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Updating the dynamic framework of thought: Creativity and psychedelics

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ABSTRACT

Contemporary investigations regard creativity as a dynamic form of cognition that involves movement between the dissociable stages of creative generation and creative evaluation. Our recently proposed Dynamic Framework of Thought (Christoff et al., 2016) offered a conceptualization of these stages in terms of an interplay between sources of constraint and variability on thought. This initial conceptualization, however, has yet to be fully explicated and given targeted discussion. Here, we refine this framework's account of creativity by highlighting the dynamic nature of creative thought, both within and between the stages of creative generation and evaluation. In particular, we emphasize that creative generation in particular is best regarded as a product of multiple, varying mental states, rather than being a singular mental state in and of itself. We also propose that the psychedelic state is a mental state with high potential for facilitating creative generation and update the Dynamic Framework of Thought to incorporate this state. This paper seeks to highlight the dynamic nature of the neurocognitive processes underlying creative thinking and to draw attention to the potential utility of psychedelic substances as experimental tools in the neuroscience of creativity.

1. Introduction

Creative thinking is a ubiquitous form of cognition that is critical for our ability to effectively and flexibly interact with the world on a day-to-day basis. Scientific investigations have typically defined creativity as the ability or act of producing ideas that are novel (original, unique, inventive; Boden, 2007) and useful (appropriate, adaptive, valuable; Diedrich et al., 2015; Runco and Jaeger, 2012). Theoretical discussions on the dynamics of the creative process have established creative thinking as a dynamic state that involves moving between different modes of thought, rather than being a singular mental state (Campbell, 1960; Finke et al., 1992; Gabora, 2005). Accordingly, recent work has highlighted the notion that the process of arriving at a creative product requires shifting between the neurocognitively dissociable modes of creative generation and evaluation (Beaty et al., 2015a, 2015b; Ellamil et al., 2012). Our recently proposed dynamic framework of thought (DFT; Christoff et al., 2016) incorporates these conceptualizations into a model that focuses on the competing forces of constraint and variability on thought. The DFT views creative generation as a relatively unconstrained mode of thought that is similar, in that sense, to dreaming. Contrastingly, creative evaluation is viewed as a particular type of highly constrained thought that is similar to the goal-directed thinking required across most cognitive paradigms used in psychological research. However, despite offering a general account of these modes of creative thought, the DFT's conception of creative thinking has yet to receive targeted discussion. This, for example, can be seen in the lack of explicit discussion by the DFT as originally proposed on the potential for dynamic variability *within* each of creative generation and evaluation. This may be most relevant for creative generation, which artists have long regarded as a particularly elusive mode of thought that can exhibit varying manifestations (Dobson, 2018).

Indeed, to overcome this elusiveness, artists have been known to employ a variety of techniques for inspiration, from invoking the muses, to sensory deprivation, to mind-altering drugs. In this context it is interesting to note that the past decade has seen a resurgence of scientific interest in psychedelic (lit. 'mind-revealing') substances (Carhart-Harris, 2018; Carhart-Harris and Friston, 2019; Carhart-Harris et al., 2014; dos Santos et al., 2016; Garcia-Romeu et al., 2016; Halberstadt et al., 2018; Johnson et al., 2019; Nichols, 2016), which have long been associated with an unconstrained and hyperassociative mode of cognition that

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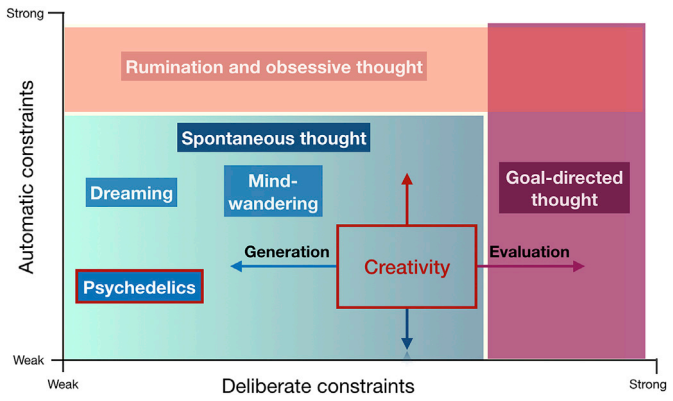

