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

by

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Abstract

How profoundly can humans change their own minds? In this paper we offer a unifying account of meditation under the predictive processing view of living organisms. We start from relatively simple axioms. First, the brain is an organ that serves to predict based on past experience, both phylogenetic and ontogenetic. Second, meditation serves to bring one closer to the here and now by disengaging from anticipatory processes. We propose that practicing meditation therefore gradually reduces predictive processing, in particular counterfactual cognition - the tendency to construct abstract and temporally deep representations - until all conceptual processing falls away. Our *Many-to-One* account also places three main styles of meditation (focused attention, open monitoring, and non-dual meditation) on a single continuum, where each technique progressively relinquishes increasingly engrained habits of prediction, including the self. This deconstruction can also make the above processes available to introspection, permitting certain insights into one's mind. Our review suggests that our framework is consistent with the current state of empirical and (neuro)phenomenological evidence in contemplative science, and is ultimately illuminating about the plasticity of the predictive mind. It also serves to highlight that contemplative science can fruitfully go beyond cognitive enhancement, attention, and emotion regulation, to its more traditional goal of removing past conditioning and creating conditions for potentially profound insights. Experimental rigor, neurophenomenology, and no-report paradigms combined with neuroimaging are needed to further our understanding of how different styles of meditation affect predictive processing and the self, and the plasticity of the predictive mind more generally.

1. Introduction

We typically experience ourselves as if in an objective world in which time, space, and self are fixed properties. However, severe psychopathology, brain trauma, psychoactive compounds, and virtual reality environments demonstrate that the way the brain constructs experiences is not set in stone. In certain circumstances, it is possible to lose control of one's body, to forget one's own name, to perceive something that is not there, and to believe one's mind is being controlled by an external force. Our sense of self is also subject to change. It is possible to dissociate, to experience depersonalization, and even to believe that one is already dead. Transformations of experience can be externally induced, but they can also be generated from within.

One way that experience can change from within is through intensive mental training, as cultivated by meditation. Thousands of meditation practitioners going back at least three millennia have reported accessing states far outside the ordinary mind. Meditators, even in laboratory settings corroborated by neural activity (Dor-Ziderman *et al*., 2016), report that aspects of experience that we often take to be stable and unchanging, such as time, space, and self, can in fact be modulated. 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 now a conventional treatment for mental health 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 through one and the same mechanism: free energy minimization. Due to the fact that the brain lacks direct access to the external world, it must 'guess' the causes of sensory experience based on past experience in order to adaptively interact with it. To improve its guesses, the brain is proposed to *minimize the difference* between these 'guesses' and external 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.

Obviously, having a mind that is constructed through past experiences is advantageous in many situations. 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 & Merzenich, 1998; Feldman, 2009) - on its head (Boonstra & 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 & 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? And what may be fruitful ways to promote such plasticity given their internal construction?

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 aims at deconstructing the mind from within, in order to allow one to experience things anew, no longer wholly determined by acquired mental habits (Friston *et al*., 2017). Therefore, here we aim to, 1) provide a unifying account of empirical and phenomenological effects of intensive 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.

The essence of our theory is quite simple. Our main contention is that meditation gradually brings 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 & 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 agency, time, space, and body representation. Even seemingly direct experiences, like that of a flower or 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). Thus, if awareness rests in the here and now, all conceptualization should also dissipate.

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 introduce three well-delineated meditation practices, known as focused attention (FA), open monitoring (OM), and non-dual (ND) meditation (Josipovic, 2010; Lutz *et al*., 2008b, 2015a). We focus on these meditation techniques for the sake of scope, but also because our account makes 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 self-specific processing. This capacity to restructure deeply engrained mental habits is what makes meditation a valuable tool for investigating the plasticity and nature of the predictive mind.

For our theory, we have chosen the name *many-to-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 layers of the hierarchy being more temporally precise and concrete, and higher layers being more temporally thick and abstract (Friston, 2008; Huntenburg *et al*., 2018). The quintessence of meditation is also being in the present moment. Thus, as a heuristic version of our model, we suggest that meditation reins in the mind's habitual tendency to abstract (*the many*) away from the here and now until all phenomenological distinctions stop (*the one*[2]). Metaphorically, we suggest that meditation *prunes*[3] *the counterfactual tree* (see Figure 1).

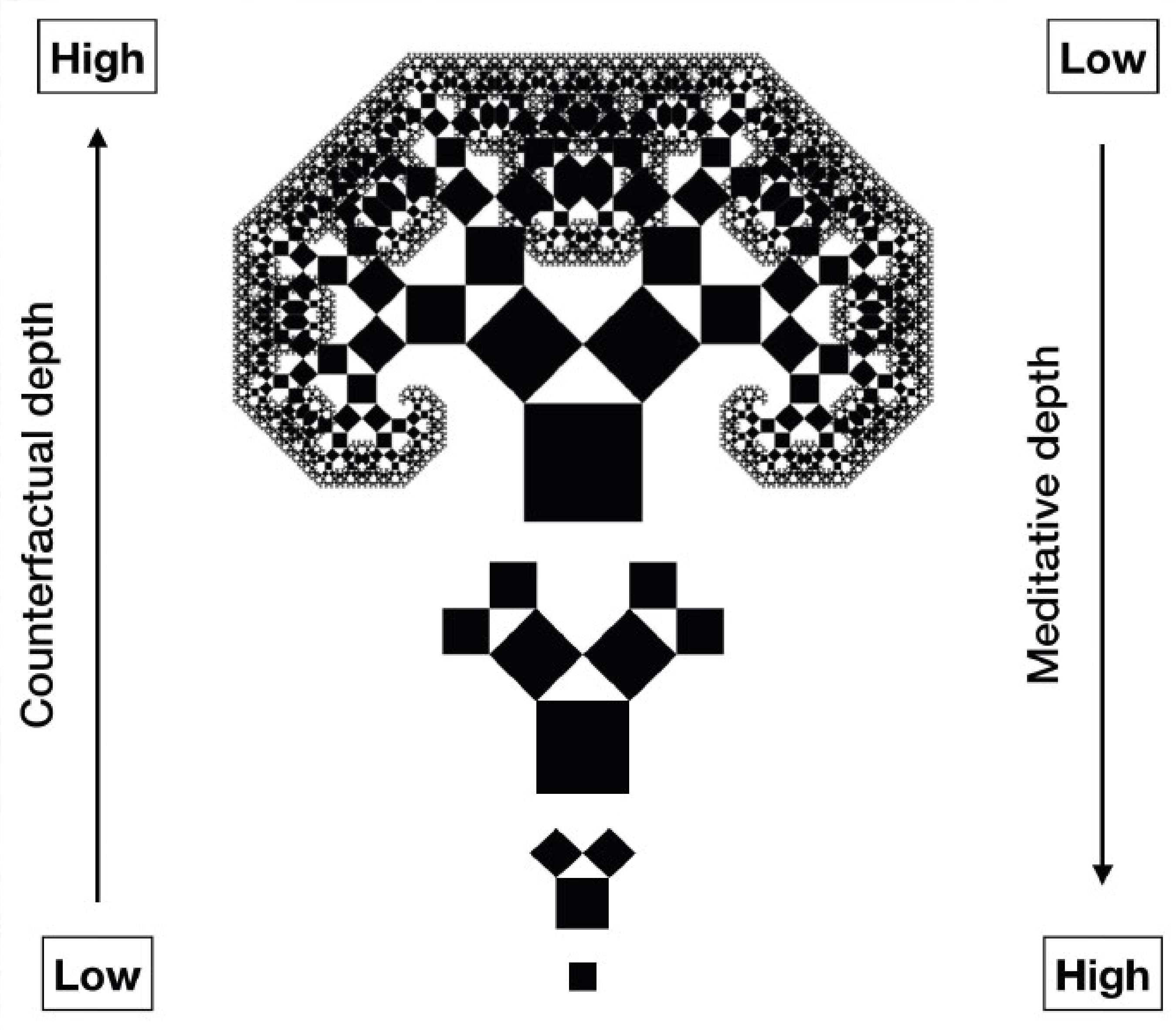

Figure 1. Here we use the Pythagoras Tree to provide an intuitive illustration of how organisms represent the world with increasing counterfactual depth or abstraction[4]. The tree is constructed using squares that are scaled down by √2/2 and placed such that the corners of the squares meet and form a triangle between them, recursively. Analogously, the brain constructs experience from temporally precise and unimodal models of present-moment sensory 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.

