CHAPTER

6

Altered states of consciousness and creativity

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> From American Indian use of peyote to Chinese people using plum wine, to Coleridge's opium use, and Hemingway's alcohol consumption, individuals have found that the exaggerated emotions and altered perspectives they've gained from drugs stimulated their creativity. ***Weiner (2000), p. 211.***

This chapter will explore the long-standing question of whether altered states of consciousness (ASC) can actually facilitate creativity. This question has stimulated scientific discussion for centuries and is again becoming explored with novel vigor. Thanks to advances in neuroimaging techniques and computational neuroscience, but also as a result of a cultural shift where research into meditation or microdosing is no longer considered taboo, ASC are yet again becoming considered to be credible topics and tools to study brain function and cognition. This chapter provides an overview of findings concerning the impact of certain ASC on creativity and presents a theoretical account (the Metacontrol State Model [MSM], Hommel, 2015) that helps us to address why and how altered states might modulate creative performance. We also consider conceptual issues and challenges in studying this topic and offer a future direction for this field of study.

The idea that unusual states of consciousness might induce creativity seems rather intuitive. Creative thinking is often characterized by its out-of-the-box nature, and ASC are arguably a prototype of out-of-the-box-ness. Indeed, history is full of examples of great artists, musicians, and scientists whose creativity occurred under an ASC. For instance, Sigmund Freud's alleged love for cocaine brought about some of the most productive years in his life, Kary Mullis admitted that psychedelics helped his Nobel Prize discovery of polymerase chain reaction, Vincent van Gogh's art was to a large extent claimed to be inspired by his mental

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illness, and the entrepreneur and business magnate Steve Jobs practiced ZEN meditation to focus his mind and improve his well-being. But before addressing the connection between creativity and altered states, we must first understand what creativity is.

Components of creativity

There are numerous definitions for creativity, yet most would agree that creativity is a process, during which a person has to generate ideas, solutions, or products, which are original but still appropriate to the task at hand (e.g., Amabile, 1996; Sternberg & Lubart, 1996). Thus, rather than conceptualizing creativity as a personal trait that is reserved for a talented few, we consider creativity to be a state of mind or a series of cognitive processes that anybody can engage in when trying to generate innovative ideas. In other words, as with any state of mind, creativity is a multi-layered state with dissociable subprocesses and neural underpinnings (Sadler-Smith, 2015; Wallas, 1926).

To isolate the underlying processes in creativity, two approaches are frequently discussed (but not always properly disentangled) in the literature. Guilford (1967) described divergent thinking as the main ingredient of creativity, wherein one has to generate as many creative ideas as possible to a single open-ended question. This principle is operationalized in the alternative uses task (AUT) where the participant has to report as many possible uses for an ordinary object such as bottle (e.g., as a magnifying glass, as a weight, as a weapon, etc.). In contrast, Mednick (1962, 1968) argued that convergent thinking is the key to creativity, being the process during which an individual finds a single logical association between seemingly unrelated objects, for instance, by assessing cooccurrence of features or bridging remotely related elements. An example would be the Remote Associates Test (Mednick, 1968) where the participant has to search for a meaningful concept that can be combined with three other objects (e.g., "… man", "… market", and "… bowl"; with the connecting concept being "super"). However, it is imperative to point out that all available creativity tests involve the interaction of both convergent and divergent thinking. For instance, the act of trying to think of alternative use of an object first triggers information retrieval from associative memory, through which loosely associated representations are generated, followed by more analytic focused processing to derive a single meaningful answer (Hommel, 2012). The interaction between divergent and convergent thinking will ultimately impact the quality of artistic products and account for some degree of individual differences in creativity.

Importantly, the relative contribution of divergent and convergent thinking is dynamic and seems to be systematically modulated by the current state of consciousness. For instance, several behavioral studies have shown that each of the two processes can be enhanced or impaired by mood, arousal, meditation, or psychopharmacological agents (e.g., Baas, Nevicka, & Ten Velden, 2014; Colzato, de Haan, & Hommel, 2015; Davis, 2009; Ritter & Mostert, 2016; Zabelina & Robinson, 2010). But can ASC do the same trick? Answering this question is particularly difficult because there is no agreed-upon scheme that would allow sorting such states into meaningful and scientifically tractable categories (Blackmore, 2017) and because there is very little, if any evidence for an active, causal role of consciousness in the control of human thought and action (Hommel, 2013). In this chapter, we will try to deal with these problems by making two assumptions. First, we are agnostic with respect to whether consciousness and the alteration thereof play a truly causal role in creative performance or whether ASC are merely a diagnostic indicator of functional or neural states that impact creativity. Leaving the causality question aside, we will thus mainly be asking whether ASC correlate with states that systematically improve or interfere with processes that are involved in creativity—convergent and divergent thinking in particular. Second, we assume that ASC systematically covary with changes in metacontrol states that, as we explain in the next section, can be described as varying between persistence and flexibility. We consider this relationship between ASC and metacontrol to be particularly important from a functional viewpoint, as it helps us to explain the computational and neural underpinnings of the relationship between altered states and creative performance. However, we do not claim that focusing on this relationship provides an exhaustive assessment of normal and altered consciousness states, or an exhaustive characterization or even explanation for the phenomenology of normal or altered conscious experience. Thus, we will begin with introducing the metacontrol perspective to structure the current understanding of creativity and ASC phenomena. Next, we will discuss existing empirical evidence and theoretical considerations regarding the question of how drugs, meditation, and hallucinations (the three causes of consciousness alterations that we decided to focus on) impact creative performance.

The cognitive control of creativity

Creativity as a product of control processes

According to the MSM (Hommel, 2015), the interaction between convergent and divergent thinking is regulated by metacontrol states. The idea is that the mode or character of information processing can vary between two extremes: persistence, which is characterized by strong competition between alternative representations and strong top-down control (resulting in a rather serial, focused, and exclusive processing style), and flexibility, which is characterized by weak competition and weak top-down control (resulting in a rather parallel, broad, and integrated processing style). Persistent control implies high mutual competition between alternatives, which is beneficial or perhaps even necessary during convergent thinking, where one steers cognitive search toward a single correct answer. In contrast, high flexibility and the corresponding weak top-down control and local competition would be expected to increase the number of possible alternatives one considers concurrently, which in turn should be beneficial to divergent thinking. Indeed, flexibility allows for accessing semantic content with lower a priori accessibility and for a more associative approach to a problem (Mayseless, Eran, & Shamay-Tsoory, 2015; Runco & Jaeger, 2012; Silvia, 2008). In sum, whereas divergent thinking calls for an associative, parallel, and flexible type of processing, convergent thinking rather calls for analytical, serial, and persistent processing to converge on a single answer. In line with this expectation, Akbari Chermahini and Hommel (2010) found evidence that performance on convergent thinking tasks correlates positively with the capacity to think logically. In contrast, the divergent quality of creativity has been argued to share phenomenological similarities with schizophrenia, characterized by unorganized, delusional thoughts that lack logical structure (Eysenck, 1993). In sum, the MSM implies that the degree of creativity depends on the cognitive control style that operates on (or is expressed by) the balance between persistence (e.g., strong competition between alternatives) and flexibility (e.g., characterized by weak competition between alternatives) (Fig. 6.1). Creative performance is then a result of these two distinct and possibly competing subprocesses, presumably together with other, less creativity-specific components (Wallas, 1926).