Fig. 1. The conceptual landscape presented in the Dynamic Framework of Thought (DFT) proposed by (Christoff et al., 2016). Red boxes represent revised parts of the DFT.

features changes in affect and meaning-attribution (Carhart-Harris et al., 2012; Carhart-Harris et al., 2016; Fox et al., 2018; Girn and Christoff, 2018; Hartogsohn, 2018; Lifshitz et al., 2018; Preller and Vollenweider, 2016; Studerus et al., 2010; Studerus et al., 2011). These psychoactive properties suggest that psychedelic substances may represent a novel and useful means of experimentally investigating particular dimensions of creative generation.

Given the limitations of the DFT's original formulation of creative thought and as well as the potential links between the psychedelic state and creative generation, the present paper attempts to address two primary aims: (1) to refine the conception of creative thought proposed by the DFT (Christoff et al., 2016) to focus on dynamic shifts between and within different modes of thinking, and (2) to incorporate the psychedelic state into the DFT. Ultimately, we seek to highlight the dynamic nature of the neurocognitive processes underlying creative thinking and to draw attention to the potential utility of psychedelic substances as experimental tools in the neuroscience of creativity.

2. Reconceptualizing creativity in the dynamic framework of thought

The recently proposed 'dynamic framework of thought' (DFT) model situates creative thought within a continuous conceptual space alongside other types of thought, such mind-wandering, dreaming, rumination, and goal-directed thought (Christoff et al., 2016). This framework views spontaneous thinking as a sequence of mental states (thoughts) which feature varying degrees of constraints on the content of each thought and on the dynamics of the transitions between them. Further, the DFT proposes two primary types of constraints, which compose the axes of a two-dimensional conceptual space: deliberate constraints and automatic constraints (Christoff et al., 2016, Fig. 1). At the cognitive level, deliberate constraints pertain to the engagement of cognitive control processes that guide or focus thoughts in a goal-directed manner. Automatic constraints, on the other hand, are a family of mechanisms that operate outside of cognitive control, including mechanisms such as sensory or affective salience, that constrain attention and thoughts. On a neural level, deliberate constraints are hypothesised to be mediated by regions within the frontoparietal control network (FPCN), and automatic constraints as mediated by each/all of the DN_{CORE}, salience network (SN), ventral attention network (VAN), and dorsal attention network (DAN). According to the DFT, these constraints operate on mnemonic information provided by medial temporal lobe regions of the default network (i.e., DN_{MTL}), which serve as the source of thought content variability. Thus, the framework holds that different types of thought can be differentiated by the degree of imposed automatic and deliberate constraints (or lack thereof) on DN_{MTL}-generated thought content.

As can be seen in Fig. 1, the DFT conceptualizes dreaming, mind-wandering, and creative thinking as forms of spontaneous thought, each differentiated by the amount of constraints placed on thought. The DFT, as originally proposed, situated creative thinking in a location corresponding to moderate deliberate constraints and weak-moderate automatic constraints. However, as mentioned in the introduction, creative thinking is best described as a dynamic movement between multiple mental states. In particular, the dissociable processes of creative generation and evaluation are thought to feature different amounts of constraints, wherein idea generation features weak deliberate constraints and idea evaluation features moderate to high deliberate constraints. Creative thought can therefore be defined as an alternation between states which respectively have lower and higher deliberate constraints, and corresponding lower and higher FPCN/executive involvement. Although the framework emphasizes deliberate constraints for creative thought, automatic constraints likely also play an important role. Supporting this, one study found greater DN_{CORE} and salience network activity during evaluation relative to generation, which supports a potential role for bottom-up affective/viscerosomatic information in the evaluation of creative ideas (Ellamil et al., 2012). Automatic constraints may therefore be greater during idea evaluation. However, one can also reasonably speculate on the involvement of automatic constraints in idea generation. For example, lines of thought that feature greater affective salience during idea generation may be more likely to be pursued, resulting in biases in creative output based on one's salience landscape.