According to the predictive processing framework, the self is also a model constructed in the brain's predictive hierarchy. Thus, pruning the counterfactual tree would also logically engender changes in one's sense of self. Indeed, the traditional roots of many meditation techniques (such as Buddhism) explicitly aim to provoke changes in the self (Dahl *et al.*, 2015). Consistent with this praxis, we will also propose that the three meditation techniques gradually deconstruct increasingly foundational forms of self-representation, beginning with the narrative self (Gallagher, 2000), and then the embodied self (Blanke & Metzinger, 2009; Seth, 2013), and finally dissolving the very foundation of a subject-object distinction (Josipovic, 2014). Moreover, we argue that reducing temporally deep processing allows certain insights to arise as the constructed nature of cognition becomes perceptible. Finally, as an interesting counter-model, we compare our account of meditation to a popular predictive processing account of psychedelics (Carhart-Harris & Friston, 2019).

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 increasingly inseparable. In order to avoid the dissolution of its boundaries, what the organism *does* is make predictions across many timescales to produce autopoietic[5] actions that minimize the tendency towards entropy (Friston & Buzsáki, 2016). 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 & Friston, 2018; Clark, 2013; Milliere & 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. 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 visuo-spatial 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. The first is the *hierarchical* nature of predictive processing, which is important because our model proposes that meditation gradually reduces the temporal depth of hierarchical processing. The second is *active inference* which accounts for action (mental and physical), and is relevant because meditation often involves either complete non-action such as sitting still, or a highly constrained action like walking slowly. Mental actions are also often constrained (e.g., thoughts) by focusing attention on a sensation such as the breath (Lutz *et al.*, 2019). The third is *precision-weighting*, which is equated with attention in the predictive processing framework (Friston & Stephan, 2007; Hohwy, 2013). Precision-weighting is also highly relevant because changes in the deployment of attention are important in many meditation techniques (Slagter *et al.*, 2011) and ordinary attention is to be released altogether in some meditation practices. And the fourth is the implication that self consciousness implies minimizing *expected* free-energy in next moments in time (Friston, 2018). As stated above, the nature of self is important because many meditation techniques explicitly aim to engender changes to one's sense of self (Dahl *et al.*, 2015; Dor-Ziderman *et al.*, 2016). Finally, we describe how the brain can learn without sampling new input - e.g., as in meditation - by refining, selecting, and compressing existing representations, through *fact-free learning* (Friston *et al.*, 2017). Learning and attaining 'insights' about the nature of one's mind are also at the heart of many meditation practices (Bodhi, 2011), and we suggest that these may naturally arise through fact-free learning[6].

2.1 A hierarchy of expectations

It is a key tenet of the free energy principle that the brain models the world hierarchically (Friston & Stephan, 2007). Early basal layers of processing are temporally precise and concrete (e.g., sensory and interoceptive input) and deeper layers are temporally thick and abstract (e.g., thoughts and concepts, Limanowski & Friston, 2020). Each layer of the hierarchy aims to predict the input of the layer 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 & 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. 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 layer 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 some range (e.g., a bodily temperature of ~37 degrees Celsius), the expectation that one has a body, and the expectation that light comes from above (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 & 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 (Allen & Friston, 2018). 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. 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 & Friston, 2018, p. 12).

It should be noted that active inference, although directed at confirming predictions, is also critical for model revision because by manipulating the sensory input through action, the brain can also test hypotheses in order to check them against the subsequent input. In other words, by generating information through action, the brain can test its models about the outside world. 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, 2017; Spratling, 2016). They allow us to disembody from the present moment flow of sensory data in order to covertly entertain possible, but nonexistent states, i.e., *counterfactual hypotheses* (Metzinger, 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). 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.

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 & 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 teacup or 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 & Friston, 2010; Smout *et al.*, 2019). Thus, attention is said to turn up the "volume" (Clarke, 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 true 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 & 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 & Metzinger, 2020), and there is still not widespread agreement among scientists on a definition of the self. Nevertheless, assuming a predictive brain, we can draw some tentative conclusions. First, like all other aspects of cognition and experience 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 future actions without representing oneself in those actions. 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 given certain behaviors. And indeed, we must have a model for that fact that we are an agent that needs such a thing as water. This 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). The second implication, which is perhaps more controversial, is that the self is itself hierarchical in nature. We will briefly provide evidence for these ideas below.

It is clear that one's usual sense of self can change, and in seemingly myriad ways. These changes may be usefully put on a continuum, from relatively minor changes (e.g., the retrospective sense that I was acting "not like myself"), to more verifiable concrete changes (e.g., the rubber hand illusion, Botvinick & Cohen, 1998), to changes that are more holistic (e.g., perceiving someone else's body as your own, Petkova & Ehrsson, 2008). Or, on the extreme end, it is also possible to completely disrupt normal self-related processing, such as during a psychotic episode (Sterzer *et al.*, 2018) or high doses of psychedelic drugs (Millière *et al.*, 2018; Timmermann *et al.*, 2018). Such changes to self-representation 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. Nevertheless, since subjective experience - including therefore any self-models (Blanke & Metzinger, 2009) - is inferred through Bayes-optimal inference under the predictive processing scheme, the existence of aberrant self-perceptions are *not* surprising (e.g., in the context of the rubber-hand or full-body illusions, highly precise sensory input contradicts proprioceptive input leading to a misperception of ownership). Taken together, the fact that the self is constructed is not controversial because it is prone to change and can even disappear under predictable conditions (e.g., virtual reality, psychopathology, or psychoactive substances).

Is the self also hierarchical? 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 & 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, abstract thought and therefore the narrative self is placed *higher* in the predictive hierarchy (*temporally thick*, Carhart-Harris & 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 & 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 & Metzinger, 2020 for a special issue). It is also worth mentioning how a minimal or basal form of self might arise (though this is an area of considerable debate). 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. 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 a system generates action predictions, and thus aims to minimize the *expected* free energy resulting from those 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 doesn't 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 (Metcalfe & 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 (indicative of model revision, Laukkonen *et al*., 2020).

