualize away from the here and now, akin to observing the pixels rather than the words. This reduction of conceptualization ought to also have profound effects on the sense of self, which also relies on abstract model building, and ultimately is said to reveal an underlying seemingly "unconditioned" state of consciousness as such (like the white background underlying the pixels).

increasingly inseparable. In order to avoid the dissolution of its boundaries, what the organism *does* is make predictions across many timescales to produce autopoietic[4] actions that minimize the tendency towards entropy (Friston and Buzsáki, 2016). This ensures that the organism continuously revisits the limited set of states conducive for its survival. It is perhaps these relatively uncontroversial axioms on which the free energy principle is founded that has made it so appealing to philosophers and scientists alike (Allen and Friston, 2018; Clark, 2013; Milliere and Metzinger, 2020; Wacongne et al., 2011).

The organism's survival depends on high fidelity predictions. But how can the organism and its brain, which has no direct access to the outside world—only to the often ambiguous and noisy sensory signals it receives via the senses—improve its predictions? In vision, for example, the size of the image on the retina is influenced by the size of the object and how far it is from the observer (Proffitt, 2006). How then does the brain know merely based on the sensory activation how large or far away an object is? The computationally efficient solution to this problem is for the brain to prune its models using *prediction errors.* By processing the difference between model predictions and sensory input the organism can indirectly quantify the accuracy of its predictions to improve the models that generated them (Friston, 2010). Focusing on minimizing prediction errors (*entropy in the long-term)* is computationally much less expensive than processing a complex temporally layered gamut of interoceptive and exteroceptive input in every instance.

To illustrate how predictive processing works, consider the following example of drinking water. Picking up a glass of water, while avoiding tipping over the dishwashing detergent, and drinking the water, entails successful modelling of one's body, movements, immediate visuospatial environment, as well as the internal mechanisms that prevent the water from entering the trachea. Moreover, if one is subsequently "surprised" by the sensory input (e.g., what is meant to be water), then it is likely that one is drinking something dangerous. Indeed, the very desire to drink fluids is itself a prediction error arising from appropriate expectations of one's bodily volume of water via osmolality. It is not difficult to see then that an organism that does not aim to minimize prediction errors over time would not survive for long.

In order to keep our discussion focused, below we review five core features of predictive processing that are relevant in the context of meditation: hierarchical predictions, active inference, precision-weighting, self-consciousness, and fact free learning.

2.1. A hierarchy of expectations

It is a key tenet of the free energy principle that the brain models the world hierarchically (Friston and Stephan, 2007). Early basal levels of processing are temporally precise and concrete (e.g., sensory and interoceptive input) and deeper levels are temporally thick and abstract (e.g., thoughts and concepts, Limanowski and Friston, 2020). Each level of the hierarchy aims to predict the input of the level below, and inconsistencies between predictions and the input (i.e., prediction errors) are propagated further up the hierarchy. The hierarchical nature of the brain is not controversial (Badcock et al., 2019; Friston, 2008; Huntenburg et al., 2018; Kumar et al., 2007; Lee and Mumford, 2003; Taylor et al., 2015; Vidaurre et al., 2017). We will unpack the nature of this hierarchy and how it relates to self-processing and meditation in later sections.

Predictive processing accounts such as Friston's free-energy principle have roots in Bayesian Brain theories (Friston and Stephan, 2007). That is, in order to answer the difficult question of, "how should I update my beliefs given new evidence" the brain is proposed to follow hierarchical *Bayesian* inference. This means that the brain computes the 'new hypothesis' (*posterior* probability) by considering the 'old hypothesis' (*prior* probability) and the *likelihood* of the new evidence given the 'old hypothesis' or prior. Clearly, in this scheme, priors—intuitively analogous to beliefs—play a key role in what the organism ends up experiencing and believing, at every level of the hierarchy. These priors are conditioned by past experience, and not just developmentally but also phylogenetically (Badcock et al., 2019). Thus, some priors may be deeply resistant to change (i.e., *stubborn*). Examples of stubborn predictions are expectations that critical physiological variables are within

[4] Autopoietic actions are those that allow an organism to reproduce, regenerate, and therefore maintain itself (Maturana and Varela, 1991).

some range (e.g., a bodily temperature of ~37 degrees Celsius), and the expectation that one has a body (Yon et al., 2019). Predictions established ontogenetically are conceivably less stubborn than predictions that are necessary for survival and developed phylogenetically, but an important outstanding question is to what extent these predictions once established, e.g., after sensitive periods in development, can still be modified based on new experiences and learning (Yon et al., 2019).

2.2. Perceptual and active inference

Prediction errors can be minimized in two ways: an organism can change its models, or it can *act in ways that are consistent with expectations*. Put differently, one can revise (perceptual inference) or confirm (active inference): like a scientist who either changes their theory in light of new evidence, or turns a blind eye, and instead conducts experiments (makes actions) that produce expected results (Friston and Frith, 2015). Under this account, actions are reflex arcs that unfold to create an experience that is consistent with an expected state of sensory affairs. Returning to our earlier example, organisms have certain stubborn expectations regarding fluid levels. If those expectations are not met, a strong prediction error is incurred in the form of thirst. Once a certain threshold is reached, the organism generates a prediction regarding a series of sensory and proprioceptive states that eventuate in an appropriate fluid to weight ratio. By reducing the difference (prediction error) between this prediction and the current sensory input, the organism will find water and regain its balance.[5] Like the imperative to stay hydrated, modeling of the world is primarily in the service of *utility* rather than fidelity: “The brain is in the game of predicting the world, but only as a means to the end of embodied self-preservation” (Allen and Friston, 2018, p. 12).

It should be noted that active inference, although directed at confirming predictions, is also critical for model revision because action allows the brain to generate its own sensory input to test hypotheses. Crucially, the hierarchical and temporally deep nature of generative models in the human brain permits that we can also *think about actions and their potential consequences without performing them* (Friston, 2018). Thinking, decision-making, and guided attention are thus kinds of *mental actions* (Metzinger et al., 2017; Spratling, 2016). They allow us to disembody from the present moment flow of sensory data in order to covertly entertain possible, but non-existent states, i.e., *counterfactual hypotheses* (Metzinger et al., 2017). This counterfactual cognition is thought to be in the service of allostasis—of predicting future states that minimize expected free-energy under different scenarios (Corcoran et al., 2019).[6] And since all predictive processes are driven by past experiences, then higher cognition is similarly conditioned by past mental experiences. That is, learning is also a pervasive feature of thought (Perlovsky and Ilin, 2010).

This perhaps uniquely human ability (Suddendorf and Corballis, 2007) to project into the *distant* past and future is the creative force behind the complex counterfactual trees that make up higher cognition. It may be humanities greatest asset in the service of survival (Bulley et al., 2016), but it may also underlie much of human suffering as it allows us to think about what is not happening (Killingsworth and Gilbert, 2010). We may imagine many possible future scenarios—e.g., being unsuccessful, or of ill-health—that we want to explicitly avoid and may spend considerable time and energy in ruminating about such possibilities (Nolen-Hoeksema et al., 2008; Rimes and Watkins, 2005).

2.3. Attention

Simply revising beliefs whenever prediction errors occur is ultimately not beneficial, as incoming signals are often unreliable or noisy or not representative of the larger world. Hence, the reliability or *precision of prediction errors* ought to also play a role. That is, not only the upcoming sensory input needs to be estimated, but also its precision (second-order prediction), which requires integrating information over time (Friston, 2009). In predictive processing, attention is equated with *precision-weighting* and plays a key role in contextualising prediction errors (Feldman and Friston, 2010). Intuitively, attention partly determines whether one changes their beliefs (priors) in light of new information. The quintessential example is that of perception in either dark or well-lit contexts. In the dark, visual input tends to be awash with inconsistency and low definition, and thus prediction errors have *low precision* and are more likely to be ignored. On the other hand, in daylight the sensory input is clear and reliable, and thus even a surprising visual event will be registered because it has *high precision*. And paying attention to a blurry object in our periphery (is it a mug?) can incur more *precision* to any incoming surprises (a teacup!). Mechanistically, paying attention to a particular sensory event is proposed to increase the synaptic gain of the cells that are encoding the prediction error (Feldman and Friston, 2010; Smout et al., 2019). Thus, attention is said to turn up the “volume” (Clark, 2013, p. 22) of the input.

To risk over-stretching the function of attention slightly: the more attention that an event receives, the more real it is. If a change in belief occurs, it is because new information is believed to be veridical and can be trusted (i.e., has high precision). And since attention is expected precision, then attention modulates reality-correspondence, ‘realness’, or “felt confidence” in input (Carhart-Harris and Friston, 2019). This reality-shaping effect of attention may be one reason that it plays such a key role in most meditation traditions. Preempting later sections, it is interesting to note that in certain meditations, attention must eventually be released in favor of a form of bare or non-preferential attention, and in yet other meditation practices of the non-dual category, attention is released altogether (Dunne, 2011).

2.4. The inferred hierarchical self

Predictive processing accounts of the self are in the early stages (Milliere and Metzinger, 2020), and there is still not widespread agreement among scientists on a definition of the self (Fingelkurts et al., 2020). Nevertheless, assuming a predictive brain, we can draw some tentative conclusions. First, like all other aspects of mind, the self must also be a construction, built out of hierarchical models driven by past experience. Indeed, according to Friston (2018) and others (e.g., Deane, 2020) possessing a self-model is a natural consequence of active inference and prospection: One cannot predict the sensory outcomes of future actions without representing oneself in those actions as a hidden cause of changes in sensory input. For example, picking up a glass of water requires that we have a model of our body as an intentional agent who *can* pick up a glass of water. And indeed, we must have a model for the fact that we are an agent that needs such a thing as water.[7] This

[5] Clearly, thirst is a rather high-level construct used to explain our interoceptive signals and dispositions to drinking something. One can read "thirst" here as interoceptive signals, such as hyperosmolality of blood.

[6] Heuristically, planning under deep temporal models means that you have your eye on the future. Imagine driving a car and think about where you are looking, and how you are driving. Invariably, you will be looking - and steering - pre-emptively, with a focus many meters in front of you and seconds (in some cases minutes) into the future. Contrast this with being a passenger, passively enjoying the passing scenery in the moment.

[7] Note that picking up a glass of water entails the realization of a complicated course of action or plan that unfolds over several seconds. It is this planning that provides the evidence for - or is most parsimoniously explained by - the hypothesis that "it is me pursuing this course of action". This can be contrasted with an autonomic reflex to dehydration, such as the release of antidiuretic hormone. Later, we will consider the fundamental difference between low-level homeostatic reflexes - that do not involve anticipation - and allostatic behaviors, which do.

self-modeling further endows the organism with the ability to consider itself in different future scenarios (i.e., entertaining counterfactuals: I'm thirsty, but I could drink water, or tea). Changes to the sense of self, as seen in virtual reality, psychopathology (Sterzer et al., 2018) or as induced by drugs (e.g., psychedelics (Millière et al., 2018; Timmermann et al., 2018), are usefully accounted for in predictive processing by aberrant priors and precision-weighting (Adams et al., 2013; Corlett et al., 2016; Sterzer et al., 2018), although the mechanisms may vary depending on the specific case. If subjective experience—including therefore any self-models (Blanke and Metzinger, 2009)[8]—is inferred through Bayes-optimal inference under the predictive processing scheme, the existence of aberrant self-perceptions is not surprising.