Rather than being a singular state, here we propose that creative generation takes place as a result of being in multiple locations in the conceptual landscape of the framework. This variability requirement contrasts with other phenomena (e.g., dreaming or goal-directed thought) – which have comparatively more defined positions. Specifically, we highlight the fact that creative thoughts can be generated in a variety of different mental states/configurations of constraints. For example, the act of creatively improvising within a circumscribed task domain, such as to produce music of a specific emotional quality as in (Pinho et al., 2015), may take place in a mental state more similar to goal-directed thought (with moderate-high deliberate constraints), while generating ideas for a divergent thinking task in a process of blind variation (Campbell, 1960) may take place in a mental state more similar to dreaming (with low automatic and deliberate constrains). Thus, creative generation may be best conceptualized as a product of mental states which can vary along dimensions of relative constraint on thought, rather than being a specific mental state thought itself.

There is already some empirical support for the predictions made by the DFT in terms of brain network interactions underpinning particular combinations of constraints on creative generation. For example, divergent thinking tasks typically advocate for a blind variation (low automatic and deliberate constraints) and selective retention approach (high automatic and/or deliberate constraints), and the framework would predict that the generation period for these tasks would involve high DN_{MTL}, low FPCN, and low-moderate SN involvement, while the evaluation phase would notably involve high FPCN involvement/FPCN-DN coupling. Although a neuroimaging study of divergent thinking which explicitly separates the idea generation and evaluation is lacking, one study examined whole-brain dynamic FC during a divergent thinking task (Beaty et al., 2015). Broadly in line with our framework, this study found increased FC between a region of the DN and salience network earlier during the task (when there is a higher likelihood of idea generation processes), and increased FC between the DN and FPCN later in the task (when there is a higher likelihood of idea evaluation processes).

A second example comes from a study which explicitly examined creative generation vs. evaluation in the context of drawing artwork (Ellamil et al., 2012),. For this study, the DFT the model would predict the involvement of low deliberate and low-moderate automatic constraints during generation and moderate-high automatic and deliberate constraints during evaluation. Neurally, the DFT would predict high DN_{MTL}, low-moderate FPCN, and low-moderate SN activations for the generation stage, and high FPCN/FPCN-DN, and moderate SN activations

for the evaluation phase. Again, broadly in line with our framework, Ellamil et al.'s study found increased activation in the DN_{MTL} during generation, and in the DN, FPCN, and SN in evaluation (Ellamil et al., 2012).

As a final example, a recent study asked pianists to improvise based on an internally-based constraint ("improvise to express a specific emotion") or an externally-based constraint (improvise using a certain subset of piano keys/pitch set; Pinho et al., 2015). Given the presence of explicit (deliberate) constraints on creative generation, the framework would predict DLPFC involvement for both of these creative generation conditions. This prediction was confirmed: DLPFC featured significant FC with other regions in both of these conditions, including with the DN for the internally-based constraints condition (Pinho et al., 2015). For all three of these examples, we contend that there is a dynamic movement between mental states which feature different combinations of automatic and deliberate constraints, and that the distinct combinations exhibited during a task are a product of its particular task demands. By conceptualizing creative thought in this manner - in terms of the dynamic movement between mental states which vary in the amount and/or type of constraints present - the DFT may facilitate more targeted neurocognitive hypotheses for creativity research.

This focus on dynamics also suggests the need for a closer examination of the phenomenology of the creative process. In order to conduct a more fine-grained examination of the relationship between neural and subjective dynamics during creative thought, more accurate characterizations of the latter are required. In the next section, we present a conceptualization of the creative process based on the concept of 'simulated annealing' in order to stimulate discussion on this area.

2.1. Viewing the dynamics of the creative process as simulated annealing

The DFT as originally posed, as well as previous investigations of creativity (Beaty et al., 2015), typically view creativity as a cyclical alternation between creative generation and evaluation – so-called 'flip-flop' thinking (Dobson, 2018). However, reports by artists on the creative process generally indicate that it is more complex than a simple oscillation (Dobson, 2018). As a potentially more phenomenologically accurate conceptualization of the movement between creative generation and evaluation, we introduce the analogy of *simulated annealing* (Kirkpatrick et al., 1983). 'Annealing' is a concept from metallurgy which refers to the slow cooling of a heated material to reduce defects and improve certain properties. 'Simulated annealing' refers to an optimization algorithm used in mathematics and computer science to probabilistically approximate the global optimum of a given function. The correspondence to the metallurgic concept is in the fact that simulated annealing involves setting an initial non-zero probability of accepting a worse solution while traversing the search space, which progressively decreases towards zero over time (i.e., analogous to the slow cooling of a metal). This is in contrast to other optimization algorithms such as 'hill climbing' which only allow the acceptance of better solutions.