Take the simple example of an anagram. An anagram is a scrambled word, such as "nirtostcpeion". If it is not immediately clear what the hidden word is, then at a certain point it may suddenly become clear, without any new input or facts. We can also speed up the process with a clue: "*Looking inward*"[7]. Similar to anagrams, there are many instances wherein a novel perspective or idea is gained without necessarily being exposed to anything new. Central to 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 posterior beliefs (i.e., not using sensory outcomes, Friston & 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 input - 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 quite obvious. 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. 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 - continues 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[8] in the predictive hierarchy by 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-related 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 meditation in Buddhism (for much more detailed reviews of these practices see, Dahl *et al.*, 2015; Dunne, 2011; Lutz *et al.*, 2007, 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. 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).

3.1 Focused attention

Focused attention (FA) 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 a candle or 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 abstract thought and the narrative self, i.e., 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 (Lutz *et al.*, 2015).

3.2 Open monitoring

Open monitoring (OM) 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 nonjudgmental 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 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. 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 layer of the predictive hierarchy (non-judgmental experiencing, or 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 also foreseeably permit *epistemic* changes to the system, in line with classical Buddhism (Bodhi, 2011) 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)[9]. 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-centred 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 layers 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)[10]. 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 (J. Dunne, 2011; Gyatso, 2010). From the perspective of the 'nondual' 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. 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.*, 2015a) 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[11]). 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. However, since all mental experience is 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 & Friston, 2020; Metzinger, 2020). 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*[12] raise certain philosophical conundrums. As noted by Limanowski & 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 intrinsic arousal. Indeed, maintaining an optimal level of arousal or alertness is central to many meditation practices. This proposal fits with a large body of 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. A different proposal from Josipovic (2014; Josipovic *et al.*, 2011), although not grounded in the notion of predictive processing, is that non-dual awareness in particular affects the fragmentation of the field of experience into habitual dualities, such as self vs. other, inside vs. outside, good vs. bad, and that this may be brought about by reducing the normally antagonistic relationship between brain networks involved in self-referential processing and external task-related processing (Josipovic, 2014; Josipovic *et al.*, 2011). Future studies are necessary to dissociate between these and other theories.

It is also possible to see how the ND state can potentially go beyond insight or fact free learning, as was the implied goals of OM practice. Having a *conscious* insight moment implies temporal depth, whereby higher levels make predictions about the input of lower levels, and thus refine themselves until a new point of view is uncovered (Friston *et al.*, 2017). Hence 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." (Lok To *et al.*, 2000). The 14th Dalai Lama also noted that the Mahāyāna tradition emphasizes emptiness (¶ūnyatā) 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 (perhaps in retrospect) that *everything* is empty can also be considered an insight, as it 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. Moreover, 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.

4. A Unifying Framework: The Many-to-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. It is perhaps worthwhile restating our aims: The goal of the many-to-one model is to provide a mechanistic predictive processing account of meditation, and in turn reveal how meditation affects the plasticity of predictive processing. In Figure 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 Figure 3, we illustrate with more nuance how the different meditations effect the time-course of prediction and precision at different levels of the hierarchy.

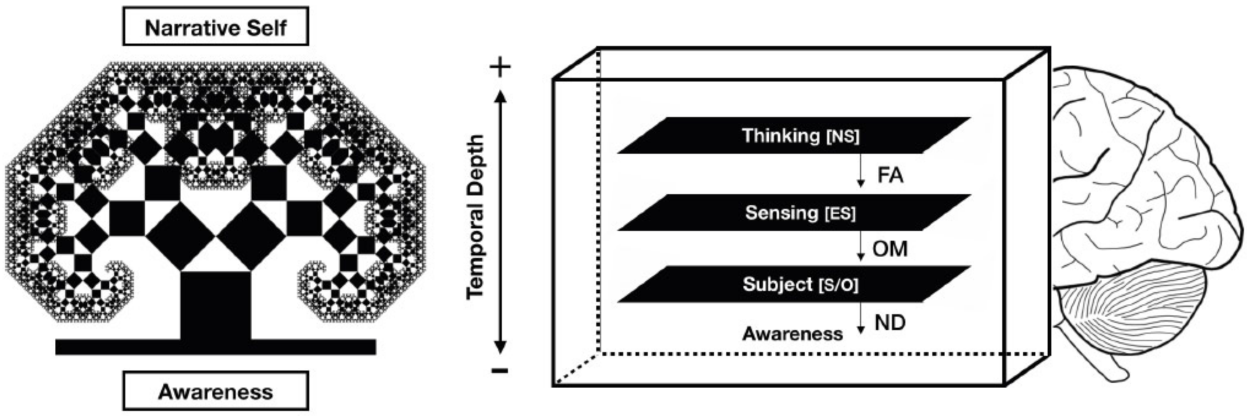

Figure 2. In this schematic we illustrate two aspects of the many-to-one model. The first and most foundational proposal is that meditation gradually *flattens the predictive hierarchy* or 'prunes the counterfactual tree', by bringing the meditator into the here and now, illustrated in the left figure. 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 layers. We propose that thinking (and therefore the narrative self [NS]) sits at the top of the predictive hierarchy (Carhart-Harris & 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.

The above figure provides a broad illustration of how each meditation technique gradually decreases abstraction in the predictive hierarchy. Although we have delineated three layers 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)[13], 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.

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 Figure 2 is *how* precisely each meditation technique reduces abstract processing. To this end, in Figure 3 below illustrates how each meditation type changes the frequency and precision of predictions over time.

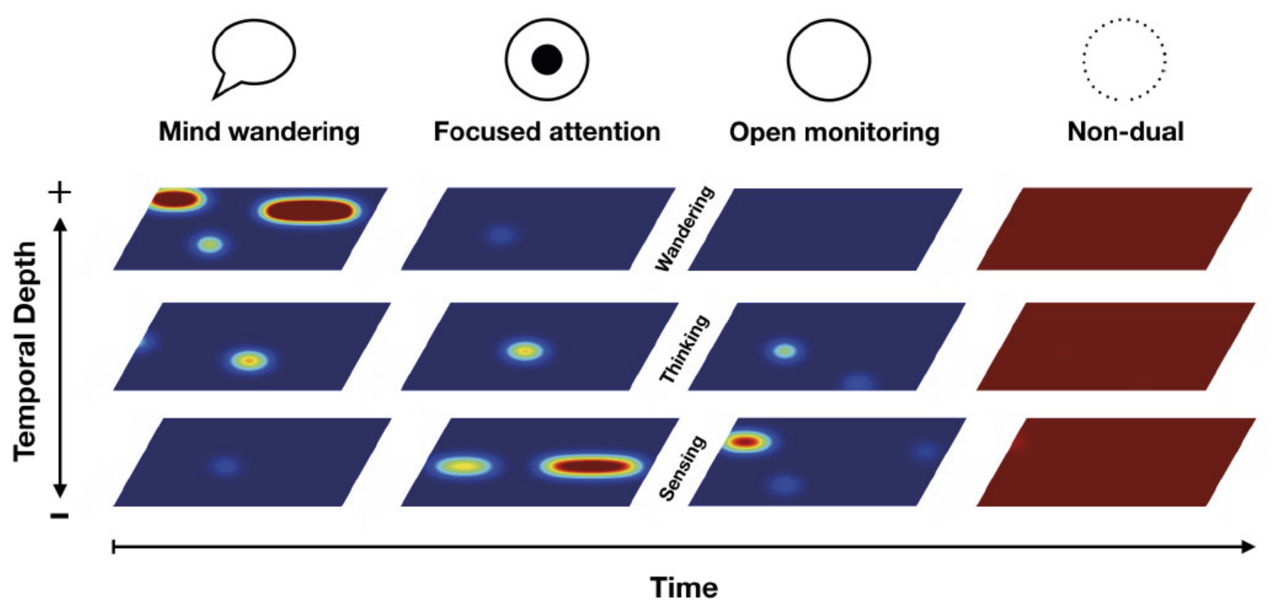

Figure 3. Here we illustrate the precision and frequency of predictions at different levels of the predictive hierarchy during mind wandering, FA, OM, and ND. Blue rectangles represent layers of the predictive hierarchy, with deeper and later layers represented at the top (e.g., mind wandering and the narrative self), task-relevant thinking in the middle, and the bottom rectangles represent earlier layers (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 layer of the hierarchy. For example, during FA meditation, one engages attention (increases precision) of a *specific* prediction at earlier layers 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 layer 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 layers of the hierarchy[14].