Shifting the metacontrol balance

The balance between persistence and flexibility appears to be modulated by frontostriatal dopamine (Cools & D'Esposito, 2011). Evidence supporting this hypothesis comes from clinical research showing that patients with Parkinson's disease, characterized by rigid patterns of behavior (high persistence), show lower dopamine function in the brain. In contrast, patients with schizophrenia show symptoms of unconstrained cognition (high flexibility) and show hyperproduction of dopamine. This suggests that well-calibrated cognition requires an optimal amount of dopamine in the brain. Such optimum likely follows an inverted-U-shape function where too much or too little dopamine leads to impairments. More specifically, the balance appears to be facilitated by two distinct pathways: the nigrostriatal pathway, and the mesocortical pathway, which transport

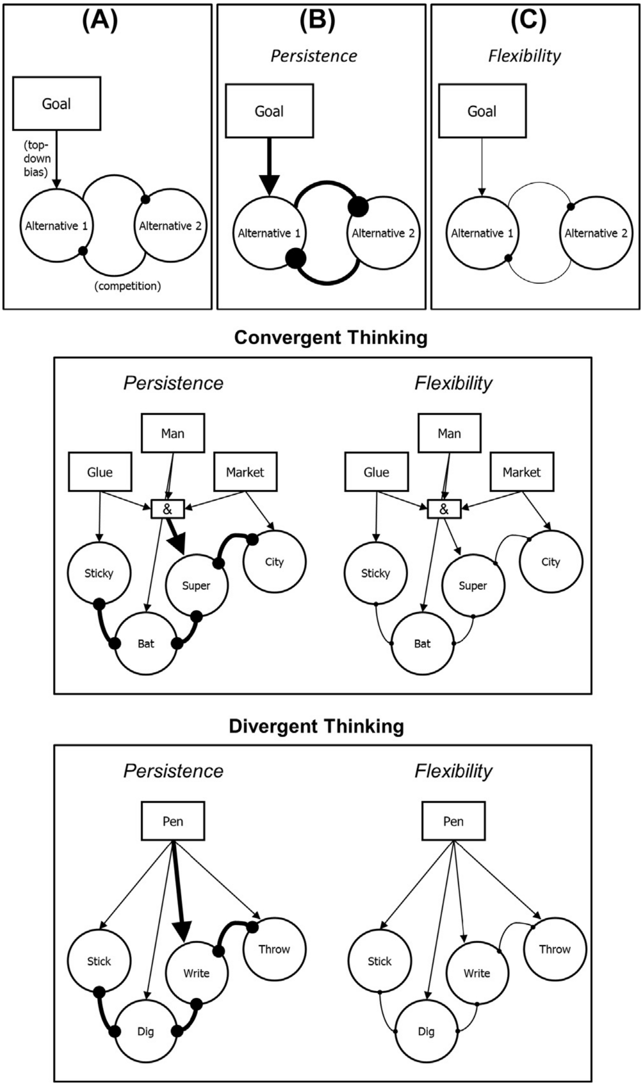

FIGURE 6.1 According to the Metacontrol State Model, metacontrol states impact information processing by establishing either strong top-down control and competition between alternative representations (persistence, panel B) or weak control and competition (flexibility, panel C). Persistence is assumed to support convergent thinking by providing strong top-down guidance to identify the sought-for solution and strong competition to shield it from alternatives. Flexibility is assumed to support divergent thinking by facilitating the consideration of multiple solutions to the vaguely defined problem. *Reprinted without changes, with permission from Elsevier based on Fig. 2 in Hommel, B., & Colzato, L. S. (2017a). The social transmission of metacontrol policies: Mechanisms underlying the interpersonal transfer of persistence and flexibility.* Neuroscience and Biobehavioral Reviews, 81, *43–58. http://doi.org/10.1016/J.NEUBIOREV.2017.01.009. Copyright 2016 by Elsevier.*

dopamine from subcortical structures (ventral tegmental area and substantia nigra) into the striatum and prefrontal cortex (PFC). The mesocortical pathway connecting PFC is associated with D1 receptors, and its stimulation with drugs has been shown to increase working memory and cognitive control and to sustain attention (Durstewitz & Seamans, 2008; Vijayraghavan, Wang, Birnbaum, Williams, & Arnsten, 2007). The nigrostriatal pathway leading to the striatum shows a high prevalence of D2 receptors and, when stimulated, is found to increase flexibility or even distractibility, characteristics of individuals with attention disorders (Dodds et al., 2009; Durstewitz & Seamans, 2008; Kellendonk et al., 2006; Mehta, Manes, Magnolfi, Sahakian, & Robbins, 2004).

This frontostriatal trade-off between flexibility and persistence implies three important inferences about creativity. First, as creativity relies on both convergent and divergent thinking, true creativity can only emerge from an appropriate balance between persistence and flexibility, or alternatively from the ability to switch adaptively between the two metacontrol modes to efficiently readjust their balance. We refer to this skill as "adaptivity" (Mekern, Sjoerds, & Hommel, 2019). The second implication is that the metacontrol balance, as well as adaptivity, can be changed by external or internal factors such as psychoactive drugs or dopaminergic affect-related states. Third, it is to be expected that individuals' baseline levels of dopamine vary, and as such, manipulations of dopamine levels via drugs or other types of altered states will have differential effects on creativity for different individuals. While some people will benefit from a boost of flexibility, others would require a more persistent focus to provide useful solutions to a challenging problem.

Mood and creativity

As already mentioned, the relative state of metacontrol is systematically modulated by the current affective state. This is important to consider because arousal and emotions are profoundly changed by ASC. The level of dopamine in the brain has been suggested to induce positive affect (Ashby, Isen, & Turken, 1999). From this perspective, it is not surprising that a recent metaanalysis of 62 experimental studies has confirmed that positive mood enhances (divergent) creativity (Davis, 2009). On the other hand, dysphoric mood and fear and anxiety have been linked to reduced creativity (Baas, Nijstad, & De Dreu, 2015). Arousal is viewed as a continuum, ranging from sleep to alert wakefulness. The impact of arousal on creativity is thought to have an inverted-U-shape function following the same logic as described for dopamine. It is assumed that simple problem-solving tasks can be most effectively accomplished with a high level of arousal, whereas more complex tasks requiring extensive concentration benefit from a low level of arousal

(Martindale & Greenough, 1973). As various types of ASC affect mood and arousal to different degrees, we can also expect variations in their impact on creativity.

Memory and creativity

In contrast to common wisdom, creative solutions do typically not come out of the blue but result from novel, often metaphorical, combination of pieces of old, available knowledge—as exemplified by the tasks assessing convergent and divergent thinking. This implies that memory and, by implication, the control of memory retrieval plays an essential part in creativity, which is of particular interest because memory processes are often impacted by ASC. How does that work? Particularly important for the possibility to generate novel solutions from the recombination of old memory entries is the existence of feature-based memory codes. While theories differ with respect to the existence of abstract, truly symbolic representations (Morgan, 2014), most theories assume that concepts are grounded in codes that refer to the sensory and action-related (perhaps even affective) features of the corresponding events in the world.

For instance, the *Theory of Event Coding* (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001a, 2001b) claims that concepts consist of integrated bindings of codes that refer to the sensory features of a given event, such as the features <green>, <round>, and <sour> of an apple one perceives, and the sensory feedback of the action one is or has been performing on that event, such as <grasping>, <biting>, and <swallowing>. This representational format naturally creates feature overlap between concepts, such as between (round) apples, balls, and balloons, which can be exploited in searching for a novel, creative solutions to a problem. This has been formalized by the Creative Cognitive framework (CreaCogs-OROC; for an overview of computational models of creativity, see Mekern, Hommel, & Sjoerds, 2019), which suggests that divergent solutions are supported in a multilayered fashion through associative search and spreading of activation. According to CreaCogs-OROC, divergent solutions can be identified through memory search at three levels. At the first level, features of objects are stored and categorized. Associations between objects are attained by matching shared features in feature space, such as between an apple and a balloon. The second level in this hierarchy is a concept level, which holds all the possible feature maps for each object, including sensory dimensions and action affordances—very similar to TEC. Finally, the last level is a problem template, which holds the topological structure and encodes concepts and relations between them, thus keeping representations coherent. The hierarchy allows for feature matching and the consequent

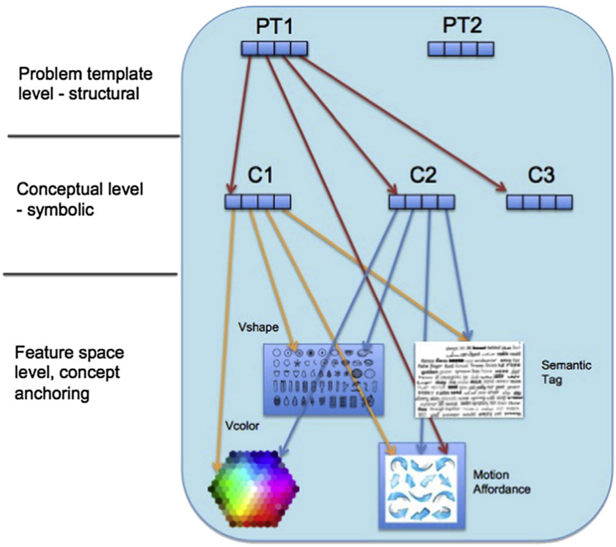

FIGURE 6.2 CreaCogs-OROC comprises three levels over which objects are encoded. Divergent thinking occurs by matching features grounded in the sensory and action-related event information. *Reprinted without changes, with permission from Elsevier based on Fig. 1 in Olteţeanu, A., & Falomir, Z. (2016). Object replacement and object composition in a creative cognitive system. Toward a computational solver of the Alternative Uses Test.* Cognitive Systems Research, 39*, 15–32. Copyright 2016 by Elsevier.*

rerepresentation of objects as necessary in divergent thinking (Batchelder & Alexander, 2012). The more feature spaces are activated (as in a flexibility-biased metacontrol state), the more divergent answers can be expected, for instance, in the AUT (Fig. 6.2).