As a consequence of this property, simulated annealing allows greater exploration of the search space and a consequent lower likelihood of settling for a local optimum rather than eventually finding the global optimum. Applied to creativity, we propose that the process of creative thinking might follow a process of progressive increase in the specificity/amount of constraints applied during generation. That is, assuming multiple cycles of idea generation and evaluation in the creative process, it may be the case that initial iterations of generation have relatively low/broad constraints, which are progressively increased/focused in successive iterations. In early stages of the process, there may also be a higher degree of oscillation between the focusing vs. broadening of constraints, as in stepping back from 'suboptimal' lines of thinking. Accordingly, there may be a reduced likelihood of entertaining a wide range of semantically-distant lines of thought later in the creative process, as constraints become more focused and proximity to a perceived 'global optimum' is reached.

This process of iterative focusing is a common theme in many fields where creativity is necessary. In addition to the traditional fine arts wherein artists may experience the creative process as a process of progressively discovering the specifics of their creation, this method is often applied at a larger scale when companies engage in rapid prototyping and testing (Dobson, 2018). In this case, rapid prototyping may first simply occur in the designer's mind (i.e. "what would this look like and is this a feasible approach?"), followed by more focused tests of the product which lead to specific refinements over time.

Although the precise phenomenology of creative generation is bound to vary across task domains, this characterization may in some form apply to a number of cases. As mentioned above, we include it here not to attempt to definitively map the creative process, but in order to draw greater attention to the need for more refined models of the dynamics of subjective experience underlying creative thought. If we are to investigate the DFT's hypotheses regarding the neurocognitive dynamics underlying creativity, a neurophenomenological (Lutz and Thompson, 2003; Varela, 1996) approach is required which is predicated on a more fine-grained linkage between neural and subjective dynamics.

3. Incorporating the psychedelic state in the dynamic framework

In addition to re-conceptualizing creativity in the DFT, we fill another gap in the framework by incorporating psychedelic states in the two-dimensional space outlined in Fig. 1. We focus on 'classic' serotonergic psychedelics such as LSD and psilocybin (Nichols, 2016). Each of these drugs exhibit a complex pharmacological profile but notably share agonist properties at the 5-HT2A receptor subtype - activation of which has been strongly linked to the 'psychedelic' effects of these drugs (Kraehenmann et al., 2017; Kraehenmann et al., 2017; López-Giménez and González-Maeso, 2017; Nichols, 2016; Preller et al., 2018; Preller et al., 2017). These drugs have notably seen a resurgence of scientific interest in recent years, spearheaded by preliminary clinical trials suggesting significant effectiveness in the treatment of multiple mental health conditions (Carhart-Harris et al., 2016; Garcia-Romeu et al., 2013; Griffiths et al., 2016; Johnson et al., 2014; Johnson et al., 2019; Ross et al., 2016) as well investigations into the neural underpinnings of the psychedelic state (e.g., Carhart-Harris et al., 2012; Carhart-Harris and Friston, 2019; Carhart-Harris et al., 2016; Lebedev et al., 2015; Muthukumaraswamy et al., 2013; Palhano-Fontes et al., 2015; Preller et al., 2018; Preller et al., 2020; Tagliazucchi et al., 2016; Timmermann et al., 2019).

Phenomenological reports of the psychedelic experience have suggested that it is a state of relatively 'unconstrained' cognition, featuring a large amount of visual imagery, hyper-associative thinking, reduced reality testing, as well as changes in affect lability, meaning attribution, and sense of self (Carhart-Harris et al., 2012; Carhart-Harris et al., 2014; Carhart-Harris et al., 2016; Fox et al., 2018; Girn and Christoff, 2018; Preller and Vollenweider, 2016; Studerus et al., 2010; Studerus et al., 2011). In terms of the DFT, prior work suggests that the psychedelic state features low deliberate and automatic constraints, similar to dreaming (Fig. 1).