To our knowledge, what we have described is the first integrated predictive processing account of FA, OM, and ND meditation styles. 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 of time and self 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, and not dissolve into entropy, which requires for example expectations to eat. 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 that "...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). Yet, we experience the world not just with our bodies, but because of our bodies, so ultimately, expectations inherited through evolution about physiological allostasis ought to 'kick in' and drive behavior towards survival, except perhaps in extreme cases[15].

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 & 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 inputs (Pagnoni & Hasenkamp, 2017). 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 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 & 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 (2019) 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 *inactive 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. Previous research under a new light

As yet there are only a handful of studies that have specifically tested how meditation affects self-specific processing, engrained habits (i.e., stubborn predictive processes), or that explicitly manipulated prediction formation, which we review in the following section. Nevertheless, existing work seems to align well with our predictive processing account of meditation, and the continuum of effects expected due to FA, OM, and ND practice. The review is divided into experimental and (neuro)phenomenological research. Given the nascent field, our model is also forward looking and we hope that it will inspire many new directions for empirical work at the intersection of meditation and prediction.

5.1 Experimental Research

Much of human waking consciousness is spent engaged in a thinking and narrative mode of being (Killingsworth & Gilbert, 2010), and we have suggested that FA meditation primarily aims to bring about an initial shift from thinking to sensing, laying the groundwork for subsequent practices. FA achieves this 'presentness' by reducing engagement with abstract temporally deep predictions (e.g., thinking) by increasing the expected precision of one source of present sensory experience, increasing the weight of actual sensory input over sensory predictions induced by spontaneous thoughts. This is evidenced by the fact that even very brief mindfulness of breathing (8 minutes) can occasion reduced mind-wandering episodes (Mrazek *et al.*, 2012), and four days (20 min/day) can improve mindfulness scores and sustained attention (compared to an active control group, Zeidan *et al.*, 2010). In a neuroimaging study, Farb *et al.* (2007) also proposed that humans possess a narrative-self bias:

> "The theory of narrative generation as a default state of self-reference is increasingly supported by neural evidence: the cortical midline activity, which underlies narrative-generating mind wandering (Mason *et al.*, 2007) is very similar to activity associated with the 'default mode' of resting attention (Gusnard *et al.*, 2001; Raichle *et al.*, 2001). This default mode suggests an endemic reliance upon the networks supporting temporally extended narrative processing..." (p. 314).

Suggestive that meditation may make it easier to voluntarily shift out of this narrative mode of being, the authors found that participants who underwent an 8-week mindfulness course (which involves characteristics of both FA and OM, Kabat-Zinn, 2003) showed a more pronounced shift in neural activity when volitionally engaging an experiencing versus narrative self-focus. For example, those who underwent the meditation training showed a more "marked and pervasive" reduction in medial prefrontal cortex activity - a key hub of the DMN associated with self-processing - during 'experience focus' compared to controls. In terms of our model, the meditators may have been able to more completely disengage temporally thick predictions in favor of a less abstracted present moment experiencing. Like many meditation studies, there are methodological limitations to be kept in mind: the design was not pre-post and there was no *active* control group, and thus it's hard to determine whether the mindfulness program was the causal factor. Nevertheless, these neural findings are broadly consistent with several other behavioral studies showing that meditation reduces mind-wandering (Levinson *et al.*, 2014; MacLean *et al.*, 2010; Mrazek *et al.*, 2012) and other neuroimaging results indicating that mindfulness reduces activity in key nodes of the DMN (Fox *et al.*, 2016). The prospect that FA can enhance present-moment experience of a sensory object, and reduce mental distraction, is also suggested by findings from an EEG study by Lutz *et al.* (2008), which 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, that was accompanied by a reduction in reaction time variability.

While FA aims primarily to increase one's sustained attention of a sensory object in order to derive a more present and tranquil state of mind, OM meditation withdraws selective attention in favor of a broad scale dereification from the contents of experience. Such non-judgmental experiencing we have suggested equates to a reduction in the relative expected precision of all contents of experience, further increasing present-moment awareness. This should also reduce the development of new expectations. Consistent with this idea, Valentine & Sweet (1999) hypothesized that FA enhances attentional capacity for *expected* stimuli, whereas OM may (relatively speaking) enhance detection of *unexpected* stimuli, because one should not be 'caught up' by expectations. The study included novice (24 months or less) and experienced meditators (25 months or more) who predominately practiced either FA or OM, and a non-meditator control group. The participants were tasked with counting a stream of sounds that were first presented at a slow rate (0.25hz, expected condition), and in a final block, at a much faster rate (7hz, unexpected condition). In the expected condition, overall counting performance was lowest for control subjects, followed by novice meditators, and highest for experienced meditators. Moreover, and in line with their hypotheses, only the *unexpected* condition differentiated between FA and OM meditators, wherein the OM group performed better. These results may suggest that the OM meditators were less biased by the previous temporal regularities in the expected condition, 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 possible explanation is that, because the unexpected condition was also *faster*, then OM meditators were better able to 'release' each appearing stimulus in order to count the subsequent sound.

Slagter *et al*. (2007) showed a similar effect using the well-established attentional blink task. After 3 months of OM practice under intensive retreat conditions, participants showed a smaller attentional blink (i.e., the ability to notice a target stimulus (T2) that is rapidly presented after another target stimulus) compared to a control group. This finding was also backed up by EEG measurements that showed a smaller P3b to the first target (T1) stimulus, which is a brain potential that is 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, permitting better detection of T2. More specifically, these data support our hypothesis that OM meditation brings the practitioner more into a state of non-judgmental direct experiencing (i.e., lower in the temporal hierarchy of processing). More shallow processing means faster 'letting go' (better behavioral performance), which is further reinforced by a smaller P3b in meditators (an index of temporally deep processing).

We have also suggested that meditative depth can essentially be defined by the modulation of increasingly engrained habits or expectations. Thus, we would expect that more advanced meditation practices and greater expertise would permit the modulation of more stubborn predictions (or reactions to prediction-violations). Next, we briefly discuss four paradigms where this has been studied in the context of meditation - neural markers of prediction errors, startle responses, analgesic effects, and binocular rivalry. Each of these paradigms invoke an experience or reaction in the organism that is ordinarily believed to be automatic. However, below we outline some preliminary evidence suggesting that meditation may be able to modulate these responses by - we suggest - preventing the construction of temporally deep predictions grounded in past experience. These findings therefore are also revealing about the plasticity of predictive processing more broadly. In many cases, the evidence is also consistent with the idea that expertise and practices that go beyond FA are required to induce effects on more stubborn predictions.