The second implication is that the self is itself hierarchical in nature, a prospect recently substantiated in a neurophenomenological study in meditators (Fingelkurts et al., 2020). Gallagher (2000) made the now well-known distinction between a *narrative* and an *experiencing* self. The narrative self is embedded in our thoughts and includes our stories about the past, the future, and all our self-referential knowledge and beliefs. On the other hand, the experiencing self refers to our awareness of bodily sensations and events occurring in the present moment. The narrative self is perhaps neurally instantiated by the default-mode-network (DMN; Raichle, 2015), which is associated with key features of high-level cognition, especially mental time-travel (Østby et al., 2012) or more basic forms of counterfactual thinking (Van Hoeck et al., 2013). Indeed, Carhart-Harris and Friston (2019) propose that "…the human DMN can be considered to sit at the top end—or center—of a uniquely deep hierarchical system…". The experiencing self is likely instantiated by task-positive and interoceptive networks (that are anti-correlated with the DMN), including executive and control areas in the prefrontal cortex and anterior cingulate cortex (Fox et al., 2016) as well as the anterior insula (Seth, 2013) and other subcortical regions associated with homeostatic functions (Damasio, 2012).

Within the predictive processing account, temporally thick processes and therefore the narrative self is placed *higher* in the predictive hierarchy (Carhart-Harris and Friston, 2010). On the other hand, sensory and interoceptive input and therefore the experiencing self would be *lower* in the hierarchy (*temporally thin*, Friston, 2008). There may also be a minimal form of self even lower in the hierarchy, such as the first-person perspective itself, but this is still debated (Blanke and Metzinger, 2009; Sebastian, 2020). Moreover, in recent years experiments and a growing database of personal accounts are leading many researchers to accept the existence of *self-less* states (see Milliere and Metzinger, 2020 for a special issue). It is also worth mentioning how a minimal or basal form of self might arise. As alluded to earlier, self-modeling may be intimately tied to action, because one cannot model one's own action pathways without modeling oneself as a hidden cause in the world. Simply put, the brain needs to model a 'self' in order to predict future states that the 'self' might inhabit. Along this line of thought, Friston (2018) suggested that self-awareness arises whenever an organism generates predictions about the consequences of its actions, and thus aims to minimize the *expected* surprise resulting from those actions. In this view, the mind comes into being when self-evidencing has temporal thickness or counterfactual depth. Similarly, it has been proposed that self-experience arises from self-specific processes that are intrinsically related to the organism's own actions (Christoff et al., 2011). That is, only through action can the organism dissociate between self (sensory changes caused by oneself) and non-self (sensory changes caused by the environment), by comparing the incoming sensory input to action-based predicted sensory input. Thus, self-awareness necessarily relies on models with temporal depth, that are capable of inferring the (not yet present) consequences of actions.

2.5. Fact free learning and insight

In the above we discussed the different roles that attention (i.e., precision weighting) and active inference (i.e., mental/physical actions) play in the revision of beliefs (priors). However, there is another way to refine generative models that does not involve active inference or novel sensory input, known as *fact free learning* (Friston et al., 2017). Aha! moments or insights instantiate fact free learning because they involve the discovery of a solution, idea, or perspective without new information. For example, we might unexpectedly discover a solution while taking a shower or while engaged in another task (Laukkonen and Tangen, 2017; Laukkonen et al., 2021a; Metcalfe and Wiebe, 1987; Ovington et al., 2018). Moreover, experiments show that such insights are usually correct (indicative of refinement, Salvi et al., 2016) and can change subsequent beliefs (Laukkonen et al., 2018, 2020a, 2021b).

Central to the idea of fact free learning is that insights arise because the brain continues to refine and compress models through *Bayesian model reduction* (Friston et al., 2016). Bayesian model reduction entails finding simpler and more parsimonious models using only prior beliefs (i.e., not using sensory outcomes, Friston and Penny, 2011). This process of refinement is comparable to the "…physiological processes in sleep, where redundant (synaptic) model parameters are eliminated to minimize model complexity" (Friston et al., 2017, p.2638). As models undergo refinement and selection—thus making them more parsimonious explanations of sensory experience—they can also engender new discoveries, such as the discovery of a new perspective (generative model) that permits a novel insight (or inference, Friston et al., 2017).

Friston et al. (2017) suggest that fact free learning may not only occur during sleep but also result from reflection (or *introspection*), both explicit and implicit: "…Having acquired data, the "good scientist" reflects on what she knows (and perhaps sleeps on it), implicitly testing plausible hypotheses of a progressively simpler (less complex and less ambiguous) nature that could provide an accurate account of the data at hand" (p. 2666). The connection between fact free learning, insight, and meditation is therefore straightforward. Meditation is in many ways the embodiment of fact free learning, by virtue of its emphasis on stillness (both in body and mind) or *in-active* inference, which may trigger some analogous physiological and synaptic processes as sleep (Friston et al., 2017). Moreover, meditation can induce extraordinary, novel mental experiences ("input"), that cannot easily be accounted for by existing models, increasing their uncertainty and necessitating revision. Thus, although we argue that meditation practice in essence reduces counterfactual abstract processing, it is simultaneously an opportune moment for model revision and selection as the brain—despite the reduced activity of body and mind—may continue its prerogative of hierarchical prediction-error minimization via internal hypothesis testing: "…much like a sculpture is revealed by the artful removal of stone" (Friston et al., 2017, p. 2669). The prospect that meditation engenders insight is also at the very foundation of (for example) classical Theravada Buddhism and vipassanā (insight) meditation practice, which aim to permit specific insights into the workings of one's mind, discussed further below.

3. Meditation

It is now worthwhile to return briefly to our central thesis in light of the previous sections. Our core proposal is that meditation gradually reduces the temporal depth of processing[9] in the predictive hierarchy by

[8] In the vast literature on 'the self', there are important differences between for example Gallagher's (2000) experiencing self, Blanke and Metzinger (2009) minimal self, Seth's (2013) embodied self, and yet other conceptions (e.g., Zahavi, 2017). Nevertheless, for the purpose of our model each of these conceptions represent a clearly more basal form of self than that which is related to our self-narratives.

[9] See Section 2.1: A hierarchy of expectations.

bringing the practitioner more and more into the here and now. This process gradually prunes the counterfactual tree, reducing the brain's tendency to abstract temporally thick predictive models. Ultimately, since self-specific processes imply temporal depth of processing (Friston, 2018), being fully immersed in the here and now may also occasion a radical shift in one's ordinary sense of self-consciousness. Moreover, meditation may also foster fact free learning (insights), where one's models are refined without active inference.

To prepare for a more nuanced overview of our model, in this section we briefly describe three categories of meditation most studied in contemplative science, that also represent three main classes of deconstructive meditation in Buddhism (for much more detailed reviews of these practices see, Dahl et al., 2015; Dunne, 2011; Lutz et al., 2007; Lutz et al., 2008, 2015). These three categories (FA, OM, and ND) are umbrella terms that do not capture the full diversity found in Buddhist theories and practices. Therefore, our model should be seen as an umbrella framework that integrates three widely practiced styles of meditation. Moreover, similar practices are found outside of Buddhism, for example in Advaita Vedanta and Sufism (Dahl et al., 2015). The practices are also not always clearly distinct and multiple techniques may be used throughout one's training (Lutz et al., 2008). In the Buddhist tradition, ND meditation (Lutz et al., 2006) is particularly emphasized within Mahayana and Vajrayana Buddhism (so-called non-dual traditions). So far, most research on ND meditation has focused on Mahamudra and Dzogchen from the Vajrayana tradition (Antonova et al., 2015; Josipovic, 2010).

As we describe each meditation technique, we also highlight key ways in which they may affect predictive processing, though these notes will be made more formally in the next section. Our central hypothesis here is that each meditation style gradually draws predictive processing closer and closer to the here and now (i.e., less abstract hierarchically deep processing).[10]

3.1. Focused attention

Focused attention (FA) meditation is often practiced when one begins meditation. It involves the explicit focus on a particular aspect of one's present moment sensorium to the exclusion of everything else. The target of one's attention is often the breath, but ultimately any object in present moment experience, like one's feet while walking, can serve the same purpose. The primary aim of this practice is to stabilize one's attention in the present moment. When thoughts or mind-wandering episodes arise, attention is guided back to the sense object. Thus, FA also involves monitoring or meta-awareness of the quality of attention on the object. With practice and the development of meta-awareness it is said to become easier and eventually effortless to sustain attention on one point of focus in the present moment. Crucially, FA may help to develop the first steps of dereification that are foundational for more "advanced" practices: the ability to discover that all of one's experience is a process rather than a true reflection of reality (Lutz et al., 2015). The development of meta-awareness and dereification permit an easier transition to more advanced practices in which these aspects are further developed (Lutz et al., 2015), as discussed further below. Yet, experienced practitioners may continue to practice FA at the beginning of a meditation period to initially stabilize attention, and indeed may continue to practice FA for other reasons, such as the achievement of deep states of tranquility (Wallace, 1999).

From a predictive processing perspective, we propose that FA meditation *increases the precision-weighting of one source of present moment sensory experience*, and thereby reduces the frequency of mental processes that rely on deep temporal models. By confining experience as much as possible to one prediction (e.g., breath sensations), FA automatically encourages less habitual 'grasping' of other predictions (such as thoughts), and reduces their appearance (as their relative precision-weighting is diminished). Novice practitioners may have trouble sustaining their attention at one point of focus, reducing the precision assigned to the corresponding sensory signals, providing space for mental distractions (e.g., mind wandering). Advanced practitioners may reach a kind of 'focused homeostasis' once distracting counterfactual hypotheses become sufficiently infrequent. Another natural consequence of restricting awareness to one "object" of experience is that with more advanced practice, one is no longer engaged primarily in the narrative self, and instead is in a less abstracted, present moment mode of experiencing.

As noted earlier, expected precision prescribes reality-correspondence, 'realness', or "felt confidence", so the up-weighting of precision for the input of the FA object (e.g., the breath) should also lead to a relative down-weighting of predictions higher in the hierarchy (e.g., thoughts), and this in turn may reduce the subjective realness of distracting thoughts and feelings and provide a first step towards dereification necessary for more advanced practices (Lutz et al., 2015).

3.2. Open monitoring

Open monitoring (OM) meditation may follow after one's mind is sufficiently anchored in the present moment through FA. The practitioner may then begin to gradually open the scope of attention to the broader field of experience: A kind of 'open monitoring'. Particularly in Theravada Buddhist schools of meditation, FA practice is often used to prepare the meditator to practice OM, which is believed to permit deeper insights into the nature of the mind (Lutz et al., 2007), namely: impermanence (aniccā), non-self (anattā), and suffering (dukkha). During OM, one does not sustain attention to an explicit object of experience. Instead, in an open and receptive way one allows whatever arises in experience to come and go: sensations, thoughts, or feelings, or other states of mind, without judgement or evaluation. The focus of this practice is in the cultivation of meta-awareness and in dereification from the contents of experience. In other words, everything that appears in experience is treated equally from the perspective of a non-judgmental observer. OM may initially require some effort to maintain awareness in the here and now, and explicit attention may be briefly given to the different events that appear in experience (e.g., through a practice of labeling the contents of experience). Advanced practitioners are said to be able to effortlessly observe experience as a whole, without being 'caught' by thoughts, emotions, or anything else that arises in one's sensorium. This way, mental events "lose their representational integrity and are experienced simply as mental events, situated and embodied within a field of sensory, proprioceptive, affective, and somatic feeling tones" (Lutz et al., 2015). Thus, in OM, awareness of the background of experience further comes to the foreground, as one develops the ability to rest in a stable sense of "pure" experiencing.