Indeed, the similarity between the psychedelic and dream state has long been acknowledged (e.g., Fischman, 1983; Jacobs, 1978), and recent work has supported the neurophenomenological similarity between the two states (Carhart-Harris, 2007; Carhart-Harris and Nutt, 2014;Kraehenmann, 2017; Kraehenmann et al., 2017; Sanz et al., 2018). For example, both feature a high degree of visual imagery, bizarre cognitive phenomena, illogical transitions between thoughts, and increased associative thinking (Kraehenmann, 2017). However, important differences between these two states also exist: the psychedelic state typically features some degree of meta-cognitive awareness (i.e. awareness that one is under the influence of a drug) and, with eyes open, is more grounded in the external world than dreaming (Kraehenmann, 2017). This makes the psychedelic state more similar to the phenomenon of 'lucid dreaming' (Kraehenmann, 2017; Voss et al., 2009), although

still importantly different according to the latter point above, i.e. particularly when one witnesses the world with eyes open under psychedelics. By eliciting a 'dreamlike' mental state that is relatively unconstrained and hyperassociative, psychedelics may represent a novel opportunity for empirically evaluating the neural predictions of our framework (see Supplementary Materials for a preliminary evaluation) and for investigating the neuroscience of creative generation more generally.

3.1. Support for incorporating psychedelics into the DFT: A review of psychedelic alterations of creativity

In order to expand on the above phenomenological discussion and provide a more complete picture of the potential relationship between psychedelics and creativity, we provide a qualitative review of existing research in this area. Our goal here is to provide a theoretical and empirical overview of past work in order to support the inclusion of psychedelics in the DFT and the potential application of these compounds to creativity research more generally.

Since their (re)introduction into Western society in the mid-20th century, much interest has been placed on the ability for psychedelic substances to enhance creativity. Indeed, the psychedelic literature is rife with anecdotal reports to this effect - a notable example being the self-professed role of LSD in Kary Mullis' discovery of the polymerase chain reaction (Mullis, 2010). Despite this, however, there is a relative dearth of rigorous scientific investigations into the relationship between psychedelics and creativity. Early research – which often featured a questionable degree of scientific rigor by today's standards – revealed largely inconclusive results (Baggott, 2015; Krippner, 1985; Sessa, 2008), and the handful of existing contemporary investigations are highly preliminary owing to the infancy of the field. Despite this, some general points suggestive of the manner in which psychedelics might influence creativity can be derived, which serve as hypotheses for future research.

Broadly speaking, research on psychedelics and creativity has suggested that psychedelics likely do not play a generalized role in enhancing creativity, but mediate changes in cognition and subjective experience that modulate particular sub-domains of creative thought. One manner in which the psychedelic experience may enhance creativity is via the induction of 'primary process thinking'. Primary process thinking – a term that originates in Freudian metapsychology (Carhart-Harris and Friston, 2010; Carhart-Harris et al., 2014; Noy, 1969) – is characterized by thinking that is hyper-associative and thus, unconstrained; featuring highly affective and affectively labile states, contradictory or illogical thoughts and feelings, the transformation and merging of images, and illogical and abrupt transitions between thoughts. It also often features compromised reality-testing and is thus associated with magical/wishful fantasy-based thinking. This manner of thinking has been noted to occur during a number of altered states of consciousness, including dreaming, sensory deprivation, hyperventilation/rhythmic breathing, trance, and psychosis (Bazan et al., 2013; Kraehenmann, 2017; Kraehenmann et al., 2017; Vaitl et al., 2005). It is defined in distinction to secondary process thinking, which is the manner of thinking that characterizes normal waking thought and which is logical, rule-based, adaptive, and reflective in character (Rapaport, 1950). The primary vs. secondary terminological distinction is a result of the view that primary process thinking is a developmental/evolutionary antecedent to the more analytically advanced secondary process thinking (Carhart-Harris and Friston, 2010; Carhart-Harris et al., 2014; Noy, 1969). Early studies sought to investigate the presence of psychedelically-induced primary process thinking by analyzing the subjective reports of subjects undergoing a psychedelic experience. Using primary process dictionaries – that is, dictionaries that catalogue words characteristic of primary process thinking – they found that subjects do indeed use a greater amount of primary process language during the acute psychedelic experience (Landon and Fischer, 1970; Martindale and Fischer, 1977; Natale et al., 1978). Following up on and supporting this research, a recent study had individuals complete a mental imagery task following LSD administration and also found a significant increase in primary process thinking as indexed by the primary index – a formal measure of this style of thinking (Kraehenmann et al., 2017). In sum, this work suggests that psychedelics can induce a hyper-associative, imagistic mode of thinking that operates with a relative lack of logical constraints and which involves making connections between relatively unrelated words and images. For a review on the action of psychedelics on primary process thinking and its hypothesised relationship to changes in brain function, particularly in relation to the default-mode network, see (Carhart-Harris and Friston, 2010).