A promising method for investigating the effect of meditation on prediction is the odd-ball paradigm, where a surprising (usually auditory) stimulus is presented after several repetitions of predictable stimuli. EEG studies show that the deviant stimulus ordinarily evokes an auditory event-related potential known as the mismatch negativity (MMN) thought to be a kind of neural correlate of prediction errors (Garrido *et al*., 2009). Initial investigations of FA meditation found increased MMN in response to surprising auditory stimuli (Srinivasan & Baijal, 2007), indicative of the development of more precise sensory expectations through FA. There is also evidence of trait effects, whereby experienced meditators showed a larger MMN than novices also while not meditating (Biedermann *et al*., 2016). These results are consistent with the idea that FA meditation leads to increased attentional capacities for low-level sensory stimuli. However, other meditation practices, according to our model, also involve a *retraction* of attention and precision-weighting to any particular components of experience, in favor of a more holistic and *bare* attention towards one's experience as a whole as in OM, or releasing of attention all together, as in ND. Interestingly, Fucci *et al*. (2018) recently found that FA meditation lead to a higher MMN than a control condition (as in Biedermann *et al*., 2016), but ND meditation did not. Non-dual meditation showed approximately the same degree of MMN as a control 'reading' or "distracted" condition, and the difference between practitioners in the FA versus ND was only different at the trend level. Thus, ND meditation in this study did *not* abate the MMN as would be expected if the meditator were genuinely not forming expectations across time. Expertise in ND meditation is hard to establish (i.e., it is very difficult to say if participants were genuinely in such a state). It is also possible that low-level neural signatures of oddballs are sufficiently automatic that they cannot be eliminated by changes in mental state (see below for a study where a higher-level prediction error is attenuated by meditation). Yet, it has been shown that the prediction error-related MMN vanishes during deep sleep (Strauss *et al*., 2015). Future research is necessary to replicate this finding by Fucci *et al*. (2018) and will be critical for establishing which predictions are capable of change through meditation and which are truly stubborn.

In a related paradigm, Kirk & Montague (2015) found that Zen meditators (compared to controls) showed *no* reward-related prediction error responses as measured by fMRI. In this experiment, participants were not meditating; thus, the results likely represent trait effects. One explanation is that, by resting in the here and now, the meditators were no longer constructing inferences about the positive or negative valence of an event. The other possibility is that Zen meditation, because it is primarily a ND tradition, makes it possible that the effect is due to a modulation of prediction error signaling more broadly.

Clearly, further research is needed to properly disentangle the relationship between FA, OM, and ND meditation on prediction error signaling. Nevertheless, we see these results as providing preliminary evidence that FA increases expected precision-weighting of sensory experience leading to higher prediction-error signaling (Srinivasan & Baijal, 2007), whereas the more advanced practices such as ND retract precision-weighting of any specific content of experience - emphasizing awareness itself - making stimuli less surprising in general (Fucci *et al*., 2018; Kirk & Montague, 2015). Yet, as noted above, some predictions, like the oddball effect, may be evolutionary engrained and difficult to abolish even by experienced meditators.

Representing another highly automatic process, the startle response is believed to be a phylogenetically primitive defense reflex (Koch, 1999). Testing whether meditation may lead to modulations in the startle response, 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. Notably, ND meditation resulted in the smallest startle response (relative to FA), consistent with our framework. In another study investigating *habituation* to the startle response, Antonova *et al*., (2015) reported no evidence of habituation in 12 expert meditators who were instructed to rest in a non-dual state while being presented with startling sounds. 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. In contrast to Levenson *et al*. (2012), Antonova *et al*. (2015) found no effect of meditation on the initial startle reflex, which they propose might be due to the meditators being less experienced or due to the use of a weaker startle stimulus in their study. These studies provide preliminary evidence that expertise and advanced practices lead to the largest modulations of the startle response, both in terms of the initial reflexes elicited by a "surprising" stimulus (Levenson *et al*., 2012) and in terms of startle habituation, a form of learned inhibition (Antonova *et al*., 2015; see also Hanley & Garland, 2019 for evidence that mindfulness training can reduce Pavlovian conditioning).

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. Indeed, there is growing evidence that some forms of meditation can have such analgesic effects. Grant (2014) reviewed experimental work on the effects of meditation on pain reduction and found that OM meditation but *not* FA showed consistent and relatively strong reductions (up to 23%, Grant & Rainville, 2009) in pain intensity ratings (see also Zeidan & Vago, 2016). Such findings are also supported by differences between meditators and non-meditators in neural activity both before and during the painful stimulus (Lutz *et al*., 2013). Reductions in experiences of pain may be driven by different mechanisms, for example the most complete cessation would occur if one were able to halt pain prediction entirely. Such a finding would theoretically be possible in a ND state. However, it is more likely that existing findings represent a more modest deconstruction of predictive processes, where OM meditation leads to less anticipation and/or judgment of the pain as aversive (Lutz *et al*., 2013). Consistent with this idea, Perlman *et al*. (2010) found that OM (but not FA) lead to significantly lower ratings of unpleasantness for painful stimuli, but *not* 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.

Finally, the phenomenon of binocular rivalry highlights how past experience affects the most basic levels of perceptual experience. In this task, two images are presented separately to each eye (e.g., a face and a house), which leads to a fascinating phenomenon wherein 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, Carter *et al*. (2005) presented binocular rivalry stimuli to Tibetan monks with extensive meditation experience. The authors 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). 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' was broken down[16]. Carter *et al*. (2005) concluded that "These results contrast sharply with the reported observations of over 1000 meditation-naive individuals tested previously". Since it is difficult to maintain deep states of meditation while providing responses, several subjects 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 in the Discussion.

In the above, we discussed several key findings from meditation studies to showcase how these findings may be re-understood based on our many-to-one model, and how meditation may shed novel light on the extent to which predictive models are plastic versus stubborn. In the below, we discuss meditation-related changes in self-reported phenomenal experience in relation to our model.

5.2 (Neuro)Phenomenological Research

Perhaps the most radical evidence for the deconstruction of the predictive processing hierarchy is found in the self-reported phenomenology of expert meditators. Indeed, many generations of practitioners from Buddhist meditation traditions have theorized about subjective experiences that are expected to occur at specific stages of practice (Bodhi, 2011; Wallace, 1999). Many expert meditators also report being able to access such states on demand, and there is now a growing effort to map these subjective experiences under controlled settings and to identify corresponding neural changes (Dor-Ziderman *et al*., 2013, 2016, 2016; Petitmengin *et al*., 2017, 2019). These reports support the notion that more advanced states correspond to the breaking down of increasingly engrained habits of mentation, including perceptions of selfhood, space, and time: Experiences that are supported by unique and consistent neural signatures (Berkovich-Ohana *et al*., 2013). In the following we describe some of the studies conducted on meditative phenomenology as they relate to our model. We are primarily interested in the possibility that meditative (neuro)phenomenology can provide evidence of the deconstruction of highly engrained models, thus offering initial evidence that predictive processes may be more malleable than previously thought.

Below we particularly focus on changes in the sense of self, since it is the explicit aim of some meditation techniques (Dahl *et al*., 2015) and has received the most (neuro)phenomenological research. Changes in the self-sense is also central to our model, which proposes that meditation gradually permits the discovery of increasingly basal forms of selfhood, culminating in the ND state, where the practitioner is "resting" in/as the here and now to the extent that there is no self-awareness or temporal experience whatsoever.