Although oscillation between FA and OM may often occur during practice, unlike the directed focus of FA, OM treats all arising signals non-preferentially (e.g., a thought, an emotion, or a sensation). Thus, from a predictive processing perspective, any content of experience is assigned equal precision, and consequently *low precision* in relative terms. Crucially, the goal of OM is *not* to stop experiences from arising. Instead, one reduces 'grasping' by quickly letting arising experiences (predictions) go without confirmation, by maintaining a restful but alert state of non-judgmental observing. Thus, OM continues to reduce the precision and temporal span of predictions arising in experience. As restful non-judgmental observing increases, the system may begin to experience a kind of 'pure' sensing without evaluation. This 'pure experiencing' is conceivably temporally *prior to* evaluations of the

[10] Later, we will see that increasing the precision in the lower (sensory) levels of a hierarchy necessarily entails a decrease in (relative) precision deep within the hierarchy. In other words, meditation re-balances the hierarchical deployment of attention or precision - from higher to lower levels of hierarchal processing. Advanced stages of meditation may release precision-weighting altogether.

sensory experience. For example, sensations in the knees or back during sitting meditation may occur prior to the evaluation of the experience as "painful". This is what is believed to allow practitioners to sit for extended (sometimes many hours) at a time without moving.[11] Thus, *non-judgmental experiencing could be said to be the natural state of the system at a lower level of the hierarchy*. We therefore propose that as the frequency and temporal span of predictions such as thoughts, emotions, and sensations, decreases, then a hierarchically lower level of the predictive hierarchy (experiencing prior to evaluation of experiencing) dominates. This state is different from FA since no experience is given preferential precision-weighting, and thus 'attention' becomes 'bare' rather than 'object-oriented'.

Under this scheme, the novice OM practitioner experiences more frequent and temporally extended predictions with higher average precision than the experienced OM meditator. The more precision the prediction errors are assigned, the more likely the corresponding content is to 'eclipse' one's mindful (non-judgmental) observation. As expertise increases, the temporal span, precision, and frequency of predictions decreases, making more 'room' for background awareness. With even further practice, experiencing may lose its evaluative quality entirely. The expert OM practitioner therefore should eventually come to rest in a non-judgmental experiencing that we propose is earlier in the predictive hierarchy.

It is also plausible that the practice of non-judgmentally observing and releasing arising predictions could permit *epistemic* changes to the system, in line with classical Buddhism (Bodhi, 2011a, 2011b) and fact free learning (Friston et al., 2017). If all generated predictions (thoughts, feelings, sensations) are continually seen as appearing and disappearing, it would be logical to conclude—have the insight—that they are *impermanent* (aniccā).[12] Moreover, if one sees that all predictions are quickly interpreted by the system as pleasant or unpleasant leading to craving or aversion respectively (i.e., later in the hierarchy), then one would see the *suffering* (duhkha) inherent in much of experience. Finally, if arising predictions are not under control (i.e., appearing spontaneously), then it is also perhaps recognizable that they—including all embodied sensations and narrative self-centered thinking that are usually ascribed self-hood—are not self-induced, i.e., *do not* have any consistent unchanging self-like character (anattā). In other words, OM by making earlier levels of the predictive hierarchy perceptible may reveal that the embodied and narrative self are just *processes* rather than concrete entities. Buddhist insights may therefore be seen as new priors engendered by OM practice possibly as a result of Bayesian Model Reduction or fact free learning.

3.3. Non-dual

Non-dual (ND) meditation is of growing interest to scientists (see for example, Dunne, 2011; Josipovic, 2010; Metzinger, 2020).[13] The key component of this practice is that one aims to discover an awareness that is unchanging regardless of what happens in experience. Metaphorically the "ground of all experience". Some historians propose that this style of meditation was developed later in time than FA and OM meditation, based on emphasizing the idea that there is an awareness that is "beyond" the subject observing experience that is implicated in FA and OM (Dunne, 2011; Gyatso, 2010). From the perspective of the 'non-dual' discovery, the duality between subject and object is itself a conceptual model constructed from past experience. Clearly FA and OM still have embedded within the practice the duality between an (unconditional) observer and objects that are observed. Thus, as a final 'release' of *any* abstraction away from the here and now, in ND meditation the idea that there is a distinction between self and objects of experience also falls away, for example, by realizing that subject and object always arise together in experience. This results in a state of awareness in which there is no background or foreground of experiencing, that is hence devoid of concepts (self, objects), intentionality or the experience of time and space, i.e., a state in which even the most basic constructs of cognition allegedly no longer persist.

It is against this awareness that all cognition is said to arise. It is somewhat paradoxical then to talk about a 'non-dual practice', since the term 'practice' itself implies a duality (someone who is practicing something). Thus, one way to understand the nature of non-dual practice is as follows: *creating the conditions that reduce ordinary cognition that normally 'hides' non-dual awareness*. Such a practice is exemplified in "open presence" and Dzogchen styles of practice within Tibetan Buddhism (Dahl et al., 2015) and Shikantaza or "just sitting" within the Zen Buddhist tradition (Leighton, 2004). There are also other even older practices with Hindu origins such as self-enquiry in Advaita Vedanta (Dahl et al., 2015) that utilizes questions such as "who am I?" that point attention towards the 'subject' of experience so that its absence may be discovered (Nisargadatta Maharaj, translated talks by Frydman, 1973).[14] For a collection of case-studies describing non-dual experiences see Metzinger (2020), and for a detailed review see Josipovic (2019).

Non-dual meditation, and particularly the qualities of the non-dual experience, is perhaps the most challenging to characterize within the predictive processing framework.[15] However, since all mental experiences are constructed through a process of abstraction away from the here and now, then if one were truly to be in the present moment—i.e., not constructing models with temporal thickness—then something akin to a non-dual experience would logically arise. That is, any mental activity that relies on active inference should disappear, including activity related to self-awareness (Friston, 2018; Limanowski and Friston, 2020; Metzinger, 2020) and time (Berkovich-Ohana, 2017). To draw this conclusion, we must assume that some minimal form of experience is still possible without contents or sense of self, though it *may*[16] raise certain philosophical conundrums. As noted by Limanowski and Friston (2020, p. 2), "How could one have a conscious experience – and able to report on it afterwards – in the absence of any awareness of oneself (as having the experience)?".

In search for a naturalistic explanation of ND experiences, Metzinger (2020) developed the concept of minimal phenomenal experience and proposed that non-dual experiences are a Bayesian representation of

[11] This continued 'in-active inference' induced by physical stillness may also gradually reduce any sensory evidence that one is a skilled actor or agent, which may begin to deconstruct the very notion of one's self.

[12] Evan Thompson (2020) has also argued that meditation involves the development of new concepts, such as 'moment-to-moment arising', 'not-self', and 'impermanence', concepts that then restructure one's experience. From the perspective of fact-free learning, novel priors such as 'impermanence' may cast a simpler and more parsimonious account of the behavior of thoughts, feelings, and sensations, thereby reducing model complexity.

[13] The non-dual state was also described early on in Western Psychology. In 1890 William James coined the term 'sciousness', which he described as an awareness preceding con-sciousness that is without subject or object (Bricklin, 2003). Other descriptions of non-duality are present in Hinduism as well as western neo-Platonic and Christian traditions. James also described an experience that has non-dual qualities as follows: "During the syncope, there is absolute psychic annihilation, the absence of all consciousness; then at the beginning of coming to, one has at a certain moment a vague, limitless, infinite feeling – a sense of existence in general without the least trace of a distinction between the me and the not-me." (James, 1890/1950, p. 273)

[14] See also Ashtavakra Gita (Byrom, 1990 translation), perhaps the oldest non-dual text with Hindu origins.

[15] It is worth noting that progression from FA, to OM, to ND is not guaranteed for individuals embarking on meditation practice. It is quite possible that there exists a 'talent' for meditation that may mediate whether one is capable, or how quickly one is capable, of passing through the stages of meditation. Determining such talent is a fruitful path for future research.

[16] Whether this is a genuine philosophical conundrum is questionable (since it's not inherently paradoxical that memories should form without selfhood, e.g., semantic memories). Moreover, it's possible that transition periods away-from and into non-dual states afford memory encoding.

intrinsic arousal. Indeed, maintaining an optimal level of arousal or alertness is central to many meditation practices and may support the maintenance of appropriate sensory precision estimates. This proposal fits with work showing that arousal levels causally determine one's level of consciousness and critically enable cortical activity and therefore cognition (Laureys et al., 2009). According to Metzinger (2020), an inner representation of arousal would be expected to possess the characteristics of non-dual awareness described by practitioners, including: "…a complete absence of time-representation and any form of sensorimotor or high-level cognitive content. Further, there would be an absence of low-level embodiment in the sense of spatiotemporal self-location, interoception, and affective background, as well as of higher levels of selfhood like attentional control and cognitive agency." (p. 36). Although there is an absence of representations of self, space, and time, there would nevertheless remain an experience of wakefulness and the *potential* for cognition. The described model is as yet speculative, and further research is necessary to test this hypothesis.

Theoretically, the ND state ought to be "empty" even of the very possibility to attain conscious insights that characterize OM meditation, assuming that the system is no longer constructing temporally deep models. This appears consistent with perhaps the most popular Mahāyāna (ND) Buddhist scripture, known as the Heart Sutra, which for example states—seemingly transcending the insights of OM practice—that there is "…no truth of suffering, of the cause of suffering, of the cessation of suffering, or of the path. There is no wisdom and there is no attainment whatsoever… And, thus, he passes far beyond confused imagination. And reaches Ultimate Nirvana." (To et al., 2000). The 14th Dalai Lama also noted that the Mahāyāna tradition emphasizes emptiness (śūnyatā) of all phenomena (including Buddhist teachings and laws, or *Dharmas*, Gyatso, 2010) whereas classical Theravada Buddhism emphasizes the cessation of suffering, or insight. While we maintain that during non-dual awareness conscious insights seem logically impossible, discovering that *everything* is empty is a consistently reported insight, that allegedly qualitatively alters one's subsequent experience of reality. This may suggest that model reduction can also occur during states of minimal temporal depth (cf. in sleep) or happens relatively quickly after coming out of the non-dual state. Despite 'experiential emptiness' some forms of fact free learning may continue (e.g., selecting between model x and equally probable model y because model x is likely to lead to the least surprising outcomes, Friston et al., 2017).