The hyperassociative nature of internal mentation in the psychedelic state is also supported by studies investigating semantic priming while under the influence of a psychedelic. One early study found that indirect semantic priming was increased during the psychedelic state, which was interpreted to suggest that psychedelics may enable a greater spread of semantic activation in response to a stimulus which facilitates the retrieval of distant associations (Spitzer et al., 1996). A recent study, following up on this work, also supports an increased spread of semantic network activation as a result of psychedelic administration (Family et al., 2016). This study employed a picture-naming task, and found that, under the influence of LSD, subjects selectively committed significantly more substitution errors for semantically-related words (e.g., responding 'foot' for a picture of a leg, or 'cat' for a picture of a dog) – a type of error that has been explicitly linked to the spread of semantic activation (Garrett, 1992). Also supporting an enhancement of associative thinking under the influence of psychedelics, a recent study found an improvement in divergent thinking following ayahuasca administration (Kuypers et al., 2016). Divergent thinking was indexed via the picture concept task, which involves generating creative associations between rows of pictures (Kuypers et al., 2016).

It is important to note, especially with regard to primary process thinking, that the presence of diverse thoughts and distant associations does not imply a greater amount of useful creative outputs. Interestingly, in the early psychedelic and creativity literature, there are many examples of a discrepancy between a subjective sense of enhanced creativity and external assessments of creative ability (Baggott, 2015). One reason might relate to the changes in affect and meaning attribution that occur under the influence of psychedelics. A number of studies have now provided evidence that psychedelics can elicit experiences of significant personal meaning and significance and can alter the attribution of meaning to previously neutral stimuli (e.g., Griffiths et al., 2008; Griffiths et al., 2006; Hartogsohn, 2018; Kaelen et al., 2015; Pahnke and Richards, 1966; Preller et al., 2017). Therefore, it could be that the acute psychedelic experience involves a non-specific increase in affective salience and meaning that is projected onto internal and external stimuli. This might therefore lead to a subjective sense of creativity enhancement that does not match the actual 'quality' of insights or realisations under the drug – as judged by others. For a relevant discussion of the so-called 'epistemic innocence' of the psychedelic experience, see (Letheby, 2016).

In addition to the alteration of the evaluation/affective appraisal of one's creative ideas, the changes in affect and meaning elicited by psychedelics may also have an effect on creative generation. One manner in which this might occur is by altering the salience landscape of one's thought patterns such that lines of thought that may regularly be ignored or that simply do not reach conscious awareness might have a higher chance of being attentionally appraised and pursued (Hartogsohn, 2018). Thus, psychedelics might facilitate the exploration of a broader search space during creative generation, which in turn leads to greater potential of discovering highly novel ideas (Carhart-Harris and Friston, 2019). Importantly, we contend that the entirety of a psychedelic state can be conceived of as a mode of creative generation and that evaluations of the usefulness of the generated ideas should take place when in a non-drug state.

In this context, it is also interesting to consider the potential relationship between increased associative thinking and enhanced meaning

in the psychedelic state. The ability to draw connections between concepts/stimuli and the ability to attribute meaning/value to ideas based on these connections appear to be necessary components of creative generation. However, it is unclear to what degree these are related or orthogonal. For example, it could be the case that increases in meaning attribution can lead to a general increase in the strength of semantic associations, notably leading to stronger links between semantically distant concepts. We hold that this is an important relationship to be investigated in future research, which may also be facilitated by work with psychedelic substances.