Now imagine what would happen if all the feature spaces for all objects would be activated at the same time, as in a metacontrol state of extreme flexibility. This would lead to the elimination of competition between alternatives, and the streamlined processing that allows us to place the world into coherent categories would be gone. Everything could potentially be misclassified and misrepresented into anything else, and the borders of our reality would become thin and ambiguous (Olteţeanu & Falomir, 2016). Such divergent quality in cognition is described in ASC such as the psychedelic state, where the constraints and logical structure ultimately result in a distorted perception of self and time (Carhart-Harris et al., 2014). This intriguing effect will be discussed below at length.

Altered states of consciousness

Defining ASC remains a challenge. The first challenge consists in specifying what “altered” or “nonordinary” states of consciousness might be, as such a definition is contingent on the operationalization of normal consciousness, which is notoriously difficult to agree on without stepping on the toes of one or the other school of thought. For simplicity, we adopt the definition of Ward (2013) as those states that are qualitatively different from a normal waking state are marked by salient changes in awareness and responsiveness to the external environment. With regard to this definition, this chapter aims to cover only those ASC that deviate significantly from ordinary fluctuations in mood and arousal and are characterized by salient changes in psychological and neurological functioning.

Attempts have been made by numerous researchers to organize altered states into meaningful subcategories. Vaitl (2012) suggested a categorization based on the way these states were induced: (1) spontaneous states (dreaming and near-death experience), (2) physically and physiologically induced (fasting and respiration changes), (3) pathological (coma, psychosis), (4) psychological (meditation, hypnosis), and (5) or pharmacologically induced (psychoactive substances). Given the vast number of ASC, their effects on cognition vary significantly. Among the most commonly reported changes are alterations in attention, memory, arousal, self-perception, meaning and significance, body image, time perception, emotions, self-control, and suggestibility (Farthing, 1992). Of these, changes in arousal, attention, and memory play a particularly important role in the connection between ASC and creativity.

Arousal and altered states of consciousness

Arousal is important because of its connection to awareness. Awareness is the optimal state of the central nervous system during which an agent is able to respond adequately to changes in its environment. The basic mechanism of awareness is regulated through the reticular activating system, responsible for regulating wakefulness and sleep transitions (Smythies, 1997). Some ASC are characterized by very low arousal such as coma, anesthesia, or dreamless sleep; others are characterized by high arousal such as the psychedelic state, certain types of meditation, or trance induced by ecstatic dance (Vaitl, 2012). The level of arousal is considered as the quantitative index of consciousness, whereas changes in cognition are classified as the qualitative changes in consciousness (Schmidt & Majić, 2016). Due to the limited scope of this chapter, we will not consider states marked by very low arousal (coma, anesthesia, sleep) and rather focus on ASC linked to qualitative changes to consciousness.

Attention and altered states of consciousness

As suggested by Nideffer (1976), attention in ASC can change along at least two main dimensions: the direction (external/internal) and the width of attention (broad/narrow). For example, meditation requires the meditator to refrain from self-referential thoughts and inner dialog to concentrate on the present moment (Grecucci, Pappaianni, Siugzdaite, Theuninck, & Job, 2015). Hypnosis requires inner focus and imagination to follow the hypnotists' suggestions. Psychoactive substances vary significantly with their effect on attention. For instance, amphetamines, which are in various forms prescribed for children with attention disorders, are characterized by feelings of increased persistence, which can allow one to perform tasks that would be otherwise considered very hard to focus on (Lakhan & Kirchgessner, 2012). These drugs work on the basis of dopamine and will be discussed in some detail later on in this chapter. On the other hand, drugs such as psychedelics mainly operate through serotonin and are characterized by states of increased distractibility and interference. Such interference often prevents the intoxicated individual from performing even very simple tasks and is likely to be linked to decrements in memory function (Chun, Golomb, & Turk-Browne, 2011; Millière, Carhart-Harris, Roseman, Trautwein, & Berkovich-Ohana, 2018).

Memory and altered states of consciousness

Memory is an integral part of the majority of higher cognitive functions, such as the ability to speak or plan ahead. Memory suppression has been described in a variety of ASC. Decrements in short-term and long-term memory are commonly experienced after intoxication with psychoactive substances such as psychedelics or Marihuana (Schoeler & Bhattacharyya, 2013). Anecdotal reports state that in moderate doses, memory suppression may elucidate symptoms such as increase in mind wandering, loss of worry, enhanced sense of surprise, and an irresistible tendency to laugh. Larger doses of psychedelics may result in complete loss of short-term and long-term memory during which intoxicated individuals become incapable of remembering any specific details regarding the current situation or the events proceedings it. Complete memory suppression is usually accompanied by inability to speak as it becomes difficult to follow one's own track of thoughts (Lakhan & Kirchgessner, 2012). This state of mind can result in loss of control associated with thought loops, confusion, disorientation, and distorted perception of sense of self and time (Lebedev et al., 2015). Apart from drugs, changes in memory function have been also linked to other ASC such as meditation, sleep, or psychosis (Chun et al., 2011; Millière et al., 2018; Vollenweider & Geyer, 2001), some of which will be explained in greater detail in later sections.

The corticostriatothalamocortical loop theory

One theoretical framework that tries to address the underpinnings of ASC is the *corticostriatothalamocortical* (CSTC) *loop theory*, according to which certain types of ASC may result from disturbances in the cortico-striatal loop. As already mentioned in relation to creativity, the PFC and the striatum allow for information maintenance and rapid updating (O'Reilly, 2006). The thalamus is a gray matter structure in the center of the brain that transmits different sensory inputs to cerebral cortex and thus regulates the degree of updating or "gating" from different modalities. The thalamus, together with other structures of the CSTC loop, influences information processing by means of filtering incoming sensory input, which would otherwise overwhelm conscious experience. The CSTC loop theory proposes that the function of thalamus (or other parts of the CSTC loop) is disrupted in ASC, leading to information overload from both the sensory and cognitive domain (Preller et al., 2019; Vollenweider & Geyer, 2001). The inability of PFC to deal with such information overload may then result in hallucinations and ultimately break down cognitive integrity, leading to disorganized thought processes, as seen in schizophrenia, dreams, or psychedelic states (Peters, Dunlop, & Downar, 2016).

The entropic brain theory

Another theoretical framework applied to ASC is the *entropic brain theory* (EBT) which, rather than describing changes in activity within isolated brain areas, such as in CSTC loop theory, focuses on the changes of functional connectivity throughout the whole brain. The EBT has been informed by neuroimaging research with psychedelic drugs, but it can be applied to various types of ASC. According to EBT, the quality of normal waking consciousness and richness of its content can be indexed by the level of entropy (e.g., chaos) measured as a parameter of spontaneous brain activity between spatially separated brain regions. Entropy refers here to the degree of synchronicity within these spatially distinct brain regions, which can be recorded by fMRI or EEG. The EBT was proposed by Carhart-Harris et al. (2014, 2018), who suggested that disorganization of these normally synchronized systems enhances the repertoire of possible states and representations that the brain can occupy. The EBT (similar to the MSM applied to creativity) suggests that normal waking consciousness is poised somewhere between two extremes—extreme flexibility or extreme persistence. On the one hand, the brain can enter states of high entropy characterized by extreme flexibility, which results in unconstrained and unstable thought processes and, on the other hand, very stable states characterized by rigid patterns of behavior and thought. Normal waking consciousness is positioned in the middle of these two extremes, and deviations from the optimal balance between the two modes will result in ASC or psychopathology.

As this brief introduction to ASC hoped to impart, there are many types of ASC with various effects on cognition and brain function. Due to the limited scope of this chapter, we will focus only on ASC induced by psychoactive drugs (with emphasis on psychedelics) and those ASC occurring spontaneously as a result of extensive training of meditation or sensory deprivation.

Drug-induced altered states of consciousness and creativity

Psychoactive drugs are all drugs that have significant effects on human mental functioning through interaction with neurochemistry. Psychedelics are among the drugs most commonly associated with creativity and will thus be described in greater detail.