In 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". Self-less experiences were defined by a lack of agency or ownership. One subject described such an experience as follows, "It was emptiness, as if the self fell out of the picture. There was an experience but it had no address, it was not attached to a center or subject..." (Dor-Ziderman *et al*., 2013, p. 6). Nearly all participants reported success in accessing all three states of self-awareness and in maintaining them for the duration of the instructed period. Consistent with the idea that deeper and more self-less states involve less conceptual processing (placing them lower in the predictive hierarchy), the minimal self and self-less conditions also showed a dramatic reduction in self-reported emotions (negative, positive, and mixed) compared to the narrative self. Furthermore, 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. And finally, some of the highly experienced meditators who reported the most vividly self-less experiences showed additional attenuation of the inferior parietal lobule and left dorsomedial thalamus in the beta band (Dor-Ziderman *et al.*, 2013). As noted by Dor-Ziderman (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) focused on the phenomenology of an advanced meditation practitioner who was entering into a state of ND awareness. Consistent with the previous study, the transition from a minimal form of self-experience to a self-less state 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). The TPJ has been extensively shown to play a key role in self-related processing, including self-awareness, self-location, agency and ownership, egocentrism, and the experiential unity of body and self (Dor-Ziderman *et al.*, 2016). 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.

Most recently, Winter *et al.* (2020) reported data from joint EEG-fMRI while an extremely experienced meditator with over 40 years and approximately 50,000 hours of practice entered a ND state. The participant reported afterwards that towards the end of the meditation, he experienced no mental or sensory content whatsoever, including no self, time, or space, but *did* report maintaining a steady 'wakefulness' throughout the whole period. Compared to a resting state baseline, the subject showed sharp decreases in alpha-band power (EEG) and functional connectivity of the DMN (fMRI). This latter finding is in line with the research reviewed above, as Winter *et al.* (2020) also noted: "The interplay between the medial and lateral parietal nodes of the DMN has been found to be associated with meditative experiences of non-dual awareness (Josipovic, 2014), selflessness (Dor-Ziderman *et al.*, 2013), spacelessness and timelessness (Berkovich-Ohana *et al.*, 2013)".

The above studies together suggest that some meditators can volitionally enter states that gradually deconstruct self-representations, including the narrative self and the minimal self (Dor-Ziderman *et al.*, 2013, 2016), and through more advanced practices may be able to collapse the subject-object distinction (Josipovic, 2014; Winter *et al.*, 2020), which are corroborated by relatively consistent neural signatures. According to our model, this gradual deconstruction of the self-hierarchy is a natural consequence of resting in the here and now, because 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.

Achieving advanced states of meditation is not a process that is always experienced positively, and that challenging and even impairing experiences can arise (Lindahl *et al.*, 2017; Lindahl & Britton, 2019). In some cases alterations to the sense of self are also experienced as distressing or resembling psychopathology (Lindahl & 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), a possibility we return to in the Discussion. The above review is not intended to be exhaustive, but a focused review of key papers that are revealing about the flexibility of predictive processing during different meditation practices. In the Discussion, we return to issues of methodological rigor and propose promising novel paradigms that may strengthen the above findings and improve our capacity to experimentally investigate deep states of meditation.

5.3 Dissolving or disappearing: Psychedelics and meditation

There seems to be some merit in briefly comparing our predictive processing account of meditation to recently formulated predictive processing theories of psychedelics. The reason for this is four-fold, 1) psychedelics and meditation both show deconstructive effects on predictive processes, 2) they can both radically alter one's sense of self (Millière *et al*., 2018), 3) they show some neuro-biological similarities (Millière *et al*., 2018; Timmermann, Spriggs, *et al*., 2018), and 4) they are both thought to lead to novel insights about the workings of one's mind and can exhibit positive effects on mental health (Carhart-Harris & Friston, 2019). Although there are clear conceptual similarities, there are also important differences between our account and predictive processing models of psychedelics. Highlighting some of these may help guide future research on the intersection of meditation and psychedelics (for recent examples see, Millière *et al*., 2018; Milliere & Metzinger, 2020; Smigielski *et al*., 2019). Below we focus on the recent predictive processing model of psychedelics termed relaxed beliefs under psychedelics, or REBUS for short (Carhart-Harris & Friston, 2019). Although competing models exist (Swanson, 2018), the REBUS model shows growing empirical support (e.g., Alamia *et al*., 2020; Girn *et al*., 2020; Herzog *et al*., 2020).

According to Carhart-Harris & Friston (2019), psychedelics induce their characteristic effects on phenomenology by inducing increased entropy via agonism of the serotonin 5-HT_{2A} receptors found predominately at high levels of the cortical hierarchy. This entropy purportedly leads to a breakdown of the DMN and temporally deep priors that ordinarily constrain input from lower layers of the hierarchy. These loosened beliefs in turn permit a kind of unconstrained "anarchic" phenomenology, where predictions that would ordinarily be explained away by deeper models, now arise in conscious experience. Moreover, since the classic psychedelics - e.g., psilocybin and lysergic acid diethylamide (LSD) - are thought to effect the highest levels of abstract processing, then self-related processing (especially that which is instantiated by the DMN, Carhart-Harris *et al*., 2014) is expected to breakdown. One similarity with our account is that meditation should also engender relaxed high level beliefs by decreasing their expected precision. But perhaps unlike psychedelics, meditation may radically reduce the frequency of high-level predictions (such as mind-wandering) and the very formation of some predictions. That is, we contend that the three meditation styles gradually reduce deep predictions from arising (e.g. thoughts, emotions, senses), ultimately resulting in the non-dual state. This contrasts with states induced by most psychedelics, including drug-induced ego dissolution, which often have a rich sensory and emotional phenomenology (Millière *et al*., 2018).

Both psychedelics and meditation also result in consistent reports of experiences where one's usual sense of self changes (see Millière *et al*., 2018 for a review). We have suggested that the reason these changes in self experience occur in meditation is through a gradual reduction in temporally deep processing by resting in the here and now. On the other hand, following the REBUS model, changes in self-processing purportedly occur due to the entropic effects of psychedelics on existing priors (which may also 'flatten' or 'collapse' the hierarchy, Girn *et al*., 2020; Deane, 2020), and thus ordinary self-modelling breaks down. Thus, we propose that meditation gradually *abates* the emergence of predictions by restricting awareness to the here and now, whereas psychedelics loosens priors and, in this way, leads to the dissolution or "mergence" of self-world boundaries in experience. Or put simply, meditation *reduces* counterfactual inference, whereas psychedelics disrupt it. This difference is evident in the fact that self-less experiences during psychedelic ingestion tend to be described with high phenomenal richness whereas meditative experiences often have very little (or no) phenomenal content. Claims of "unity", or "oneness" with the environment, and statements such as "...merging with my surroundings" are common among psychedelic reports (Millière *et al*., 2018). On the other hand, meditators more commonly report "emptiness", "space", and "nothing" (Metzinger, 2020; Millière *et al*., 2018). Indeed, if the experience is truly non-dual, then there should be no experience of self, environment, or their 'mergence'. These reports are not surprising under our account, where meditation abates counterfactual processing, whereas psychedelics relax them. Put simply, we suggest that meditation prunes the counterfactual tree, whereas psychedelics dissolve it, both leading to possibly unique changes and absences in one's sense of self (see Figure 4).