The ability for the psychedelic state to facilitate creative generation also finds theoretical support in a recently proposed model of psychedelic drug action, which offers a mechanistic account of how this facilitation might occur (Carhart-Harris and Friston, 2019). This model, couched in terms of hierarchical predictive coding and the Free Energy Principle (Friston, 2010), proposes that psychedelic elicit their characteristic effects by decreasing the precision-weighting of high-level priors (e.g., beliefs or assumptions) which are encoded by high-level aspects of brain function, such as by the default network and other regions of association cortex (Carhart-Harris and Friston, 2019). According to this model, these high-level priors regularly provide an informationally-compressive explanatory role with regard to low-level bottom-up inputs from the sensory modalities or limbic system (e.g., memories or spontaneous thoughts). Thus, as a result of a decrease in the weighting of these high-level priors during the psychedelic experience, low-level inputs are liberated from top-down constraints and are more available to conscious awareness. In effect, this is viewed to broaden the volume and breadth of available sensory and mnemonic content and increases the potential for 'out of the box' ideas, novel insights, and new perspectives (Carhart-Harris and Friston, 2019). This model is supported by a number of empirical findings and is broadly consistent with the notion of relaxed constraints highlighted by the DFT. It also suggests that the relative hierarchical level of imposed constraints on thought might be a neurocognitive phenomenon of interest relevant to the DFT model and spontaneous thought/creativity more generally. However additional empirical work is needed to ascertain whether this is the case.

An additional noteworthy source of (indirect) empirical support for a relationship between psychedelics and creativity is a recent investigation of musical improvisation (Dolan et al., 2018). This study employed EEG to measure brain electrical activity in both audience members and performers during a classical music performance. The performers (classical musicians) were instructed to perform each piece of music twice: once in a 'strict' mode that adhered to a memorized interpretation, and once in a 'let-go' mode which was explicitly instructed to be improvisational and spontaneous (Dolan et al., 2018). The study found increases in the entropy of the EEG timeseries (using Lempel-Ziv complexity as their measure) in both performers and audience members during the 'let-go' condition relative to the 'strict' condition. Interestingly, increased fMRI timeseries entropy (which can be understood as timeseries unpredictability) has been found for each of the classic 5-HT2A agonist psychedelics - LSD, psilocybin, and DMT/ayahuasca (Lebedev et al., 2016; Schartner et al., 2017; Tagliazucchi et al., 2014; Timmermann et al., 2019; Viol et al., 2017) - and has been specifically highlighted as an important component of psychedelic brain action (Atasoy et al., 2018; Carhart-Harris, 2018; Carhart-Harris et al., 2014). Although direct investigations are needed, this provides evidence that the psychedelic state may bear similarities to the mental state of creative improvisation. Finally, as a proof-of-concept for more targeted investigations into the role of psychedelics in creative processes, we refer interested readers to our Supplementary Materials for an exploratory re-analysis of a previously published dataset (Carhart-Harris et al., 2016b).

4. Conclusions and future directions

In this paper we presented a refinement of our recently proposed Dynamic Framework of Thought (DFT)'s conception of creativity. We emphasize the dynamic nature of creative thought and offer a view of creative products as emerging from multiple potential mental states, each which differ in the amount and type of constraints on thought that are present. In addition, we incorporated the psychedelic state into the DFT and, on the basis of both theoretical and empirical work, argue that it is a strong candidate for the generation of creative ideas. We also refer interested readers to some preliminary neuroimaging results on dimensions of creative thought in the LSD state.