Stimulants

Stimulants include many drugs that increase the activity of the central nervous system. Stimulants are frequently prescribed in the treatment of attention-deficit hyperactivity disorder (ADHD) in the form of methylphenidate (Ritalin), dextroamphetamine (Dexedrine), and dextroamphetamine–amphetamine (Adderall). People with ADHD have been shown to have genetic alterations in the D1 signaling, which are linked to distractibility (Misener et al., 2004). Stimulant drugs increase dopamine signaling in the brain and thus facilitate better focus (Lakhan & Kirchgessner, 2012). The strength of focus facilitated by stimulants is usually much larger than what a person is capable of in the normal drug-free state allowing for effortless, continuous, and sharp focus on a specific activity without interference. Although focus-enhancing drugs bring benefits such as the ability to engage with a task effectively, they can also come at the cost of flexibility. For example, a hyperfocused person may spend too much time on redundant details or neglect important peripheral information that would facilitate divergent thinking. Farah, Haimm, Sankoorikal, and Chatterjee (2009) examined the effect of Adderall on cognition and creativity in a double-blind placebo-controlled study with healthy adults and found that Adderall improved convergent thinking but not divergent thinking. This study suggested improvements rather than decrements in creativity, but this was true only for the individuals who performed lower on the baseline measure, thus supporting the inverted-U-shape theory of dopamine and creativity, which suggests that individuals with lower dopamine levels will benefit more from a dopamine boost than those with high dopamine (Akbari Chermahini & Hommel, 2012). Other research lines show evidence for impairments in constructs related to creativity. For example, Burns, House, Fensch, and Miller (1967) found that dextroamphetamine decreased the speed of associative learning in adults, and Elliott et al. (1997) reported a relative decrease in accuracy on the Tower of London task, which requires good executive functioning. This result suggests working memory, and planning in healthy young adults is impaired by methylphenidate. Moreover, Schroeder, Mann-Koepke, Gualtieri, Eckerman, and Breese (1987) showed decreases in switching rate in a strategic choice task, suggesting further decreases in flexibility after methylphenidate. In sum, although stimulants may enhance focus and promote the ability to engage with a task effectively, they can also come in the cost of flexibility. Furthermore, addiction and tolerance are a major concern associated with stimulants, as they are known to increase dopamine in the ventral striatum, which is a brain area linked to reward (Wise, 2002). Due to stimulants' ability to directly activate the pleasure center within the brain, stimulants tend to be highly addictive, and thus, their use should be approached with the upmost caution.

Marihuana/cannabis

Marihuana (also known as Cannabis) has been used by humans for millennia and, according to the World Health Organization (2010), it is the most popular illicit drug in the world. Cannabis is known to induce a range of negative effects such as memory suppression, inability to integrate complex information, addiction, and an increased risk of psychotic symptoms (Henquet et al., 2005). Marihuana is esteemed for its ability to elevate mood, reduce stress, and possibly improve creativity. Sebastian Marincolo, in his book *High: Insights on Marijuana* (2010), wrote the following: *"Marijuana enhances our mind in a way that enables us to take a different perspective from 'high up' … Maybe this euphoric and elevating feeling of the ability to step outside the box and to look at life's patterns from this high perspective is the inspiration behind the slang term 'high' itself."* Such a self-report is not rare, as a recent literature review by Green, Kavanagh, and Young (2003) showed that more than half of marijuana users agree that cannabis makes them more creative. The psychoactive substance in cannabis is delta-9-tetrahydrocannabinol (THC) that has been shown to have an inhibitory effect on cognitive control in healthy adults (McDonald, Schleifer, Richards, & de Wit, 2003; Ramaekers et al., 2006; Ramaekers, Kauert, Theunissen, Toennes, & Moeller, 2009) as well as to indirectly stimulate dopamine release in the striatum (Bossong et al., 2009; Kuepper et al., 2013). We could expect that such a change in the brain dynamics could potentially lead to increases in divergent thinking performance, at least in participants with low striatal dopamine, as divergent thinking was associated with increased subcortical dopamine levels (Akbari Chermahini & Hommel, 2010), and decreases in cognitive control (Hommel, 2015).

A study by Schafer et al. (2012) investigated the effect of cannabis on divergent thinking and schizotypy in 160 cannabis users. Participants were tested 1 day, when they were sober, and another day, while under the influence of cannabis. Interestingly, cannabis increased verbal fluency, but only in the group scoring low on creativity, which improved to the same level as a high creativity group. Cannabis also increased psychosis-like effects in both groups, but the effect was not related to verbal fluency improvement. A similar study by Bourassa and Vaugeois (2001) investigated the effect of cannabis on divergent thinking in regular users and novices in three conditions: with, and without marijuana, and with placebo. The results showed no effect of marijuana on the Torrance Tests of Creative Thinking in novice users and reduced performance in regular users. A study by Kowal et al. (2015) examined the effects of low and high cannabis doses as well as placebo on divergent and convergent thinking tasks. The study was randomized, double-blind, and between-subjects, with 18 participants in each condition. Participants who received the high dose of cannabis (22 mg THC) performed worse on the divergent thinking tasks compared with the other groups, and no significant effect was found for convergent thinking. These results suggest that cannabis has rather detrimental effects on creativity; however, the interaction between the low- and high-creativity individuals and cannabis was not assessed in this study and thus could account for the inconsistent findings.

In sum, the link between cannabis and creativity is not clear, and scientific evidence is often contradictory. This may be due to differences in administered dosage, methodological inconsistencies, and also differential effects for low versus high creative individuals—reflecting a nonlinear, presumably inverted-U-shaped function relating individual base level of the involved neurotransmitters and dosage to performance (Akbari Chermahini & Hommel, 2010, 2012; Colzato, Slagter, de Rover, & Hommel, 2011).

Psychedelics

Psychedelics are naturally occurring compounds (in addition to man-made ones) expressed in different living forms throughout nature. The classical psychedelics include psilocybin (contained in psychedelic mushrooms), mescaline (the active constituent of peyote), DMT (the active constituent of ayahuasca), 5-MEO-DMT (an endogenous compound produced by *Bufo alvarius* toad), and LSD (which is a synthetic psychedelic). Although psychedelics vary in their physical envelope, they produce remarkably similar effects on cognition. At low doses, psychedelics cause mild perceptual changes, such as patterning of surfaces, enhancement of color and saturation, increased body awareness, and elevated mood. Higher doses result in visual morphing, shape warping, increased arousal, loss of short-term memory, and feeling of loss of sense of self and time.

> That was a real ego death stuff, feeling of no boundaries … Oneness, I was travelling in spirit world … of beautiful wonder and chaos.—Experiences of participants enrolled in recent psychedelic research ***Carhart-Harris (2016)***.

The phenomenology of transcendental flexibility in psychedelic state is similar to phenomenology described in other ASC, such as meditation, mystical ecstasy, REM sleep, or psychotic episodes, which often motivates speculations regarding similar brain mechanisms (Millière et al., 2018; Peters et al., 2016). What is known about these mechanisms with respect to psychedelics?

Psychopharmacology and brain function

Psychedelics are drugs that elucidate their action through interaction with serotonin especially as agonists on the 5-HT2A receptor, though some other activities have also been reported (for a review, see Nichols, 2016). The function of serotonin in the brain remains "elusive" due to its special diversity and complexity, which includes at least 16 different serotonin receptor subtypes. The function of serotonin 2A receptors is still to be determined, but existing studies show that deficit in 5-HT2A signaling induces perseveration and repetitive behavior (Clarke, 2005; Clarke, Dalley, Crofts, Robbins, & Roberts, 2004; Matias, Lottem, Dugué, & Mainen, 2019), whereas increased signaling improves associative and reversal learning in rats (Boulougouris, Glennon, & Robbins, 2008; Harvey, 2003). Serotonin 2A receptors were also found to stimulate neurogenesis in the cortex (Catlow, Song, Paredes, Kirstein, & Sanchez-Ramos, 2013; Gewirtz, Chen, Terwilliger, Duman, & Marek, 2002). Furthermore, studies in humans have shown that the use of psychedelics is correlated with an increase in the personality trait "Openness" (MacLean, Johnson, & Griffiths, 2011) and psychedelics used as clinical treatment successfully reduced symptoms in disorders associated with rigid behavior and thought patterns such as obsessive-compulsive disorder and depression (Carhart-Harris et al., 2016; Grob et al., 2011; Moreno, Wiegand, Taitano, & Delgado, 2006). Based on this evidence, 5-HT2AR functioning was proposed to play an important role in cognitive flexibility in humans (Boulougouris et al., 2008), and there is some evidence suggesting that 5-HT2AR agonists also enhance creative thinking (Frecska, Móré, Vargha, & Luna, 2012; Kuypers et al., 2016; Prochazkova et al., 2018; Sessa, 2008).