It is important here to note that, although we have placed FA, OM, and ND practice on a continuum of reducing counterfactual or deep temporal processing, we are not claiming that any particular practice or tradition is superior. The interconnectedness and progression of practice highlights that they are in many ways inseparable, and may have different effects that might be perceived as valuable or not depending on the tradition. For example, whether self-less states are beneficial or detrimental has long been and still is debated within Buddhism (Thompson, 2020), as well as in the scientific literature (Britton, 2019). In classical Buddhism, subject-object orientation is not considered problematic (Dunne, 2011). Only in later non-dual Buddhist traditions, the aim became to eliminate the duality of a knowing subject and known object. Generally, it is important for researchers to realize that Buddhism is not monolithic. As a final caveat, the term non-dual has been used with some variability in the literature (Dunne, 2011; Fucci et al., 2018; Josipovic, 2010, 2019; Travis and Pearson, 2000). Our conception here is of the most 'radical' kind, wherein all possible distinctions in experience have fallen away. There are likely many phenomenological states that are less dualistic (e.g., mindful observation) and some that *feel* non-dual (e.g., reflexive awareness, Josipovic, 2019). But by virtue of these states containing subjectivity and even the ability to *know* some separate thing (e.g., reflexive awareness is believed to be recognizable even during normal states of activity) there is inherently some duality built into the experience that permits categorisation, perception, and action.

4. A unifying framework: the many-to-(n)one model

Having now laid most of the groundwork for our model, in this section we provide two illustrations and with them aim to capture the key components of the theory. In Fig. 2 below, we illustrate the effects of FA, OM, and ND meditation specifically as they relate to the depth of processing in the predictive hierarchy. Then, in Fig. 3, we illustrate with more nuance how the different meditations may affect the time-course of prediction and precision at different levels of the hierarchy.

The above figure provides a broad illustration of how each meditation technique gradually decreases abstraction in the predictive hierarchy. Although we have delineated three levels of the hierarchy to correspond to the three meditation techniques, the hierarchy is of course far more multilayered. For instance, within sensations there is also a hierarchical constructive process, whereby two-dimensional impressions are built into more complex shapes through learned statistical regularities grounded in past experience (Friston, 2005; Serre, 2014). Thus, intensive and prolonged FA practice may also be able to break down sensations into its earlier stages of construction in the hierarchy. Thinking is also likely hierarchical, ranging from simple conceptualization of an object (e.g., noting the observation of a cup), to task-unrelated and disembodied mind-wandering.

We also intentionally did not specify the nature of the subject-object distinction because what precisely constitutes the 'subject' of experience, whether it be a unified proprioceptive model (Friston, 2005; Serre, 2014), or something more basal like witness consciousness (Albahari, 2009),[17] is still debated. Nevertheless, drawing on Friston (2018), we suggest that the experience of being a subject as separate from objects (that is *self*-consciousness but not consciousness per se, see Deane, 2020; Metzinger, 2020) occurs due to predictive models aiming to reduce expected uncertainty. Thus, by being truly present, it may be possible that there occurs a release of any expectations of future states, and thus a 'non-activation' of the most basal self-model and duality itself. Also, if the current moment is no longer situated with respect to the previous and the next moment in time, the experience of timelessness is a logical consequence.

Strikingly consistent with the continuum of decreasing abstraction in our framework, in a recent meta-bioinformatics study of 17,000 experiments and approximately 1/4 of the fMRI literature, Taylor et al. (2015) used connectivity models and a data-driven approach to reveal "…an objective hierarchical landscape of cognition in the brain, *with awareness at its structural core*, and all results defined solely by a computational analysis, largely devoid of human bias" (p. 11, emphasis ours). Moreover, ~500 subjects intuitively ranked the behavioral tasks used in the analysis on a spectrum from concrete to abstract, and this ranking—somewhat astonishingly—mirrored the objective physiologically-based ranking. Thus, indicating that the brains functional hierarchy can be considered a process of abstraction further away from the core (awareness) followed by direct sensory input, and then further abstraction in the hierarchy from there (e.g., conceptual thought).

An outstanding question following Fig. 2 is *how* precisely each meditation technique reduces abstract processing. To this end, in Fig. 3 below illustrates how each meditation type may change the frequency and precision of predictions over time.

To our knowledge, what we have described is the first integrated predictive processing account of FA, OM, and ND meditation styles.

[17] Albahari (2009) proposes that the Eastern construct of witness-consciousness "captures the essence of subjectivity". The concept is originally derived from the contemplative tradition of Advaita Vedānta, and was described as follows by Gupta (1998) in his book *The Disinterested Witness: A fragment of Advaita Vedānta Phenomenology*: "[it is] the basis for all knowing [but] different from the object known. It is implied in every act of knowing. It is the ultimate subject; it can never become an object of knowledge."

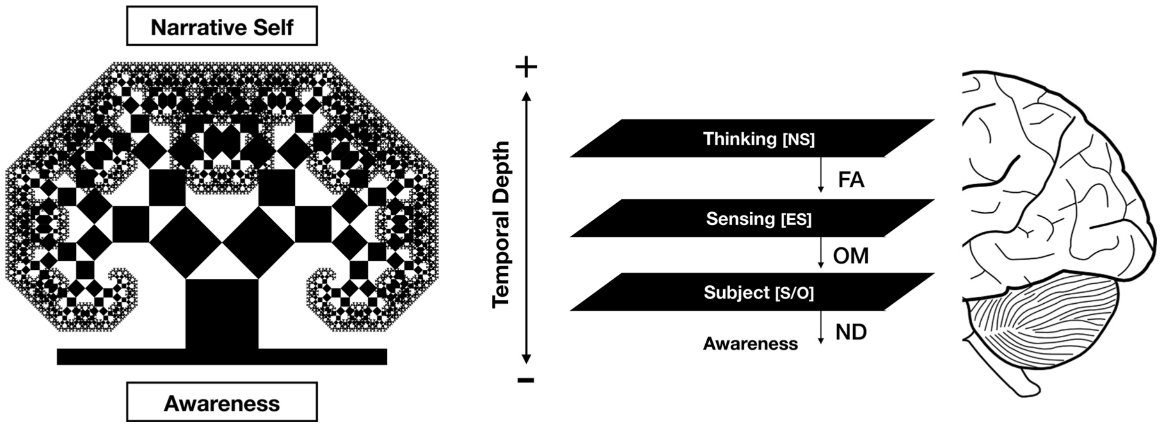

Fig. 2. In this schematic we illustrate two aspects of the many-to-(n)one model. The first and most foundational proposal is that meditation gradually *flattens the predictive hierarchy* or 'prunes the counterfactual tree', by bringing the meditator into the here and now, illustrated in the left figure. Thus, meditative depth is defined by the extent that the organism is *not* constructing temporally thick predictions. In the right figure, we dissect the predictive hierarchy into three broad levels. We propose that thinking (and therefore the narrative self [NS]) sits at the top of the predictive hierarchy (Carhart-Harris and Friston, 2010, 2019). Sensing and perceiving and therefore the embodied experiencing self [ES] sits below it (Gallagher, 2000; Seth, 2013). Finally, a basal form of self-hood characterized by the subject-object [S/O] duality sits at the earliest level. FA brings the practitioner out of the narrative self and into a more experiencing and embodied mode of being. Then, through dereification from present moment experience (including bodily sensations) OM brings the practitioner more into a state where contents of experience are treated equally, and one is able to experience non-judgmentally (sensing without appraisal), but even in very advanced states, a subject-object duality remains. During OM, certain epistemic discoveries or insights about the nature and behavior of generative models may occur. Finally, through ND practices the subject-object distinction may fall away and the background or "groundless ground" of all experience—awareness itself—can be uncovered. Another way to characterize this process is as follows: FA employs *regular* (conditional) attention to an object of sensing, OM employs *bare* (unconditional) attention, and ND practice employs *reflexive* awareness that permits the non-dual witnessing of the subject-object dichotomy and finally pure or non-dual awareness by releasing attention altogether.

Although each meditation is proposed to uniquely modulate predictive processes, they nevertheless exist on a continuum where each strategy gradually breaks down increasingly ingrained expectations. Yet, one may wonder if true present-momentness is ever possible, given that also in the ND state, vital bodily parameters must remain within bounds. Thus, we propose that the ND state is characterized by a collapse of predictive processes that possess temporal depth and involve minimization of *expected* surprise. If one is no longer making any predictions about the next moment in time, then there is also no reference for time (i.e., past or future within which to define the present) or a continuous sense of self (i.e., no construct of self that was, is, and will be). Under this view, vital homeostatic predictive processes that operate at low levels of the hierarchy and do not elicit subjective experiences may continue, such as the maintenance of body temperature and blood circulation within necessary bounds. Yet, obviously, if one would stay in the ND state too long (as in the dark room), one would naturally end up dead. Ultimately, humans, like any living creature, have evolved to occupy a specific econiche that allows them to maintain their boundary, to not fall into entropy, which requires for example expectations to eat or drink. Expert meditators report that it is possible not to experience hunger or thirst (indeed any bodily experience whatsoever) during meditation, which makes sense from our perspective given the counterfactual nature of allostatic processing in hierarchical models. To illustrate with the example of hunger, "…hunger does not simply reflect an inference about hypoglycaemia but the belief that if I act in this way, I will avoid (surprising) interoceptive (low blood sugar) cues. This reflects the quintessentially counterfactual nature of allostatic processing in hierarchical models." (Pezzulo et al., 2015, p. 26). As we experience the world not just with our bodies, but because of our bodies, ultimately, expectations inherited through evolution about physiological allostasis ought to 'kick in' and drive behavior towards survival, albeit in extreme cases.[18]

4.1. *Predictive processing & meditation: A nascent field*

> "…it is easy to see that the FEP [Free Energy Principle] framework appears optimally suited for the scientific investigation of contemplative practices. In fact, it ties together in a coherent theoretical scaffold the core meditative notions of attention (top–down deployment of precision weighting), the conditioning power of habitual self-related patterns of thought and behavior (priors), and the embodied nature of cognition and emotion (interoceptive inference)." (Lutz et al., 2019, p. 167)

Several theoretical proposals have been put forward in recent years about how meditation may affect predictive processing, although none of these distinguished between effects of different styles of meditation (although the existence of possible differences were acknowledged by both Lutz et al., 2019 & Pagnoni, 2019). In a published conversation on predictive processing and meditation between Pagnoni (a neuroscientist) and Guareschi (an Abbot of a Zen monastery, Pagnoni and Guareschi, 2017), the role of attention and bodily posture was emphasized as important ingredients to make generative models more susceptible for revision in light of new input. More recently, Lutz et al. (2019) framed FA meditation in predictive processing terms as corresponding to "the selection of a policy that includes the mental action of setting a high precision for the sensory prediction errors associated to the chosen attentional target and the prescribed bodily posture". They furthermore describe the shift from a state of focus to mind wandering as involving

[18] In the famous case of Ramana Maharshi, it is said that he was so absorbed in ND awareness that "…he was completely oblivious of his body and the world; insects chewed away portions of his legs, his body wasted away because he was rarely conscious enough to eat and his hair and fingernails grew to unmanageable lengths… [a return to a normal physical condition] was not completed for several years." (Godman, 2017). When he was discovered, food had to be placed in his mouth to prevent him from starving.