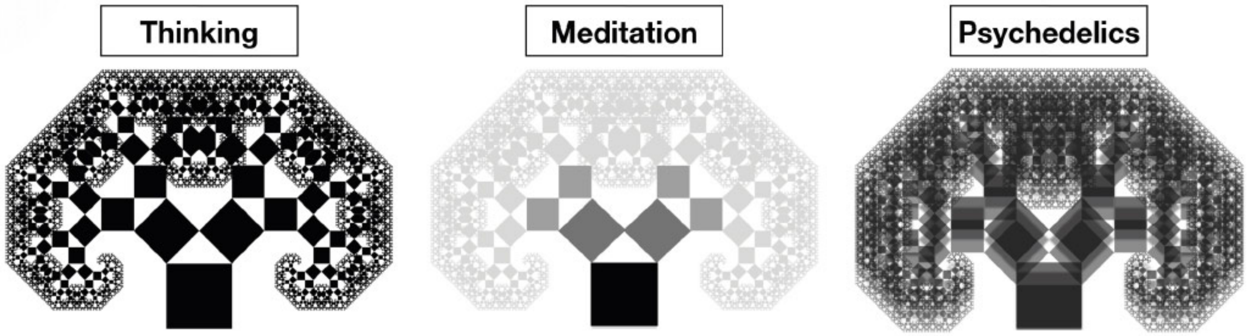

Figure 4. Here we provide an intuitive illustration of how meditation and psychedelics may differentially affect counterfactual processing. On the one hand, the psychedelic state may lead to greater counterfactual richness through its reduction of sensory gating, where relaxed high-level beliefs release low-level predictions (or counterfactuals) that would normally be explained away. Existing priors about one's self and bodily representation may then begin to dissolve because the usual models that maintain such boundaries are less precise (or *relaxed*). On the other hand, in the meditative state, counterfactual processing is gradually reduced, permitting a more progressive reduction in self-related processing, first at the higher levels (e.g., narrative self) and later at the lower levels (e.g., embodied self). During psychedelics, narrative and experiencing aspects of self-hood may begin to dissolve simultaneously and affect each other in innumerable ways, which is perhaps consistent with the more variable changes in self-processing that seem to occur during psychedelics (Millière *et al*., 2018). Although this figure is meant to serve as an intuitive illustration, it is consistent with the fact that psychedelics are known to induce greater entropy in neural activity, which is further believed to correspond to increased phenomenological richness (Carhart-Harris *et al*., 2014).

These differences also raise an intriguing, albeit speculative possibility that deep meditation may prevent some of the classic psychedelic effects. Hallucinations as well as changes in cognition and emotion experienced in the psychedelic state imply altered deep temporal processing, and if meditation halts the construction of models based on past experience, then it may also reduce some forms of hallucination and distorted perception - particularly since psychedelics are thought to target the highest levels of the cortical hierarchy (5-HT_{2A} seratonin receptors). A simple hypothesis is that classic psychedelic effects at higher levels of the hierarchy (e.g., that pertain to changes in *narrative* self-processing) would be reported to a lesser degree by experienced practitioners during meditation. There is some preliminary evidence for this idea. In a double-blind placebo controlled study, Smigielski *et al*. (2019) administered Psilocybin to experienced meditators on the fourth day of a meditation retreat. Using the well-known Five Dimensional Altered States of Consciousness scale (5D-ASC), the meditators exhibited some of the usual effects of the psychedelics. Notably however, no signficant effects were found on the Dread of Ego Dissolution dimension (items include, loss of thought control, negative derealization, and thought disorder), which is in contrast to the results of eight other experiments administering psilocybin to non-meditators (Studerus *et al*., 2011). If the meditator has halted much of high-level narrative processing, then indeed any effects related to thinking ought to be diminished[17].

Providing an interesting anecdote, the late Richard Alpert (known as Ram Dass) and former Harvard Professor who assisted in the famous Good Friday LSD experiments - the first controlled double-blind study of its kind - reported giving an extremely high dose of LSD to his meditation teacher in India (Dass, 2010). On two occasions, he watched as the "Guru" (Neem Karoli Baba) ingested approximately 900 and then 1200 micrograms of LSD - up to ten times a normal dose - and appeared to show no effects, eventually asking if Alpert "...had anything stronger" (Dass, 2014). The recent renaissance and rapid growth of research on both meditation (Van Dam *et al*., 2018) and psychedelics (Swanson, 2018), and their purported positive effects on mental health, make their interplay an exciting domain of future study, particularly as they relate to the ability of the mature mind to change.

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 conditioning - is remarkably similar to Buddhist ideas at the root of mindfulness-based interventions now popular in Western science, as the above quote illustrates. Moreover, the gradual breaking down of concepts in Buddhist meditation maps on strikingly well to the gradual building up of a concept in the brain.

Previous research has often focused on how meditation can improve functioning in one way or another, including stress reduction, cognitive performance, or emotion regulation (Kabat-Zinn, 2003; Lutz *et al*., 2008a; Slagter *et al*., 2011b; 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, 1999b)[18]. 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. However, 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 reducing the frequency of predictions and 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*[19] error-minimization and thereby conceptualization (including self and time) ceases.

We also proposed in Section 4 (see also Figure 2) that FA, OM, and ND 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 discuss the scientific value of meditation and outline important avenues for future research.

6.1 From Many to One: Novel insights from a unifying framework

There is a growing body of work investigating how meditation can change cognitive, emotional, and neural functioning (Dahl *et al*., 2015; Hölzel *et al*., 2011; Josipovic, 2014; Lutz *et al*., 2015b; Raffone *et al*., 2019; Vago & David, 2012; Vago & 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 unified account of meditation. Below we outline the scientific value of this new framework, with implications to our understanding of plasticity, psychopathology, rumination, and self. There are also several remaining outstanding questions in contemplative science (Van Dam *et al.*, 2018) that our Many-to-One framework may specifically help address, 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.

6.1.1 The scientific value of meditation: Plasticity

It is not only interesting to know how meditation 'works' but also what meditation can teach us about the brain and mind. Clearly, such an intensive mental practice that can fundamentally shift perception and cognition may also be revealing about how the mind and the organ that gives rise to all mental activity, the brain, work. We have particularly suggested that meditation can be used as a tool to investigate the plasticity of brain and cognition by revealing what is amenable to change from within, and what is not. For instance, given at least preliminary evidence that meditation can modulate strong mental habits (see Section 5), then meditation could in turn be used to investigate which features of phenomenology are more or less engrained, thereby also informing theory in cognitive neuroscience. For instance, Yon *et al*. (2019) recently proposed 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; Lindahl & Britton, 2019; Metzinger, 2020). Meditation research may also be revealing regarding the processes that are most phylogenetically constrained in human beings: Some predictive processes may simply be too stubborn for any voluntary regulation. Nevertheless, it is important to keep an open mind since it is often very difficult to find and test multiple subjects who can reliably induce profoundly altered states during meditation, and very hard to determine who can do so a-priori. As contemplative science progresses valuable strides will perhaps occur when scientists are able to better establish expertise (see also 6.1.7) and gain access to highly advanced practitioners from a variety of different meditation traditions.

6.1.2 The scientific value of meditation: Psychopathology

Beyond brain plasticity, our framework can also shift the way we look at clinical outcomes. Meditation and mindfulness-based interventions show promise in treating depression, anxiety, stress, and more (Chiesa & Serretti, 2009; Hofmann *et al.*, 2010). All such findings represent transformations in the way individuals construct their experience and behave in the world, and thus can be conceptualized as changes in predictive processing. Given our framework, 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). Moreover, the inherently explorative nature of meditation - where the curious observation of all inner-experiences is strongly encouraged - may also serve the refinement of predictive modeling, and make perceptible hitherto ignored interoceptive, emotional, and cognitive processes (Schwartenbeck *et al.*, 2019). Taken together, meditation may induce positive clinical outcomes by reducing habitual patterns of mental activity, revising stubborn habits and by increasing self-awareness.