How do psychedelics induce cognitive flexibility?

One hypothesis explaining why psychedelics promote flexibility refers to their indirect ability to stimulate dopamine. Indeed, recent evidence by Sakashita et al. (2015) found that administration of psilocin (the metabolite of psilocybin) in rats significantly increased extracellular dopamine in nucleus accumbens (as well as serotonin) and in the mesocortical pathway, which seems counterintuitive as the mesocortical pathway was previously linked to persistence, not flexibility (Boot, Baas, van Gaal, Cools, & De Dreu, 2017). However, the potential psychotropic effect of psychedelics on creativity may be due to downstream interaction with other neurotransmitters. Namely, the CSTC loop theory proposes that the interaction between the mesostriatal and serotonergic pathway, both of which project into the striatum, ultimately results in net inhibition of the thalamus and opens the thalamic gate (Preller et al., 2019). Vollenweider et al. (1999) supported this with evidence from a positron-emission tomography (PET) study, showing that psilocybin indirectly activated dopamine (D-2) in the striatum, which was previously linked to cognitive flexibility (for review, see Boot et al., 2017). If thalamic function is disrupted, this may lead to information overload from both the sensory and memory domain, and the inability of PFC to deal with information overload will result in disorganized thought processes. The CSTC loop theory found support from studies monitoring brain metabolism using PET. The results indicated that psychedelics increased metabolic activity in higher cortical areas, and specifically the PFC, but decreased metabolism in the thalamus, which is the key structure in the gating mechanism (Gouzoulis-Mayfrank et al., 1999; Vollenweider et al., 1997). However, the CSTC hypothesis was only partially supported by later fMRI studies in combination with arterial spin labeling to measure fluctuations in cortical blood flow in psychedelic states. The results showed decreased net activity in the PFC, temporal, and parietal cortex as well as the thalamus during acute effects of psilocybin (the active compound in psychedelic mushrooms). This observation was explained by the EBT theory as a by-product of the change in effective brain connectivity (Preller et al., 2019). In contrast to CSTC, which focuses on isolated brain areas, the EBT approach considers psychedelics-induced changes in functional connectivity throughout the entire brain (where functional connectivity refers to the changes in statistical correlations within and between the activity of specific brain regions). Specifically, psychedelics have been found to elicit an excitatory effect on layer 5 pyramidal neurons by increasing their firing rate (Nichols, 2016). MEG studies with psilocybin indicated that increase of firing rate leads to desynchronization of neural activity (e.g., increase in entropy), resulting in detrimental effects on connectivity within specific functional brain networks (Carhart-Harris, 2018; Carhart-Harris et al., 2016; Lebedev et al., 2015).

In normal waking consciousness, functional connectivity can be defined as statistical dependencies among remote neurophysiological events (Friston, 2011), so that if distinct brain areas correlate in their activity, they can be considered to be part of a functional neural network. For instance, a good example is the default mode network (DMN), which is a large-scale functional network that is activated when people engage in self-referential processes such as day dreaming or rumination. Brain regions involved in DMN are normally highly correlated in their activation, but they tend to be anticorrelated with distinct other networks supporting different functions. Psychedelics were found to desynchronize these functional networks as indicated by network analysis, indicating that regions that are normally highly functionally connected become less integrated or even "disintegrated" under psychedelics.

The disintegration of the DMN was proposed to play an important role in psychedelic phenomenology, as its functional disintegration was shown to correlate with the feeling of loss of "self" or "ego" (Carhart-Harris et al., 2014, 2018). It was previously argued that if the experience of "self" is diminished, cognition will become less "anchored," so that time and space and "self-other" overlap will become more ambiguous. Ultimately, the reduced contribution of self-narrative processes will render the representations of the world more chaotic, less coherent, and more flexible (Carhart-Harris et al., 2014). Furthermore, the areas within the DMN are highly functionally interconnected and receive 40% more blood than any other brain network (Zou, Wu, Stein, Zang, & Yang, 2009; Raichle et al., 2001), creating thus important hub structures that integrate and guide information routing (van den Heuvel, Kahn, Goni, & Sporns, 2012). In normal waking consciousness, the DMN (e.g., as involved in internal focusing) works separately from, and even in competition to, the task-positive network (TPN) (e.g., as involved in external focusing). However, after psilocybin intake, as the entropy increases the functional connectivity between the networks, the brain infrastructure becomes less distinct, more overlapping, and more distributed. According to EBT, this enables more flexible traffic within the brain (Fig. 6.3). This was supported by studies showing an increase in global functional connectivity where areas that were previously distinct become functionally connected (Muthukumaraswamy et al., 2013; Petri et al., 2014). EBT also explains why fMRI studies reported decrements in BOLD activity in frontal, temporal, and parietal cortex after psychedelics, since the activity within these networks becomes less centralized. Previous research suggested that shifts and interactions between internally (DMN) and externally (TPN) oriented functional networks are vital in divergent thinking (Beaty et al., 2018; Jung, Mead, Carrasco, & Flores, 2013; Kuypers, 2018).

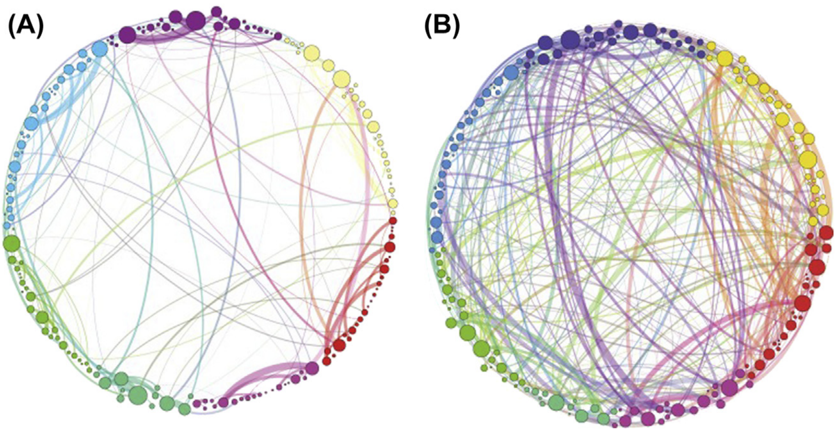

FIGURE 6.3 The image shows the increase in functional connectivity pattern from the left image (A) placebo to right image (B) psilocybin. It is a simplified visualization that depicts the strength of connectivity pattern between and within brain functional networks, which are presented in different colors. The visualization of the width of the links between different brain networks is in proportion to the weight and strength of the functional connectivity in the system. Psychedelics show increase connectivity pattern between distant brain networks, which is represented by heavy links between colored areas. *Fig. 6.3 is reprinted without changes, with permission from The Royal Society Publishing, Interface based on Figure 6 in Petri, G., Expert, P., Turkheimer, F., Carhart-Harris, R., Nutt, D., Hellyer, P. J., & Vaccarino, F. (2014). Homological scaffolds of brain functional networks.* Journal of the Royal Society, Interface, *11, 20140873. The Royal Society Publishing. Fig. 6.4.*

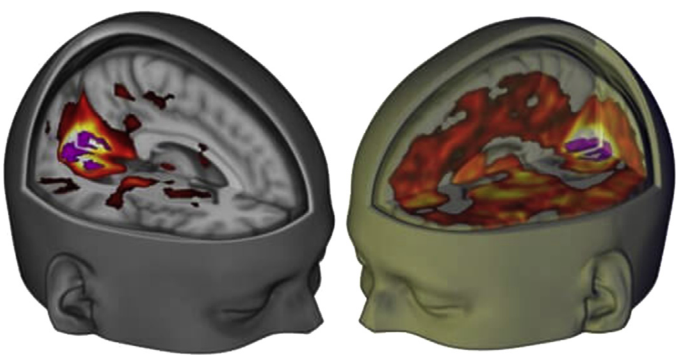

FIGURE 6.4 The image shows resting state functional connectivity pattern between visual area V1 and the rest of the brain before (left image) and after (right image) the intake of LSD. The image shows the significant between-condition difference (orange [black in print version] = increase), where in the LSD condition, V1 shows greater connectivity pattern with the rest of the brain. *The image is derived from a study by Carhart-Harris, R. L., Muthukumaraswamy, S., Roseman, L., Kaelen, M., Droog, W., Murphy, K., … Nutt, D. J. (2016). Neural correlates of the LSD experience revealed by multimodal neuroimaging.* Proceedings of the National Academy of Sciences of the United States of America, 113*(17), 4853–4858. https://doi.org/10.1073/pnas.1518377113 and reprinted without changes, as a courtesy of the Beckley Foundation. Retrieved from https://beckleyfoundation.org/the-brain-on-lsd-revealed-first-scans-show-how-the-drug-affects-the-brain/.*

Carhart-Harris et al. (2014, 2018) suggested that such an increase in whole-brain connectivity enhances the repertoire of possible states and representations and thus leads to a breakdown of stereotypical patterns and to higher flexibility.