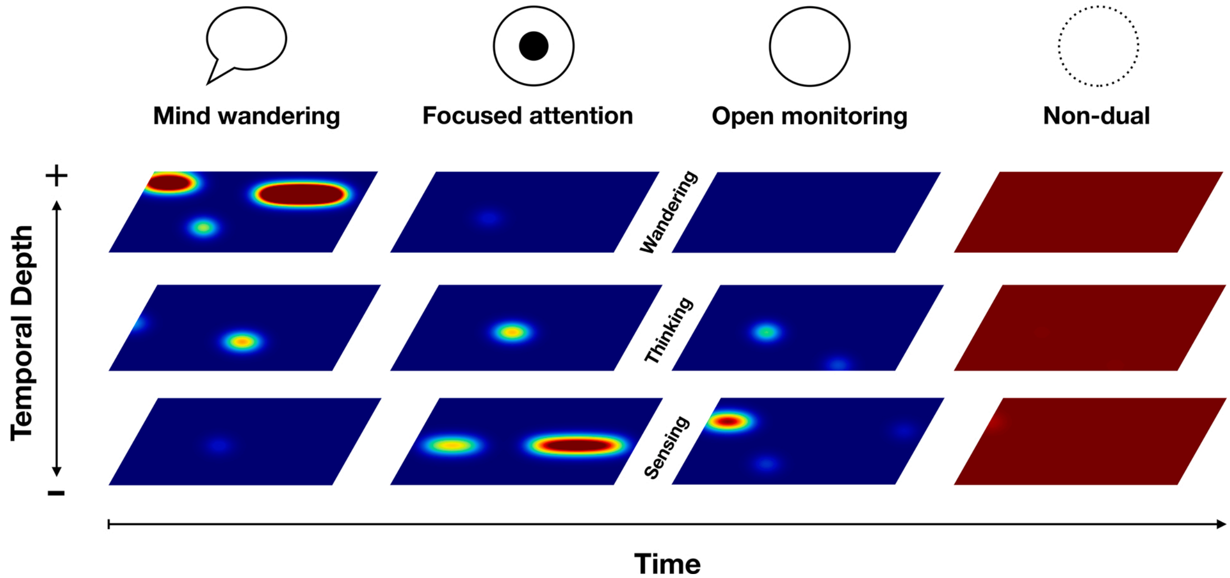

Fig. 3. Here we illustrate the precision and frequency of predictions at different levels of the predictive hierarchy during mind wandering, FA, OM, and ND. Blue rectangles represent levels of the predictive hierarchy, with counterfactually deeper and later levels represented at the top (e.g., mind wandering and the narrative self), task-relevant thinking in the middle, and the bottom rectangles represent earlier, temporally thin levels (e.g., present moment sensory experience). Ovals represent the predictions active in one's experience. The redder the oval the higher the precision-weighting of the prediction. The location of the oval in a specific rectangle represents a different prediction of the same level of the hierarchy. For example, during FA meditation, one engages attention (increases precision) of a *specific* prediction at earlier levels of the predictive hierarchy (e.g., the breath). With practice, one can sustain attention on the same prediction for a longer period of time while decreasing the frequency and relative precision of predictions higher in the hierarchy. When one practices OM, different predictions will still arise in experience but are assigned lower precision, as illustrated by smaller and lighter ovals. With ongoing practice of OM, predictions arise less frequently and become less 'sticky', thus also disappearing faster. Increasingly experiencing without appraisal (an earlier level of the predictive hierarchy) dominates as predictions, or contents of experience, become less relevant and capture attention less. Finally, during ND meditation, the awareness inherent in experience becomes the foreground. In FA and OM, predictions within experience are still the prominent event in experience. However, in the ND state, all contents of experience, as well as the subject of experience, fall away, and only awareness (without background or foreground) remains. This is represented by the background of the rectangle becoming red instead of blue. Note that for the FA, OM, and ND categories we have exemplified a relatively advanced practitioner. For a more novice meditator one can generally expect longer, more frequent, and more variable predictions at higher levels of the hierarchy.[25]

two processes: a change in prediction from sensory input (e.g., breath) to mental events (e.g., thought), and a corresponding shift in expected precision higher in the hierarchy (e.g., from sensing to thinking). This characterization is largely consistent with our account of FA meditation, where the goal is to bring attention away from thoughts (predictions high in the hierarchy) via increasing expected-precision of a sensory object (lower in the hierarchy).

Lutz et al. (2019) further proposed that FA meditation is characterized by inaction at multiple levels: the level of behaviour (sitting still), vision (e.g., keeping one's eyes centrally directed), and thought (by maintaining attention on a specific object). This non-action radically restricts active inference, and thus reduces the influence of prior beliefs and upweights the influence of sensory evidence. Indeed, past theorizing emphasizes that the strict bodily posture adopted in meditation is not arbitrary (Pagnoni and Guareschi, 2017; Pagnoni, 2019; Lutz et al., 2019). Lutz et al. (2019) suggested that the posture aids focus by alerting the meditator to mind-wandering whenever one "slouches", thus eliciting a prediction error that brings the meditator back to the sensory object, functioning as a kind of bio-feedback device (Pagnoni, 2019). Pagnoni also recently connected another specific meditation technique to predictive processing known as Shinkantaza, a form of Japanese (ND) Zen meditation. Interestingly, and at first glance in contrast to our model, Pagnoni suggests that this meditation practice *increases* the counterfactual richness of processing. Noting that this is "paradoxical" given the meditators focus on the here and now, the idea is that meditation weakens ingrained prediction loops and this in turn permits one to entertain a broader set of counterfactuals (particularly outside of formal meditation). Thus, while we propose that meditation itself "prunes the counterfactual tree", this pruning may be precisely what allows the system to *then* embody a more flexible and variable—or more rich—set of counterfactuals post-meditation by down-weighting the precision of ingrained habits of mentation. Put simply, the *state* of meditation decreases counterfactual processing (as we propose), but the enduring result or *trait* of meditation may permit a more flexible and rich counterfactual processing in daily life.

To date, no distinctions were made regarding the way that different styles of meditation may change predictive processing. Moreover, our model takes an important step by proposing a single mechanism that can account for the effects of FA, OM, and ND: They progressively reduce abstract processing in the brain. We also suggest that when viewed as a continuum of 'hereness and nowness', the purpose of these practices go beyond the regulation of cognition, attention, and emotion (as typically emphasized in the literature, e.g., Slagter et al., 2011) and instead emphasize the reduction of habitually generating predictions based on past experience. Like previous work, we also acknowledge the crucial role played by the embodied, holistic *in-active inference* of meditation that we think serves to prevent habitual predictions from arising in experience. Our model also goes further to propose how the three main meditation techniques may gradually deconstruct self-related predictions, unraveling increasingly basal forms of self-hood, until that which is even prior to self-modeling can be experienced. And finally, we also provide a framework for understanding how certain key insights may arise through fact free learning, which may cascade a radical revision of one's generative model and key priors.

5. Key empirical predictions and support

In this section, we delineate key empirical predictions that can be derived from our many-to-(n)one model. As yet few studies have specifically examined how meditation may modulate predictive processing.

Also, so far, most research has focused on the effects of FA and OM meditation on brain and mental functioning, possibly because these meditative states can be applied to an external task more easily than the ND state. Therefore, we here selectively review some seminal studies for initial evidence in support of our model and to illustrate how existing findings can be reevaluated within our framework. Given the nascent field, our model is also forward looking and we hope that it will inspire many new directions for empirical work.

5.1. Meditation reduces the temporal depth of generative models and corresponding mental processes

Our core proposal is that the temporal depth of mental activity reduces from FA to OM to ND meditation (Fig. 3). This first of all leads to the key prediction that (neural) activity should decrease across the temporal hierarchy across meditation styles. This should ultimately affect any temporally thick mental process, including conceptualization and the sense of self.

First, as FA meditation brings about a shift from thinking to sensing by increasing the expected precision of one source of present sensory experience, engagement with temporally thick counterfactual predictions (e.g., mind wandering, planning for the future) higher in the hierarchy should naturally be reduced. Indeed, one seminal study by Lutz et al. (2009) found that practitioners of a three-month meditation retreat exhibited an increase in the temporal consistency with which the brain responded to auditory tones presented in the attended ear during FA meditation, that was accompanied by a reduction in reaction time variability, suggestive of a more stable focus of attention. Other studies have accordingly associated FA meditation with reduced mind-wandering (Levinson et al., 2014; MacLean et al., 2010; Mrazek et al., 2012), and decreased default mode network activity typically associated with self-referential processing and offline thoughts (Fox et al., 2016) proposed to lie at the top of the processing hierarchy (Carhart-Harris and Friston, 2010, 2019). These findings align with the notion that FA enhances present-moment awareness of one source of sensory input, thereby logically reducing temporally thick processes detached from the current environment.

Next, OM meditation withdraws selective attention in favor of a broad scale dereification from the contents of experience. Such non-judgmental experiencing, we have proposed, equates to a reduction in the relative expected precision of all contents of experience, resulting in non-reactive awareness of whatever rises in experience. This should be reflected in reduced mental acting on events (e.g., judging, evaluating). In line with this, Slagter et al. (2007) found that after 3 months of OM practice under intensive retreat conditions, participants showed an enhanced ability to notice the second of two target stimuli (T1 and T2) presented in close temporally proximity (i.e., a reduced attentional blink). Moreover, this increase in T2 perception was brought about by a reduction in attentional clinging to the first target stimulus, as reflected by a smaller T1-evoked P3b, a brain potential associated with higher-order stimulus processing. These results make sense within our framework: if each passing stimulus is assigned lower precision, then the first target is less likely to capture attention (be temporally deeply processed), permitting better detection of T2. Further evidence that OM meditation reduces the construction of temporally deep models comes from meditation studies on painful experiences. The experience of pain is also a highly automatic inference. But, like other subjective experiences, under the predictive processing framework, pain is the outcome of an inferential process. Thus, being fully immersed in the here and now—i.e., not constructing temporally deep models—it would *theoretically* be possible for meditation to modulate the construction of painful experiences. Consistent with this idea, Perlman et al. (2010) found that OM (but not FA) meditation leads to significantly lower ratings of unpleasantness for painful stimuli, but *not* of intensity. This finding also makes sense under our framework where OM works to reduce the temporal depth of processing to a more direct experiencing prior to appraisal/judgment.[19]

Finally, in ND meditation, even processes that are temporally prior to appraisal/judgement, e.g., related to perceptual categorization or semantic processing, should disappear. Yet, what is exactly left in the ND state is unclear (Srinivasan, 2020). Stimuli (e.g., a spoken word) may still evoke responses in early sensory regions in a bottom-up manner, as in coma patients (Morlet and Fischer, 2014; Qin et al., 2008), but they may no longer be responded to in a top-down manner by regions further up the processing hierarchy (e.g., that bind features or derive word meaning). This would be in line with proposals that the ND state is devoid of conceptual representational content, as even the conceptualization of e.g., a cup relies on past experiences with a cup and incorporates counterfactual elements regarding its future use (Dunne, 2015; Metzinger, 2020). Yet, so far, few studies have examined the effects of ND meditation, likely because one cannot ask meditators to engage in an external task while in the ND state, since this would immediately disrupt this state of in-active inference. Most studies have looked at changes in “resting state” fMRI and EEG activity during ND, reporting changes in rhythmic neural activity and connections between brain networks (Berman and Stevens, 2015; Josipovic, 2014).