The conception of creativity presented in this paper highlights the notion that it involves the dynamic movement between multiple mental states. As described, we hold that this movement can occur both within and between the neurocognitively dissociable idea generation and idea evaluation stages of creative thought. On the idea generation side, the generation of creative ideas can occur, for example, with low automatic and deliberate constraints (e.g., blind variation (Campbell, 1960) in a state akin to dreaming), with moderate automatic and low deliberate constraints (e.g., when strong biases towards certain lines of thinking occur as a result of affective salience), or with low automatic and moderate-high deliberate constraints (e.g., when creative output is circumscribed by particular task demands, such as when improvising within a specific emotion (Pinho et al., 2015)). On the idea evaluation side, the evaluation of creative ideas can occur, for example, with low automatic and high deliberate constraints (e.g., architects evaluating the practical feasibility of a novel building design), or with moderate automatic constraints and moderate deliberate constraints (e.g., evaluating artwork based on the emotion it elicits as well as its technical quality). Future work should focus on devising experimental tasks that have the potential to differentially elicit distinct forms of creative generation and creative evaluation, and which offer more fine-grained characterizations of the phenomenology of the creative process.

We also incorporated the psychedelic state into the DFT and argued that it exhibits properties that make it a strong candidate for facilitating the generation of creative ideas. As described above, research suggests that the psychedelic state is a state of relatively unconstrained cognition that notably features increased associative thinking and changes in affect/meaning attribution – two components central to creative generation (Carhart-Harris et al., 2012; Carhart-Harris et al., 2014; Carhart-Harris et al., 2016; Girn and Christoff, 2018; Hartogsohn, 2018; Preller and Vollenweider, 2016; Studerus et al., 2010; Studerus et al., 2011). In the language of the DFT, the psychedelic state is one of relatively low automatic and deliberate constraints – similar to that of dreaming (Kraehenmann, 2017; Kraehenmann et al., 2017; Sanz et al., 2018). As such, the phenomenology of the psychedelic state presents it as a candidate for facilitating the emergence of wide-ranging novel and 'out of the box' ideas. Offering additional support for a potential relationship between psychedelics and creativity, past empirical findings also provide evidence of psychedelically-induced alterations to a number of creativity-related aspects of cognition and subjective experience (Baggott, 2015; Family et al., 2016; Kraehenmann, 2017; Kraehenmann et al., 2017; Kuypers et al., 2016; Preller et al., 2017; Sessa, 2008). We presently complemented these results with exploratory analyses conducted on a previously collected dataset on subjects under the influence of LSD (interested readers should see Supplementary Materials). Critically, future work should build on these findings and employ behavioural paradigms that directly assess creativity in subjects following psychedelic administration, in tandem with self-report measures. Such work is needed to evaluate the degree/manner in which there may be mismatches between subjective attributions of creativity enhancement and objective performance on creativity tasks in the psychedelic state – an important issue raised but not resolved in early research (Baggott, 2015). It is interesting to note in this regard that the quality of personal insights and realisations during the acute psychedelic experience has been directly related to the efficacy of their therapeutic effect (Belser et al., 2017; Carhart-Harris and Friston, 2019; Letheby, 2016; Roseman et al., 2018) - although, to our knowledge, there are have been no investigations which explicitly attempt to examine the prevalence and

characteristics of 'true'/useful vs. 'false'/misleading insights in the psychedelic state.

Moving forward, we contend that research should seek to characterize the neurocognitive dynamics both within and between the modes of creative generation and evaluation. In addition, we hold that psychedelics present a potentially valuable means of experimentally inducing a state conducive to creative generation. Despite consistent evidence suggesting their safety when proper precautions are taken into account (Johnson et al., 2008; Schmid et al., 2015; Studerus et al., 2011), collecting data in the context of psychedelics is currently difficult due to hurdles pertaining to legality, ethics approval, and available funding (Nutt et al., 2013). However, with a rapidly increasing body of work suggesting their value in both basic science research and in a variety of clinical applications (Carhart-Harris and Friston, 2019; Johnson et al., 2019; Kyzar et al., 2017; Nichols, 2016), the coming years are likely to see a relaxing of institutional barriers to conducting research with these compounds. Among other applications, psychedelics are therefore poised to become more accessible experimental tools for different areas of cognitive neuroscience, such as for the investigation of self-experience (Girn and Christoff, 2018; Nour and Carhart-Harris, 2017) and for creativity as argued here. It is our hope that this paper will help stimulate discussion and motivate the inclusion of psychedelics into theoretical accounts and empirical approaches in the scientific study of creativity, in addition to highlighting the dynamic and multidimensional nature of the creative process.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuroimage.2020.116726.

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