In sum, the EBT suggests that the relative richness of conscious experience (e.g., cognitive flexibility) can be indexed by the level of entropy (e.g., chaos) within brain activity. The theory has been recently supported by various studies showing that states associated with loss of consciousness such as anesthesia, sedation, sleep, or coma show very low brain entropy according to Lempel-Ziv complexity index (Burioka et al., 2005; Schartner, Carhart-Harris, Barrett, Seth, & Muthukumaraswamy, 2017; Schartner et al., 2015). On the other hand, fMRI and MEG measures of spontaneous brain activity under psychedelics have indicated high entropy exceeding the levels in normal waking consciousness (Carhart-Harris, 2018; Schartner et al., 2017). In principle, the CSTC and EBT theories are not mutually exclusive, but they refer to a different level of focus regarding the neural underpinnings of psychedelic states (Preller et al., 2019). This means that a comprehensive theoretical framework is still needed to deepen our understanding of psychedelic phenomena.

Empirical evidence

Preliminary evidence for an increase in creativity induced by psychedelics comes from experimental research in the 1960s and 1970s that reported that hallucinogens such as LSD or mescaline render verbal communication more unpredictable, associative, and image-based (Amarel & Cheek, 1965; Martindale & Fischer, 1977). Zegans, Pollard, and Brown (1967) conducted a placebo-control study, where 20 participants received a low dose of LSD, whereas 11 participants received a placebo. The results indicated that the LSD group showed more original responses on the Rapaport word association task but decrease in performance on the Gottschald figure-perception task as compared with the control group.

A more recent line of research examined the effect of psilocybin on the indirect semantic priming task to assess the degree of free associations under intoxication (Spitzer et al., 1996). In this task, participants carry out a speeded lexical decision (word/nonword) task, which is known to show facilitated performance if the target stimulus is preceded by a semantically related prime—an effect that is attributed to the spread of activation in a semantic or feature-based network (Neely, 1977). The indirect priming task also uses indirectly related word pairs (e.g., "sun" and "banana," which are related by "yellow") to assess distant associations between words. Interestingly, participants under psilocybin showed increased responses when primed with indirectly related words, suggesting an extension of the functional semantic network (suggesting a flexibility-biased metacontrol state). Another study by Spitzer, Braun, Hermle, and Maier (1993) showed the same effect on indirect semantic priming in patients with schizophrenia, suggesting that both groups lack inhibition in the spreading of associations.

As a reaction to the study by Spitzer et al. (1996), a recent study by Family et al. (2016) investigated the effect of LSD on the semantic spread in a speeded picture-naming task. During this task, participants ordinarily perform faster when naming pictures from unrelated categories rather than from the same category, because pictures from the same category require similar semantic coding and thus compete for input (Damian, Vigliocco, & Levelt, 2001). Family et al. (2016) found that participants under LSD made significantly more lexical substitution errors, such as saying "car" when the picture of a bus was presented, indicating an increase in the spread of activation around a semantic concept (e.g., "vehicle"). Furthermore, participants under LSD took longer when naming objects from the same or related categories. This result suggests that LSD results in even greater interference from similar semantic concepts as compared with placebo. This can be interpreted as reduced inhibition and more competition in the system (a flexibility-biased metacontrol state that is) and thus a greater repertoire of alternatives reaching conscious access.

Indirect support for this hypothesis was demonstrated by Carter, Pettigrew et al. (2005) who used a Binocular Rivalry paradigm to assess perceptual stability in the psychedelic state. During binocular rivalry experiments, participants are presented with different images to each eye, which commonly makes conscious perception alternate between the two images without voluntary control. Spontaneous switching between alternatives in normal consciousness was suggested to result from mutual inhibition between neural populations, which are competing for dominance. Interestingly, the mutual competition between neural populations seems to be attenuated under psychedelics, which is indicated by slower switching rate (Carter et al., 2007; Carter, Pettigrew, Hasler, Wallis, & Vollenweider, 2010). Interestingly, this effect was replicated in expert meditators, who were sometimes able to eliminate the switch altogether (Carter, Presti et al., 2005). It is tempting to interpret these observations in the context of recent suggestions that reduced mutual competition between alternatives implies an increase in cognitive flexibility. Seeing things from a different perspective is an important part of the creative process, and such multidimensional perception under psychedelics could in this respect boost creativity. However, research with psychedelics and standardized creativity tests is still very rare. We shall discuss the existing findings in the next section.

Recent field research by Kuypers et al. (2016) investigated the effect of psychedelic brew Ayahuasca on creativity. The team administered convergent and divergent creativity tasks before and during an Ayahuasca ceremony to 26 participants. Participants provided more original answers under the influence of Ayahuasca (when controlled for fluency) in the picture concept task (a measure of divergent thinking) but decreased performance on tasks requiring convergent thinking. This result is supported by similar field research (Frecska et al., 2012) showing that the longitudinal effect of 3-week-long Ayahuasca retreat increased the number of highly original responses on Torrance task (divergent thinking task) as compared with a control group. Yet it is important to note that originality is a relatively unreliable index of creativity, as the score favors uniqueness over the usefulness and, as a relative score, is dependent on the performance of the entire sample.

Microdosing

Microdosing is a recently popularized trend that involves taking very small doses of psychedelics (1/10th or regular dose) and allegedly has various beneficial effects on cognition. However, research in this area is lacking. The first exploratory research on microdosing was conducted by Fadiman and Krob (2017) who send out an online survey asking 418 volunteers to repeatedly self-report on their experiences while microdosing for extended periods of time. Most reports were positive, including experiences of elevated mood, alertness, improved social perception, and creativity. However, qualitative studies based on self-reports are known to suffer from validity problems due to participants' inaccurate memories and unintentional or willful distortions of subjective experiences.

Prochazkova et al. (2018) aimed to substantiate these anecdotal claims and investigated the acute effect of microdosing on creativity and fluid intelligence in an open-label filed study, where 36 participants completed a battery of tasks before and during the acute effects of a microdose. Interestingly, the results indicated that both convergent and divergent thinking performance was improved during the acute effects of a microdose, whereas performance on the intelligence test was spared. This result differs from previous findings with large doses of psychedelics, which not only increases in divergent thinking but also decreases in convergent thinking (Frecska et al., 2012; Kuypers et al., 2016). We can speculate that the discrepancy in findings is a result of dosage. Whereas large doses of psychedelics might induce an ultraflexible mode of cognition associated with unconstrained cognition (Carhart-Harris 2014), microdoses may be able to drive brain functioning toward an optimal balance between persistence and flexibility. Optimal balance in this pathway would indicate better adaptivity (Mekern, Sjoerds et al., 2019) between the two states and explain why people are able to generate many ideas but also converge on one single correct solution. However, this speculation is to be approached with caution before the findings are confirmed by a more rigorous placebo-controlled study, which is under way already (Prochazkova et al., forthcoming).

In sum, the evidence derived from brain imaging and behavioral experiments suggests that psychedelics induce more unconstrained cognition, which could potentially increase the repertoire of representations and thus boost creativity. Some evidence exists showing that psychedelics increase semantic associations and thus could be effective in shifting away from rigid thought processes and representations. However, research in this area is still very sparse and, in view of a lack of robust findings, still inconclusive. Furthermore, it is likely that creativity is too complex of a construct and that the putatively beneficial effects of psychedelics will not translate fully to account for creativity. Lastly, the more general effect of psychedelics, such as increased suggestibility, alterations in mental availability, and misrepresentations, may account for some of the alleged effects on creativity—a topic we will get back to later when discussing hallucinations. Overall, research concerned with psychedelics and standardized creativity tests is still very rare and suffers from selection bias and other methodological issues. Further rigorous research is required to draw an educated conclusion on this matter.