Yet, there is some evidence that meditation may affect even basic perceptual predictions from a study by Carter et al. (2005), which examined effects of extensive meditation experience on binocular rivalry. Binocular rivalry is the fascinating phenomenon that when two images are presented separately to each eye (e.g., a face and a house), the observer perceives an alternating face *or* house image (and sometimes a mix). Under the predictive processing framework (Hohwy et al., 2008), the rivalrous perception occurs because the input violates the brains expectations that two different images can occur in the same spatio-temporal location. Thus, past experience prevents the perception of the ‘true’ input, i.e., a coalesced face-house image. Moreover, perception continues to switch between percepts because the unperceived stimulus continues to trigger prediction errors until it leads to a revision in the posterior hypothesis (and the cycle continues). Intriguingly, when Carter et al. presented binocular rivalry stimuli to Tibetan monks with extensive meditation experience, they found that one-point meditation (an advanced form of FA) reduced perceptual switch rates (including three monks who experienced a stable stimulus for the whole five-minute period!). From the predictive processing perspective, this makes sense if the meditators, through FA, increase the precision of the prediction errors of the attended stimulus (thus, overpowering prediction errors from the unperceived stimulus). Yet, more strikingly, the authors also found something highly unusual: One of the monks reported experiencing a prolonged so-called ‘mixed percept’. Under the predictive processing framework this suggests that the stubborn prediction ‘two images cannot appear in the same spatio-temporal location’

[19] In the present framework, evaluation, appraisal and judgement can be read as synonyms for inferring the most plausible policy to enact. Crucially, a suspension of evaluation requires a loss of precision of policy selection. On this view, OM meditation precludes precision at higher levels responsible for evaluating the affordances of an action; namely, any predictive processing that could realize the self as agent.

was broken down.[20] Carter et al. (2005) concluded that "These results contrast sharply with the reported observations of over 1000 meditation-naïve individuals tested previously". Since it is difficult to maintain deep states of meditation while providing responses, participants were not comfortable in responding during the experiments, and thus the results were dependent on post-hoc self-reports. An important direction for meditation research is to develop paradigms that do not interrupt the meditation, but can track neural representations and perceptual experience, which we address further below. The findings by Carter et al. also highlight the fact that effects of different meditation styles can overlap, and that non-dual awareness can also be realized through FA and OM meditation practices (Wallace, 1999). We will also return to this topic in our Discussion.

Reductions in the temporal depth of processing should also logically lead to changes in the sense of self, as noted above. As meditation 'prunes the counterfactual tree' (flattening the predictive hierarchy), it necessarily also prunes one's sense of self, from a narrative form of selfhood all the way to selfless awareness. In line with this, a seminal neuro-phenomenology study by Dor-Ziderman et al. (2013), 12 experienced vipassana meditators were instructed to enter 3 states of "self--awareness", while MEG recordings were made. The three states—similar to our characterization—were: the narrative self, the minimal self (or experiencing self), and the "self-less". Consistent with extensive fMRI research on self-related processing (Gusnard et al., 2001), attenuation of the narrative self was supported by decreases in gamma oscillations source localized to frontal and particularly medial prefrontal cortices. Self-less experiences were consistently self-reported to lack agency or ownership and emotions (negative, positive, and mixed). Notably, some of the highly experienced meditators who reported the most vividly self-less experiences showed additional attenuation of beta-band activity in the inferior parietal lobule and left dorsomedial thalamus (Dor-Ziderman et al., 2013). As noted by Dor-Ziderman et al. (2013), the inferior parietal lobule has been implicated as a key region associated with the sense of agency and subjective control (Nahab et al., 2011). In another study with a similar design, Dor-Ziderman et al. (2016) the transition from a minimal form of self-experience to a self-less state in ND meditation was associated with changes in beta oscillations localized to the temporo-parietal junction (TPJ, including the inferior parietal lobule (as in the previous study) as well as the medial parietal cortex including the precuneus (a key node for self-representation). Another study using functional magnetic resonance imaging (fMRI) in 24 Tibetan Buddhist meditation practitioners suggests that ND meditation may lead to alterations in interactions between intrinsic networks involved in self-referential processing, of which the precuneus is a central node, and extrinsic networks involved in external, task-related processing (Josipovic et al., 2011). This finding is consistent with the idea that ND practice particularly influences the habitual organization of cognition along a subject-object dichotomy. Thus, neuroimaging studies combined with phenomenal reports in some cases support radical changes in the sense of self as a function of meditation. Yet, more work is necessary to directly test our prediction that the sense of self is hierarchically pruned away across meditation styles. Also, achieving advanced states of meditation is not a process that is always experienced positively, and challenging and even impairing experiences can arise (Fingelkurts et al., 2015; Lindahl, 2017; Lindahl and Britton, 2019). In some cases alterations to the sense of self are also experienced as distressing or resembling psychopathology (Lindahl and Britton, 2019). Thus, the outcomes of (especially) more intensive meditation may not coincide with the goals of mindfulness practice for many lay practitioners (e.g., reducing stress, being more productive), and more work is necessary to address these negative experiences, as we further discuss in the Discussion.

To summarize, we discussed key findings in the literature in support of our hypothesis that the temporal thickness of mental activity reduces from FA to OM to ND meditation. These findings also provide initial evidence for the notion that mental processes of corresponding temporal thickness disappear along the way, including eventually basic self-evidencing.

5.2. Meditation reduces prediction formation and prediction error signaling

If experience is more and more reduced to the present moment across meditation styles, this should also modulate novel prediction formation and prediction error signaling. Consistent with this idea, Valentine and Sweet (1999) found that OM meditators were less biased by past temporal regularities than FA meditators. That is, when a stream of auditory tones that participants had to count, suddenly shifted from a slow rate (0.25hz) to a much faster rate (7hz), the OM group performed better. These results may suggest that the OM meditators previously did not develop strong temporal expectations that biased subsequent perception, in line with the notion that OM induces a state of present-moment awareness in which experience is less influenced by what just happened or may happen in the future. Another not mutually exclusive explanation is that, because the unexpected condition was also *faster,* the OM meditators were better able to 'release' each appearing stimulus in order to count the subsequent sound (see also Hanley and Garland, 2019 for evidence that mindfulness training can reduce Pavlovian conditioning).

Whether or not FA meditation reduces novel prediction formation may depend on whether the inducing stimulus is the object of FA meditation. Prediction formation may be accelerated when the object of FA contains predictable sensory variance, given that attention reduces the relative influence of prior expectations by increasing the gain of sensory prediction errors hence promoting model revision and new learning. In line with this, several studies have reported a larger mismatch negativity, an event-related potential evoked by an unexpected stimulus, during FA meditation (Fucci et al., 2018; Srinivasan and Baijal, 2007), indicative of the development of more precise sensory expectations through FA. Yet, for events that occur outside of the focus of FA meditation, prediction formation and error signaling should be reduced, as those are not assigned precision, decreasing prediction formation.

ND meditation has also been associated with reduced prediction formation. For example, a study by Antonova et al. (2015) found reduced habituation of the startle response to unexpected, startling sounds. Normally, this phylogenetically primitive defense reflex (Koch, 1999) reduces in strength after repeated presentation of the inducing stimulus. However, this study reported no evidence of startle response habituation in 12 expert meditators who were instructed to rest in a non-dual state while being presented with startling sounds. This may suggest that in the ND state, the brain does not develop predictions based on new experiences. Interestingly, participants with moderate meditation experience showed more habituation than control subjects, highlighting that expertise or depth of meditation may not be a linear process, but something more akin to an inverted U-curve (see also Brefczynski-Lewis et al., 2007). Similarly, Levenson et al. (2012) found that a highly experienced meditator (40 years of practice) showed a smaller startle response when meditating compared to 12 control subjects, as shown by several physiological markers. Notably, ND meditation resulted in the smallest startle response (relative to FA), consistent with our framework. Yet, in another study, the mismatch negativity generated by an unexpected stimulus was not smaller during ND meditation compared to a control (reading) condition (Fucci et al., 2018). This null finding may suggest that developing predictions based on simple sensory regularities is an automatic process (stubborn), which is corroborated by the fact that the mismatch negativity is still observed in comatose patients (Boly et al., 2011). The above studies suggest that

[20] The Carter et al. (2005) findings also highlight the fact that very advanced FA practices may also be able to break down stubborn predictions. Indeed, it is believed that some practitioners are able to discover non-dual awareness through advanced FA, thus bypassing OM (Wallace, 1999).

during more advanced meditative states, the development of new predictions and prediction error signaling is reduced during some forms of meditation, as our model also predicts. They also highlight the potential of meditation to reveal which predictions may be stubborn to change.

5.3. Methodological considerations

In the above, we discussed main empirical predictions that can be derived from our model and selectively reviewed key findings from meditation studies in light of our many-to-(n)one model. This selective review also brought up some general challenges inherent to the scientific study of meditation, that the field of meditation research needs to (continue to) address to grow into a mature field of science (Davidson and Kaszniak, 2015; Slagter et al., 2011; Van Dam et al., 2018). First, meditation practice is inherently a subjective endeavor, and the number of hours of meditation experience does not necessarily indicate how advanced someone is in their practice. Thus, developing better methods to determine the quality of meditative states and track meditation experience is of utmost importance for understanding the physiological and psychological effects of meditation. Neurophenomenology, the combination of brain imaging with micro-phenomenology—detailed reports about one's mental experiences—provides one fruitful approach (Petitmengin et al., 2019; Varela, 1996). This could for example clarify if a practitioner was truly able to induce a ND state in an experimental setup. But much further progress is still possible and necessary. It is particularly important that a systematic and validated set of first-person methods is developed, that is also specifically tailored towards different styles of meditation, but also treats them as lying on a continuum with partially overlapping effects. While the three styles of meditation are here proposed to lie on a continuum, gradually reducing the temporal depth of processing, their effects also greatly overlap. Present-moment awareness and dereification are for example conceivably higher during advanced states of FA than during novice OM states (Lutz et al., 2015). It is even possible to realize non-dual awareness through FA in exceptional cases (Wallace, 1999). This emphasizes the importance of being able to quantify and track individual meditation experiences.

In developing methods to track stages of meditation advancement, it is also very important to acknowledge that different meditation traditions may have different aims. For instance, classical Buddhism emphasizes insight into the three characteristics of experience: impermanence (aniccā), non-self (anattā), and suffering (dukkha). Thus, while we may be able to scientifically determine a meditators capability to enter 'deep states of meditation' based on our framework, what exactly constitutes "progress" is also determined uniquely by different meditation traditions and involves factors well beyond the meditation practice, such as ethical action. In general, researchers should be well aware of the many different meditation practices and Buddhist traditions that exist, and the historical context in which they developed (Dunne, 2015).

Another methodological challenge is that some very advanced meditative states may make it difficult to provide *any* useful self-reports whatsoever (during meditation or post-hoc) given the inherently non-conceptual nature of the meditation states. Moreover, one cannot ask meditators to engage in typical experimental tasks that require them to respond to stimuli during more advanced meditative states either, as this would automatically force them to engage in active inference. Yet, the consequence of this is that there is very little systematic data about the mind during more advanced meditation practices, such as ND. One promising approach that may reveal the nature and neural basis of phenomenal experience during advanced meditative states without relying on reports is to combine so-called no-report paradigms with brain imaging (Tsuchiya et al., 2015). Specifically, machine learning methods that utilize neural activity as *representational information*, for example multivariate pattern analysis or "decoding" techniques—in concert with the delivery of stimuli through so-called no-report paradigms—could be used to learn more about advanced states of meditation that would otherwise be out of scientific reach, and their effects on predictive processing. Future studies should also include measurements of physiological activity, such as bodily arousal, that may critically change during meditation (Britton et al., 2014; Metzinger, 2020).