6.1.3 The scientific value of meditation: Rumination

There may also be some further truths in the metaphor of '*pruning* the counterfactual tree'. It's obvious that excessive rumination is not conducive to a happy life (Killingsworth & Gilbert, 2010). Moreover, ruminative counterfactualizing seems to play a key role in the maintenance of psychopathologies such as anxiety and depression (Nolen-Hoeksema *et al.*, 2008). We also earlier mentioned the tendency for humans to think about things that they are trying to avoid (Bulley *et al.*, 2017) - what we called *anti-predictions* (e.g., "I don't want to get Alzheimer's disease"). Such ruminations may underlie substantial unnecessary mental turmoil and energy expenditure, as evidenced by the high metabolic demands of the DMN and links between rumination and negative mood states (Smallwood *et al.*, 2009). Although rumination can have adaptive value when it is not excessive (Baird *et al.*, 2012; Vago & 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. Although meditation creates the potential for profound change, the nature of those changes also needs to be carefully and gently guided in constructive directions to mitigate harmful experiences (Britton, 2019). There are many meditation styles that are suited for this, for example compassion meditation, or loving kindness. These more 'constructive' practices (Dahl *et al.*, 2015) may be important ingredients for guiding 'change' in a positive direction.

6.1.4 The scientific value of meditation: Self

Conducting experiments often require the manipulation of some variable. Therefore, in order to carry out rigorous experiments that are revealing about the nature of self-processing in the mind and brain scientists require ways to modulate it. Meditation is therefore obviously well placed as a tool for investigating the nature of the self, and relatively rare states of consciousness where self-processing either changes or entirely disappears. Both modern science and Eastern traditions of contemplative practice concur that the self is a kind of 'construct' that can breakdown or disappear under various conditions. Yet, science has gained most of its insights about the constructed nature of self-processing through clinical populations where such events can be highly debilitating and accompanied by several comorbidities and other symptoms. Meditation may uniquely permit the scientists to study the targeted modulation of specific self-processes constructed at various layers of the brain hierarchical system, and the changes to behavior, emotion, and phenomenology therein. 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 below, this will require the development of novel methodological approaches.

6.1.5 The scientific value of meditation: Summary

Informed by our framework, we conclude that meditation has promise in expanding scientific frontiers by increasing our understanding of brain plasticity, the concomitants of psychopathology, as well as thinking and counterfactual cognition. Meditation is also well placed to help scientists address basic and fundamental questions for how the experience of an 'I' as an agent separate from a world 'out there' emerges from prediction-error minimization. There is also promise that meditation may unveil properties of consciousness itself, such as the possibility that there exists a state in which *only* consciousness remains, a kind of 'minimal phenomenal experience' (Metzinger, 2020), which raises the possibility of more targeted investigations of consciousness as such, rather than the experiences appearing through it. In the below, we outline how our framework can also push contemplative science to the next level by addressing outstanding questions in the scientific study of meditation.

6.1.6 Insights for contemplative science: From state to trait

As state-level meditation changes are known to lead to longer-term trait-level changes (Rael & Polich, 2006), one may also expect that meditators should display differential functioning of the predictive processing machinery 'off the cushion'. Drawing on our framework, more advanced meditators would 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. 20255). Moreover, some well-known adepts of non-dual meditation have 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.

The transition of meditation from state to trait may also be driven by fact free learning and insight (Friston *et al.*, 2017). 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. These revisions may then result in the development of new and potentially stable priors. Meditation experience could also render mental activity more counterfactually rich in the long term, as proposed by Pagnoni (2019). If meditation weakens ingrained prediction loops during practice, this would permit one to entertain a broader set of counterfactuals outside of formal meditation contexts. In other words, the broadscale loosening of beliefs may permit more flexibile and multidimensional processing (a prospect there is already some evidence for, Moore & Malinowski, 2009). In general, meditators should also 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 & Ricard, 2011).

6.1.7 Insights for contemplative science: Establishing expertise

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*., 2020), other meditation practices may reduce the ability to learn and retain new information or extract statistical regularities. Indeed, a study in nonmeditators showed that individuals scoring high on self-reported mindfulness displayed impaired artificial grammar learning (Whitmarsh *et al*., 2013). Thus, meditation could also impede performance in some everyday life settings. Just as meditation may not always improve performance, it may not always lead to positive experiences.

6.1.8 Insights for contemplative science: Challenging experiences

Profoundly deconstructing the mind is not a simple and straightforward endeavor, and recent evidence suggests that negative and challenging experiences do occur and can be severe (Britton, 2019; Lindahl *et al*., 2017; Lindahl & 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'. 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 & 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 meditation training. Similarly, as counterfactual processing is deconstructed and early layers of the predictive hierarchy become perceptible, what is discovered may not coincide (indeed strongly contradict) one's models at higher more abstract layers of the hierarchy, which may cause uncertainty and distress. 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. Looking to the future, below we make specific recommendations for how to improve methodology in contemplative science to ensure balanced and accurate findings.

6.2 Methodological considerations

For the field of meditation research to grow into a mature field of science it has to address several methodological challenges (Davidson & 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), as discussed above. 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 likely higher during advanced states of FA than during novice OM states (Lutz *et al.*, 2015). 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), nonself (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. One promising approach that may reveal the 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 subtle or even pre-conscious 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).

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; Baskin *et al.*, 2003). 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 to 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). 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 & Slagter, 2014). This 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.

6.3 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 Eastern and Western ideas closer together, showing how first-person tools of contemplative enquiry can lead to similar viewpoints as the third-person tools of science.

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Footnotes

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.
4. 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 layer 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.
5. Autopoietic actions are those that allow an organism to reproduce, regenerate, and therefore maintain itself (Maturana & Varela, 1991).
6. Here we have already introduced many novel terms for readers new to predictive processing. By the time our theory is more concretely described these words should make much more sense.
7. The hidden word is 'introspection'
8. See Section 2.1: A hierarchy of expectations.
9. 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 shape 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.
10. 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)
11. See also Ashtavakra Gita (Byrom, 1990 translation), perhaps the oldest non-dual text with Hindu origins.
12. Whether this is a genuine philosophical conundrum is questionable (certainly 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.
13. 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 Vedãnta, 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."
14. In Figure 3 we have used different layers of the hierarchy than Figure 2 in order to emphasize the behaviour of generative models. In lower layers in the hierarchy (i.e., "pure witnessing" or the subject/object divide shown in Figure 2) there is no longer phenomenology of sensory objects, and if there are, they are arising in later layers.
15. 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.
16. 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, 1999b).
17. On the other hand, if a meditation practitioner is naturally embodying a more *experiencing* mode of self - but not yet in a non-dual state - then psychedelics may help to further deconstruct hierarchical processing in tandem with meditation. Consistent with this idea, the authors *did* find significant increases in Oceanic Boundlessness - a construct reminiscent of ND awareness - among meditators administered the psilocybin.
18. As noted by (Britton *et al*., 2014): "In his *Science and Buddhism: A Guide for the Perplexed*, Buddhist studies scholar Donald Lopez [(Lopez Jr, 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)]"
19. 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).

7. References

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