Meditation-induced altered states of consciousness and creativity

In recent years, research on meditation has seen remarkable progress. Although people often associate meditation with stress reduction and relaxation, from a neuroscientific perspective, meditation can also have a meaningful impact on cognition and information processing and thus also on creativity (Lippelt, Hommel, & Colzato, 2014). Attentional control plays a pivotal role in meditation and potentially facilitates cognitive and emotional regulation. Effortful allocation of attentional resources during meditation engages several attentional brain networks related to alerting, self-referential processing, salience, orienting, and executive control. Training of attentional skills leads to more efficient resource allocation and, as a result, reduces rumination and mind wandering (Malinowski, 2013) and possibly also boosting creativity.

Notably, diverse meditation techniques provide differential effects, as they rely on distinct attentional processes and brain networks (Fox et al., 2016; Hommel & Colzato, 2017b). Lutz, Slagter, Dunne, and Davidson (2008) attempted to categorize meditation types based on the main instructions and mental techniques involved. The three main categories of meditation currently researched are focus-attention meditation (FAM), open-monitoring meditation (OMM), and loving kindness meditation (LKM). The goal of FAM practice is to direct attention to one object at the time (e.g., candle light or one's breathing pattern) for extensive periods of time without the mind wandering. This type of meditation requires, and thus presumably induces, sustained and narrow focus without distractions—which implies a metacontrol state that is biased toward persistence. On the other hand, OMM requires a broader attentional focus that is more open and nonselective—which implies a metacontrol state that is biased toward flexibility (Hommel & Colzato, 2017b). Attention should be given to the flow of the present moment without any judgment. Lastly, LKM involves emotional training cultivating in compassionate and altruistic views on one's own-self and others and is likely to combine elements of both FAM and OMM (Vago & Silbersweig, 2012). Given these different characteristics of the different meditation techniques, it would be naïve to expect and impact meditation as such. This should be particularly true in the context of creativity, which is also likely to comprise different, partly contradictory subcomponents, such as convergent and divergent thinking. From a metacontrol point of view, it would be unlikely to expect a positive or negative effect of meditation, in general, or creativity, in general. Rather, one would expect that persistence-heavy FAM to be beneficial for cognitive operations that require focus, such as convergent thinking, while the flexibility-heavy OMM should rather be beneficial for cognitive operations that rely on the breadth and the free flow of information, such as divergent thinking (Hommel & Colzato, 2017b).

Behavioral evidence

In accordance with these expectations, Slagter et al. (2007) showed that 3 months of intensive Vipassana meditation (an OMM-related technique) improved performance on the attentional blink task as compared with a control group. In the attentional blink task, participants are asked to detect numbers that are embedded in a stream of a rapidly presented sequence of letters. Performance in detecting the second target typically suffers if it is presented within about 500 ms after the first target—which is referred to as attentional blink. Participants after Vipassana showed improvements in detecting the second target, suggesting that OMM facilitates distributed and flexible attention allocation. This was supported by Colzato, de Haan, 2015, Colzato, Sellaro, Samara, Baas, 2015, Colzato, Sellaro, Samara, Hommel, 2015 who showed that the attentional blink was considerably smaller after OMM than after FAM. A study by Valentine and Sweet (1999) investigated the effect of FAM- and OMM-related meditation on a sustained attention task (Wilkins' counting test). Both meditation types were associated with superior performance on the sustained attention task as compared with a control group, and the OMM group outperformed the FAM group on the trials when stimuli were presented unexpectedly, while performance was comparable on the expected trials. This supports the idea that OMM facilitates a more distributed attentional scope. In contrast, tasks that require control and selective information processing are likely to benefit from FAM rather than OMM. Colzato, van der Wel, Sellaro, and Hommel (2016) showed that participants who engaged in FAM as compared with OMM were able to suppress task-irrelevant information more effectively, assessed by means of the congruency effect in the global local task. Also, trial-to-trial adaptation in the Simon task was significantly more pronounced after FAM as compared with OMM, suggesting boosts in control after FAM (Colzato, Sellaro, Samara, & Hommel, 2015). Similarly, a study by Tsai and Chou (2016) assessing differences in information processing on an attentional network task indicated that practicing FA meditation skills promotes executive control as compared with a control group.

Colzato, Ozturk, and Hommel (2012) investigated the impact of OMM and FAM on convergent and divergent thinking and found that while OMM induces a state that promotes divergent thinking, no effect was found for FAM. In a follow-up study, Colzato, Szapora, Lippelt, and Hommel (2017) attempted to verify the previous finding and implemented a more focused version of FAM (less mood enhancing) as well as examined strategies utilized when attaining creative solutions. The study replicated previous finding showing that OMM improved performance on divergent thinking tasks and also showed that, during convergent thinking task, FAM practitioners tend to use more analytical strategies that require persistence rather than insight strategy, which is associated with flexibility. This is in line with the hypotheses that FAM facilitates more serial and analytical problem-solving as compared with OMM (Hommel, 2012). Ding, Tang, Tang, and Posner (2014) compared performance on divergent thinking tasks between two groups, where one group engaged in 7 days of integrative body–mind training, which closely resembles OMM practice, and the second group of participants practiced an FAM-related exercise in which participants were asked to concentrate on different muscle groups. The results showed that the OMM group showed significantly higher improvements in divergent thinking tasks and better emotional regulation than the FAM group.

Neural evidence

Fox et al. (2016) conducted an extended metaanalysis of 78 neuroimaging studies carried out across different types of meditations and confirmed that FAM and OMM have dissociable brain activation patterns. FAM was found to be associated with significant activation in higher cortical regions such are premotor cortex, dorsal anterior cingulate cortex, and dorsolateral prefrontal cortex, which have been consistently linked to top-down control and may thus enable us to inhibit distractions and spontaneous thought processes. Deactivations were found in the posterior cingulate cortex and inferior parietal lobe, which are important nodes of the DMN, a network activated during self-referential processes such as mental time travel or rumination. Notably, posterior areas of DMN, associated with episodic memory retrieval, are found to be significantly deactivated during meditation. Thus, FAM practice reduces spontaneous thoughts about past events and shifts focus from introspection toward external focus. In contrast, the metaanalyses on OMM were linked to significant cluster activations in the insula, which is a region linked to interoceptive processing. Other areas that play important roles in conflict monitoring, action control, and awareness exhibited heightened activity during OMM (e.g., supplementary motor area, rostrolateral PFC, and middorsolateral PFC). Additionally, significant deactivation of the thalamus during OMM indicates decreased sensory gating, corresponding with the goal of this meditation type: to process multiple sources of information simultaneously.

One of the most consistent results across meditation styles is observed attenuation in activity and functional connectivity within the DMN network (Fox et al., 2016). While increased functional connectivity in DMN was found to positively correlate with maladaptive rumination in depression, meditation on the contrary can dampen DMN activity and thus upregulate networks associated with external information processing (Hamilton et al., 2011; Mulders, van Eijndhoven, Schene, Beckmann, & Tendolkar, 2015; Tang, Hölzel, & Posner, 2015). According to Bar (2009), engaging in narrow, cyclic, and negative thought patterns during rumination reduces cortical activation of associations. Even if rumination is associative, it is narrow in focus. Bar (2009) proposed that the limited scope of attentional focus in rumination is a result of hyperactivation of the MPFC (medial prefrontal cortex) and the MTL (medial temporal lobe). The MTL is a region essential for declarative memory and associative thinking (Squire, Stark, & Clark, 2004) and, together with MPFC, is a key region of the DMN. Deactivation of these hub structures within the DMN during meditation was proposed to increase associative thinking and thus break through the rigid pattern of thoughts. The shift from a narrow focus to broad associative focus can help to overcome cognitive biases and deductive reasoning and explore new unfamiliar pathways and approaches.

As already described in previous sections, the spread of activation within memory plays an important role in creativity. Meditation requires to focus on the present moment without mind wandering, and this implies that meditators have to learn to consciously limit the access to their autobiographical memories (by means of attentional control). Specifically, a recent study by Fujino, Ueda, Mizuhara, Saiki, and Nomura (2018) examined functional connectivity in experienced meditators contrasting

OMM with FAM. Results indicated that both meditations reduced functional connectivity within the DMN. Moreover, OMM reduced functional connectivity between the ventral striatum and visual cortex (suggesting reduction in outward focus) as well as decreased connectivity in attentional network and the retrosplenial cortex that are linked to memory formation in the DMN. The opposite pattern was shown for FAM. Such findings suggest that OMM reduces narrow focus and allows for detachment from autobiographical memories and potentially allows to break free from biases and preconceptions stored in memory.