Yet another major methodological challenge in the scientific study of meditation concerns the fact that participants cannot be blinded to the nature of the study (i.e., meditation) and hence may have certain expectations on how meditation should affect e.g., their cognitive performance that can (implicitly) bias results (i.e., the well-known placebo effect; Wampold et al., 2005). A recent study, for example, found that participants that were recruited using a suggestive flyer, advertising a "brain training and become smarter" study, scored 5–10 IQ points higher on an intelligence test after performing a 30-min cognitive "training" than participants that were recruited using a non-suggestive flyer that simply advertised a psychological study for monitory reimbursement (Foroughi et al., 2016). This example illustrates the profound effects that expectations can have on study outcomes. Participants in a meditation study may also be more motivated to do well because they believe meditation has positive effects or because they think the experimenter expects them to do well. It is therefore critical that meditation researchers try to control for these non-specific effects that can confound results by including active control groups. Active control groups could consist of experts in some other domain (e.g., athletes; Andreu et al., 2017) that are also invited to participate because of their specific expertise, or of participants that undergo a different intervention that is matched to the meditation intervention in the extent to which both the participants and teachers believe in the effectiveness of the intervention and on other important variables, such as number of contact hours (MacCoon et al., 2014). Yet, an issue here is that it does not make much sense to ask a meditation-naïve person to induce an advanced meditative state. One solution is to compare expert to novice meditators. Another possibility is to use meditators as their own controls, for example, by comparing their brain activity or task performance during different states of meditation that are expected to induce differential effects (e.g., Josipovic et al., 2011; van Vugt and Slagter, 2014). This would not only allow for a better understanding of how different styles of meditation may differentially affect the predictive brain, and testing of our many-to-(n)one model, but may also better control for potential pre-existing differences between expert meditators and controls, e.g., in sleep habits or personality characteristics.

Besides proper controls for non-specific effects, it will be important that the field of meditation research moves in the direction of a-priori specification of study predictions and analysis plans through preregistration, to counter experimenter biases during data collection and analysis. This is particularly important given that many meditation researchers are themselves meditators, and believe in the value of meditation.

To summarize, despite much promise of meditation as a powerful intervention for neuro-cognitive change, and its potential contributions to science, progress critically depends on methodological rigor and the development of novel approaches that allow for more objective and/or non-intrusive assessment of the effects of meditation. Neurophenomenology and no-report paradigms in particular provide fruitful avenues for future research. Embracing Open Science is another important step towards scientific progress.

6. Discussion

> "The senses perceive the object, which then the mental consciousness instantly conceptualizes in a manner conditioned by all of our past experience, and superimposes this conceptualized version back onto the originally neutral data of our senses—all of this occurring so fast that we don't even notice the process, and are only left in the end with the mind's conceptual version of things that we take to be reality." (Thrangu, 2011)

Cognitive neuroscience is undergoing a kind of Gestalt switch, from an understanding of the brain as a vessel that 'drinks in' the world, to an organ that repeatedly regurgitates the world through predictions derived from the past. This view of experience—as deeply contrived through past learning—is remarkably similar to Buddhist ideas of the conditioned nature of experience, as the above quote illustrates. Moreover, the gradual breaking down of concepts in Buddhist meditation maps on strikingly well to the notion of the predictive model-building brain.

Previous research has often focused on how meditation can improve cognitive performance or emotion regulation in one way or another (Kabat-Zinn, 2003; Lutz et al., 2008; Slagter et al., 2011; Tang et al., 2015). However, many contemplative traditions from which these practices emerge suggest that meditation can go much deeper, focusing instead on understanding one's "true nature", "the nature of the self", or attaining certain insights about the nature of reality (Bodhi, 2011a; Suzuki, 1961; Wallace, 1999).[21] These seemingly esoteric aspects of meditation have been largely washed out of modern science perhaps for easier integration within a secular vision of mind, body, and brain. Yet, from the perspective of predictive processing, these facets of meditation suddenly become less mysterious and instead—we propose—the logical consequence of being truly "at one" with the present moment. That is, simply being present enough would naturally reduce abstract predictive modeling within the brain, and this in turn would naturally give rise to the phenomenology reported at various stages of practice.

More specifically, we have put forward the novel hypothesis that the habitual *modus operandi* of hierarchical predictive processing is progressively broken down by three main styles of meditation (FA, OM, and ND). We postulated that: (1) FA meditation reduces the precision and frequency of deep temporal models by up-weighting the precision of one input lower in the predictive hierarchy (e.g., the breath). (2) OM meditation further reduces counterfactual processing by balancing expected precision, thus permitting non-judgmental experiencing. Finally, (3) ND meditation creates the conditions for the final subject-object abstraction to fall away. In the ND state, all *expected*[22] error-minimization and thereby conceptualization (including self and time) ceases.

We also proposed in Section 4 (see also Fig. 2) that FA, OM, and ND may gradually abate the construction of self-processing at different levels of the predictive hierarchy, from the narrative self (i.e., thinking), to the embodied experiencing self (i.e., sensing), to non-self (i.e., awareness). We also showed how key insights—as targeted in classical Buddhism—can occur through meditation (Section 3.2). We proposed that reducing abstract processing in the predictive hierarchy may reveal certain insights about one's mind by increasing the transparency of predictive processes (e.g., discovering the impermanent or 'conditioned' nature of one's predictions as they are constructed and deconstructed). Further insights may arise through fact free learning (Friston et al., 2017)—the internal revision and refinement of models supported by the holistic non-action of meditation (i.e., *in-active* inference, Section 2.5). Below, we first discuss the scientific value of understanding meditation as pruning the counterfactual tree and outline important avenues for future research. We then review how our framework may also help address current challenges within the field of contemplative science specifically.

[21] As noted by Britton et al. (2014): "In his *Science and Buddhism: A Guide for the Perplexed*, Buddhist studies scholar Donald Lopez [(Lopez, 2009)] laments "Where is the insistence that meditation is not intended to induce relaxation but rather a vital transformation of one's vision of reality?" Others warn how "a practice that only relaxes the mind might eventually prove harmful." [(Lutz et al., 2006)]"

[22] As discussed in section 2.4 & 4, *expected* free-energy minimization involves predictions about states in the next moment (thus, counter-facts to the present moment, Friston, 2018).

6.1. From many to (n)one: Novel insights from a unifying framework

There is a growing body of work investigating how meditation can change cognitive, emotional, and neural functioning (Berkovich-Ohana et al., 2013; Dahl et al., 2015; Dor-Ziderman et al., 2013; Fingelkurts et al., 2020; Hölzel et al., 2011; Josipovic, 2014; Raffone et al., 2019; Vago and David, 2012; Vago and Zeidan, 2016). This work has also related specific styles of meditation to changes in predictive processing (Lutz et al., 2019; Pagnoni, 2019). Here, we extend this work by delineating how predictive processing may change from FA to OM to ND meditation, providing a more unified account of meditation. While our many-to-(n)one framework integrates three widely practiced styles of meditation, it naturally does not capture the full diversity in meditation techniques, particularly more constructive practices such as loving-kindness and compassion (Nash et al., 2013).[23] Yet, our framework could be extended to include other styles of meditation, for example, practices that construct mental content and use perspective taking and reappraisal as methods to strengthen mental patterns and conceptions of self that foster well-being (Dahl et al., 2015). It is also important to emphasize again that Buddhism is not monolithic. Different meditation practices were developed at various moments in history within different cultural contexts, and ideas and aims shifted along the way (Dunne, 2011). For example, although FA (samatha) is common to many Buddhist traditions, in non-dual traditions that developed historically later (e.g., Mahamudra), subject-object orientation is considered problematic and hence the aim became to quickly move beyond focus on an object and to cultivate non-conceptual sustained attention from the outset (Dunne, 2011; Wallace, 1999). Researchers should be well aware of the many different meditation practices and Buddhist traditions that exist, and the historical context in which they developed (Dunne, 2015).

In Section 5, we derived several key empirical predictions from our novel framework and reviewed existing scientific evidence in their support. Here we outline the larger scientific value of our framework, with implications to our understanding of mental plasticity, psychopathology, and self. We then discuss how our many-to-(n)one framework may specifically help address several main outstanding questions within contemplative science, including how meditation practice may induce enduring or trait changes in brain and mental functioning, how to determine meditation expertise, and how to approach negative meditation-related experiences.

[23] We certainly do not seek to devalue constructive practice, and in many traditions, they play a most central role (e.g., Vajrayana Buddhism). It is primarily for the sake of scope that we have omitted a discussion of constructive meditation practices, however, by simply reversing the causal arrow within our model (from deconstruction of the predictive hierarchy to reconstruction), one can see how these practices could fit naturally within our framework in a complementary fashion to deconstructive meditation.

[24] As soon as one is 'away' from the present moment, one has made an 'abstraction'. For example, there are the wavelengths of light that represent the shape of a 'teacup'. However, once it has been conceptualized *as a teacup* there is a new level of abstraction that demands further inference from past experience than simply representing the wavelengths of light (i.e., more temporally deep processing). And yet, experiencing a 'tea cup' first necessitates the representation of the wavelengths of light contacting the retina (thus, hierarchical processing). Representing the teacup *then* permits further hierarchically deep processing: Such as recalling the time you drank green tea with brown rice kernels in a Japanese garden.

[25] In Fig. 3 we have used different levels of the hierarchy than Fig. 2 in order to emphasize the behaviour of generative models. In lower levels in the hierarchy (i.e., "pure witnessing" or the subject/object divide shown in Fig. 2) there is no longer phenomenology of sensory objects, and if there are, they are arising in later levels.

6.1.1. The scientific value of meditation

Meditation, as conceptualized as deconditioning the predictive mind, may provide a unique method to scientifically investigate the plasticity and automaticity of predictive processing by revealing what is amenable to change from within, and what is not. Yon et al. (2019) recently coined the term 'stubborn' prediction, to emphasize that some predictions may be so deeply engrained in the structure of our minds that they are not amenable to change. They for example suggested that the sense of agency is a stubborn prediction, but as now suggested by multiple studies, the sense of agency can fall away during meditation (Dor-Ziderman et al., 2013, 2016; Fingelkurts et al., 2020; Lindahl and Britton, 2019; Metzinger, 2020). Thus, meditation studies may reveal what predictions are evolutionary or phylogenetically constrained in human beings, and what structures of experience are amendable to change.

Our framework may be particularly useful for gaining an understanding of the plasticity of mental processes at levels of the hierarchy that are detached from the current environment, and involved in counterfactual cognition. Building on the notion put forward within predictive processing that our inner mental landscape too is dominated by generative models that through past experience have come to reliably minimize uncertainty, we propose that by assigning less precision to predictions that normally habitually arise in experience, meditation may in the long term 'decondition' the mind. This may have beneficial effects, for example reducing excessive rumination. Although rumination can have adaptive value when it is not excessive (Baird et al., 2012; Vago and Zeidan, 2016), *pruning* these high-level counterfactual cognitions through meditation may be one way to revise the immense multiplicity of thoughts to those that are adaptive to one's goals. Counterfactual pruning may also explain the clinical effects of mindfulness-based interventions in treating depression, anxiety, stress, and more (Chiesa and Serretti, 2009; Hofmann et al., 2010) although more work is still necessary (Van Dam et al., 2018). Such clinical outcomes may conceivably follow from an initial deconstruction of problematic habits of prediction, and then a 'healthier' reemergence. This healthier reconstruction may be achieved particularly through model selection, optimization, and compression mechanisms (described in Section 2.5) or through active reconstruction of alternative modes of thinking and feeling. Many meditation traditions also include 'constructive' practices that for example target maladaptive self conceptions and replace them with more adaptive conceptions of self (Dahl et al., 2015). These practices likely provide important ingredients for guiding 'change' in a positive direction.

Our framework also generates testable predictions about the plasticity of self or how meditation may gradually break down the self across the predictive processing hierarchy. So far, science has gained most of its insights about the constructed nature of self-processing through clinical populations, such as depersonalization disorder and schizophrenia, that display alterations in the sense of self that are highly debilitating and accompanied by several comorbidities and other symptoms. The scientific study of ND meditation in particular may be crucial for better understanding the nature and neural basis of the so-called minimal phenomenal experience, consciousness without self-location in space, time representation or self-consciousness (or 'sciousness as William James termed it) (Metzinger, 2020). This state of awareness is currently not included in any major cognitive neuroscience theory of consciousness, yet, proposed by some to lie at the core of all conscious experiencing, as discussed above. Some expert ND meditators can allegedly reliably induce the non-dual state in laboratory settings, rendering this basic self-less awareness accessible to scientific investigation. Yet, as elaborated on in Section 5.3, this will require the development of novel methodological approaches, that include neurophenomenology and no-report paradigms.

To summarize, approaching meditation as a method to deconstruct hierarchical predictive processing can provide unique insights into the plasticity of the predictive mind, the construction of experiences, and states of selfless awareness. It can also well explain the alleged clinical effects of meditation-based interventions.

6.1.2. Insights for contemplative science

Next to its scientific value, our many-to-(n)one framework may specifically help address several main outstanding questions within contemplative science, including how meditation practice may induce enduring or trait changes in brain and mental functioning, how to determine meditation expertise, and how to approach negative meditation-related experiences.

As state-level meditation changes are known to lead to longer-term trait-level changes (Cahn and Polich, 2006), one may also expect that meditators should display differential functioning of the predictive processing machinery 'off the cushion'. Drawing on our framework, and earlier suggestions (Pagnoni, 2019), we propose that meditation may *increase* the counterfactual richness of processing outside of formal meditation by weakening ingrained prediction loops during meditation. The broadscale loosening of beliefs may permit more flexibile and multidimensional processing (a prospect there is already some evidence for, Moore and Malinowski, 2009). More advanced meditators may also be expected to naturally reside in a state where, over time, there is less abstract counterfactual cognition. This does not mean that a meditator is *incapable* of abstract processing, but that the habitual tendency to engage with deep temporal models ought to decrease, and be more easily attenuated. Indeed, there is fMRI evidence that meditators (regardless of tradition) may "…transform the resting state into one that resembles a meditative state" (Brewer et al., 2011, p. 20,255; see also Fingelkurts et al., 2016). Some well-known adepts of non-dual meditation have even claimed that perceptions, sensations, and hence 'the world' does not exist for them, because the appearance of sensing and high-level thinking may be highly infrequent or barely noticeable (Maharshi, 2004; Nisargadatta, 1973). Long-term practice may hence also reduce the frequency of arising predictions in experience and their expected precision over time. In general, meditators should experience less habitual grasping onto passing experience i.e., they should display a decrease of salience and stickiness of arising predictions (see for example, van Leeuwen et al., 2009). Thoughts and feelings may also become less self-related, which may foster an enduring sense of psychological well-being (Dambrun and Ricard, 2011).

Our many-to-(n)one model can also mechanistically explain the occurrence of insights in meditation, and how these may penetrate subsequent experience (which has not been addressed by any theory of meditation to our knowledge). In our model, meditation-induced insights simply reflect another way in which the brain revises its predictive models, through Bayesian model reduction through fact free learning. Fact free learning allows the brain to construct new, simpler models with greater explanatory power (Friston et al., 2017), which may drive the transition of meditation from state to trait. Meditation is a unique practice in the sense that it reduces typical active inference processes (including mental actions) and may thereby accelerate the revision or refinement of *existing* models.

Our model also has implications for what might constitute markers of meditation expertise. Currently, expertise in meditation is notoriously difficult to pin down and there has been much inconsistency on what counts as an experienced meditator in the literature (Van Dam et al., 2018). According to our account, meditative expertise could be partly captured by the extent to which the meditator is able to voluntarily modulate objective markers of stubborn predictions. For example, Antonova et al. (2015) found that startle habituation discriminated intensity of meditation practice better than self-report, dispositional, and practice-related measures. Thus, they proposed that habituation to the startle response could be used as an objective marker of expertise. We suggest that the startle response represents one of many possible objective markers of meditation expertise because it is a highly automatic response (i.e., a stubborn prediction). Many other measures could foreseeably be used, ideally in combination, to test whether a practitioner is able to enter states that are free from such habitual responses. Crucially, the more automatic the prediction, the more expertise would be required to prevent the habitual response.

To provide a few new directions for research on meditative depth, we suggest the following automatic responses are worthwhile investigating further, (1) implicit learning, statistical learning, and conditioning, (2) conceptual processing, such as the automatic formation of words from sounds, (3) visual illusions, such as perception of illusory shapes, and (4) the volitional modulation of wakefulness and arousal (Britton et al., 2014). Intriguingly, since many decisions and tasks require abstract, self, time, and space related processing, it is also possible that performance on some tasks would be *impaired* due to meditation. For example, while some mindfulness-based interventions might improve learning by enhancing the ability to focus attention (Laukkonen et al., 2020b), other meditation practices may reduce the ability to learn and retain new information or extract statistical regularities. Indeed, a study in non-meditators showed that individuals scoring high on self-reported mindfulness displayed impaired artificial grammar learning (Whitmarsh et al., 2013). Thus, just as meditation may not always improve performance, it may not always lead to positive experiences. Impairments in predictive learning based on regularities in the environment could thus provide a useful marker of meditative depth.

It is also possible for future experiments to directly test the continuum of deconstruction that we proposed, wherein FA, OM, and ND gradually reduce predictive processing at deeper levels (see Figs. 2 and 3). For example, linguistic processing requires multiple levels of integration at different temporal scales and levels of abstraction (Bekinschtein et al., 2009; Dehaene et al., 2015; Ding et al., 2017; Gilead et al., 2019; Henin et al., 2019). Thus, we would expect that relative to a non-meditative state, FA reduces markers of higher order processing and conceptualization (e.g. later components in the ERP) but possibly increases processing at early stages (e.g., earlier components in the ERP). This pattern of decreased later ERP components and therefore diminished higher order processing would be expected to increase with meditative depth. Thus, in response to linguistic stimuli, OM ought to lead to decreased differentiation in later components than FA, and ND the least of all. Besides ERPs, multivariate methods such as decoding could also be used to disentangle early versus late conceptualization (Grootswagers et al., 2017). For example, as with the ERPs described above, we would expect decoding of linguistic representations from neural activity to become increasingly 'short' and show less temporal generalization as meditative depth increases from FA to ND. The above, in concert with markers of hierarchical prediction-error processing (Wacongne et al., 2011), and learning statistical regularities over time (Dehaene et al., 2015), provide concrete ways to test the continuum of deconstruction proposed in the many-to-(n)one model. Of utmost importance for such studies is carefully identifying expertise (e.g., using multi-pronged methods) and tracking trial-by-trial phenomenology (e.g., using experience sampling) so that state meditative depth can be measured with fidelity.

Finally, within our framework, which considers the self an inferred model that is hierarchically deconstructed by meditation, negative meditation-induced changes in the sense of self can also be understood in a novel way. As already briefly mentioned, meditation-induced changes in self are not always positive, and can in fact be debilitating in daily life when they persist (Britton, 2019; Lindahl et al., 2017; Lindahl and Britton, 2019). Of particular relevance is a study conducted by Lindahl and Britton (2019) on changes to sense of self. They found that 72 % of meditators—many of which were meditation teachers—reported experiencing changes to their sense of self as a consequence of practice, and 55 % of these were accompanied by distress, and 45 % with impairments in functioning. Changes to sense of self included changes to the narrative self, loss of ownership, loss of agency, changes to embodiment, changes to self-other or self-world boundaries, and the most debilitating experiences tended to accompany a loss of one's 'basic' self or sense of 'being'. These findings emphasize the necessity of being able to experience oneself outside of the meditation context as a bounded individual that unifies experience from within, across time, and that is capable of exerting effects on the world, to function in this world. Changes to the narrative self often occurred even during daily practice (33 %), whereas the vast majority of more profound changes to one's basic embodied self happened while on a meditation retreat (93 %). Under an 'emotion and attention regulation' view of meditation, such experiences seem surprising. However, within our framework, a deconstruction of self-related processing naturally arises from being immersed in the here and now, and changes to more basal forms of self-hood are expected with more prolonged and advanced practices, like those employed on meditation retreats. Thus, our framework is able to also account for the negative side effects of meditation, especially as they pertain to changes in self-related processing.

The prospect of severe negative side effects that outlast the actual meditation, including depersonalization and dissociation (Lindahl and Britton, 2019) certainly demands further research. One possibility drawn from our framework is that if during meditation one's sense of self does not fully abate, but instead is *partially* altered, this may then be experienced as distressing. Many aberrant experiences of self that may occur during for instance psychosis and schizophrenia, may indeed represent *changes* to self-modeling processes rather than the explicit *absence* that may arise through carefully guided and personalized (Fingelkurts et al., 2015, 2020) meditation training. Similarly, as counterfactual processing is deconstructed and early levels of the predictive hierarchy become perceptible, what is discovered may not coincide (indeed strongly contradict) one's models at higher more abstract levels of the hierarchy, which may cause uncertainty and distress, particularly if these changes persist outside of the meditation session. Meditation thus may engender enormous prediction errors that can demand significant support and integration. As the popularity of meditation grows, more attention is needed within the secular meditation movement about the side-effects that practitioners may unwillingly encounter, and what 'priors' may be necessary to integrate surprising experiences in a healthy way. We stress that being present is not just an easy way to feel better but can in fact profoundly change how we view ourselves.

6.2. Conclusion

We have taken on the daunting task of providing a theory for understanding the effects of meditation within the predictive processing framework. Contemplative science is a young field and predictive processing is a new theory, although both have roots going much farther back. All theories are subject to change, but perhaps particularly so for such new domains of enquiry. Nevertheless, we think the conditions are suitable for a more overarching theory that may also thwart further siloing and fragmentation of scientific research, as has been commonplace among the mind-sciences. A strength of our framework is its simplicity: Being in the here and now reduces predictive processing. And yet, this basic idea can explain how each meditation technique uniquely deconstructs the minds tendency to project the past onto the present, how certain insights may arise, the nature of hierarchical self-processing, and the plasticity of the human mind. There is scope here, we think, to eventually reveal what makes a meditator an expert, why meditation has such broad clinical effects, and how we might begin mitigating some of the negative consequences of meditation. Last but not least, our framework seems to bring ancient Eastern and modern scientific ideas closer together, showing how the notion of conditioned experience in Buddhism aligns with the notion of the experience-dependent predictive brain.

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