Interestingly, similar changes in brain connectivity to OMM are observed under psychedelics. Psychedelics are reported to decrease connectivity within DMN especially between the retrosplenial cortex and the parahippocampus, which are areas essential for memory function (Carhart-Harris et al., 2016). The disconnection was positively correlated with the perception of nondualism, where the self-other dichotomy is “transcended” and consciousness is described as “present” and “centerless” and lacking “dichotomies.” The feeling of loss of sense self, as well as recognizing own-self in others (compassion), is common in the psychedelic state, as well as in deep OMM meditative practices. This phenomenological commonality for psychedelic state and deep OMM practice was suggested to be linked to changes within semantic autobiographical memory function, where the loss of access to memory results in a complete breakdown of personal identity (Millière et al., 2018). However, whereas in a deep meditative state, a person can consciously block access to autobiographical memories, in the psychedelic state, the access seems to be lost as a consequence of disorganized brain function. From this perspective, meditative practice allows for more controlled information processing and thus is more likely to benefit all the phases of the multilayered creative process as compared with the psychedelic state.

Overall, current discoveries support the notion that different types of meditation will have positive but selective effects on particular kinds (subcomponents) of creativity. Whereas divergent thinking can be supported by OMM, convergent thinking is likely to benefit from FAM. Furthermore, the narrative aspect of self-consciousness seems to be temporarily dampened by meditation freeing up attentional resources, which can be allocated elsewhere to generate novel original associations.

Hallucinations and creativity

Hallucinations and perceptual misrepresentations experienced in certain psychiatric disorders, or resulting from naturally induced ASC, could potentially increase feelings of insight and altered meaning and thus promote creativity. Hallucinations were extensively studied during the 1960s. Heron, Doane, and Scott (1956) observed that aviators sometimes suffer hallucinations during long flights as a result of the monotonous environment. Similarly, American neuroscientist John C. Lilli (1956, 1977) discovered that hallucinations can be spontaneously evoked in sensory deprivation tanks, which isolate participants from sensory input, whereas neurologist Oliver Sacks (2012) reported that many blind people who lost their sight later on in life experience perceptual hallucinations. What do these types of hallucinations have in common and could they be helpful in boosting creativity?

Woodburn Heron (1957) was one of the first scientists to examine this intriguing phenomenon. In his paper "The Pathology of Boredom," Heron investigated the effect of extended periods of perceptual isolation on cognitive functions. In this study, participants lied on a bed, blinded, in a sound restricted room, wearing cotton gowns to eliminate touch sensations, and had to remain stationary in this position for 24 h for several days (with only short breaks for meals). Based on subjective statements of the participants in this study, Heron (1957, p. 54) reported that: "*Our subjects' hallucinations usually began with simple forms. They might start to "see" dots of light, lines or simple geometrical patterns. Then the visions became more complex, with abstract patterns repeated like a design on wallpaper, or recognizable figures, such as rows of little yellow men with black caps on and their mouths open.*" Apart from subjective statements, participants also performed a short cognitive examination before and after the experiment. The test battery included a simple arithmetic task and a word association and suggestibility test. Interestingly, participant performance dropped on all the tasks requiring analytical thinking when compared with the control group, except for measures assessing suggestibility, where the pattern was reversed, namely, participants after isolation became more agreeable to experimenter's proposals for the existence of supernatural phenomena such as ghost or aliens.

What might be the mechanisms underlying such observations? A possible account may be provided by recent predictive coding approaches that characterize perception as more than the passive registration of external stimulus information but, rather, the active testing of perceptual hypotheses based on previous perceptual experience (Friston, 2010). As suggested by Seth (2014), predictive coding might induce hallucinations by trying to make sense of noisy sensory data in dark environments and/or during sensory deprivation. Hence, in the presence of noisy sensory signals, people may rely on their previous knowledge to deal with the resulting perceptual uncertainty and attempt to generate the best hypothesis for the limited sensory input. From this perspective, perceptual hallucinations may reflect the brain's best guess to interpret perceptual noise.

Alternatively, hallucinations may occur even if sensory information is noise free, as a result of inflated predictions superimposed on sensory data. Such hypotheses were recently supported by artificial neural networks that were able to produce remarkably similar visual effects to those described in psychedelic states or during sensory deprivation experience (Suzuki, Roseboom, Schwartzman, & Seth, 2017). Namely, Google Deep Dream works with deep convolutional neural networks (DCNNs), which are machine learning algorithms with many hidden layers trained to recognize images (DiPaola, Gabora, & McCaig, 2018). DCNNs were found to work in similar ways to a primate's visual system, where representations are organized in a hierarchical fashion. DCNNs are organized in layers where the higher-order layers attempt to predict lower-level features processed by early input layers. The Google Deep Dream algorithm inverted the information flow in DCNNs so that the input images change according to higher level predictions. Google Deep Dream was thereafter able to mimic the progression from simple perceptual distortion, such as a change in surface patterning, to more complex hallucinations such as morphing and image misclassifications (DiPaola et al., 2018; Suzuki et al., 2017). This was achieved by selectively clumping different layers in the network and increasing their predictive power. A recent study by Suzuki et al. (2017) found empirical evidence, suggesting that Google Deep Dream implemented in VR system induces qualitatively similar perceptual experiences to classical psychedelics and other types of ASC.

Some scientists have speculated that creativity or novel insights are by-products of spontaneous predictions that arise in the absence of appropriate sensory signal (Wiggins & Bhattacharya, 2014). These associative predictions can give rise to "aha-moments," where one's mind connects ideas from previously unvisited conceptual spaces (Kounios & Beeman, 2009). In ASC, the distortion of brain mechanisms, or noisy sensory input, stimulates top-down predictions to make sense of the environment. This effect is likely to induce cognitive flexibility where different perspectives and connections can be considered and ultimately improve the repertoire of possible representations, thus enhancing creativity. In other words, an increase in flexibility and misclassifications could explain the purported ability to see many viewpoints at the same time under ASC. Similarly, Ritter and Dijksterhuis (2014) reviewed evidence showing that creative insights often follow the stage of incubation, where one disengages from task-related thought and engages in an unrelated activity such as mind wandering or sleeping. This is because such incubation period might lead to a wider consideration of associative phenomena that would be normally missed. However, it is possible that misclassifications are mistaken for creativity because of their novel/unusual qualities yet they may not translate to everyday practical creativity. Indeed, creativity may be too specific a construct to benefit from enhanced prediction as such. And yet, the relationship between hallucinations and creativity seems worth investigating more systematically.

Conclusions and future directions

This chapter provides a selective overview of findings that connect ASC and creativity, in an attempt to shed light on the question of how these two constructs might be related. In accordance with the MSM, and in keeping with our hypothesis that ASC is systematically associated with changes in metacontrol states, we have reviewed evidence showing that certain states induced by ASC improve creative processes that require persistence, whereas others improve creative processes that require flexibility. This seems to suggest that certain types of ASC correlate with metacontrol biases toward persistence (e.g., stimulants, focused attention meditation, or depression), whereas others correlate with biases toward flexibility (e.g., psychedelics, open-monitoring meditation, or sensory deprivation). In a few cases, ASC seems to be associated with improvements in both persistence- and flexibility-heavy tasks, suggesting that ASC may also be correlated with adaptivity, the optimal balance between persistence and flexibility. However, the influence of ASCs on creativity is not always consistent across individuals, which reflects on the important interaction of ASCs with the genetical and cultural predisposition of the individual. If we consider that individual neurotransmitter levels and metacontrol biases differ at baseline, it is very likely that different types of altered states will have a differential effect on different kinds of creativity for different individuals. While some people will benefit from a boost of flexibility, others would require a more persistent focus to provide useful solutions to a challenging problem. This makes the discussion about possible one-to-one relation between altered state and creativity very difficult. Yet, this chapter provides some empirical support for the idea that certain altered states tend to contribute to creative thinking more than others. And it does not only encourage the development of comprehensive theoretical frameworks but also provide a solid basis for such development. We thus hope that this chapter will inspire researchers to further tackle the underlying functional and neural foundations of both ASC and creativity. For instance, valuable insights could be gained from rigorous comparison studies examining systematic changes in metacontrol policies as a result of different altered states and controlling for metacontrol-related personality traits at baseline. Along the same lines, systematic research into how arousal, emotional valence, memory, and level of uncertainty affect metacontrol and creativity would be valuable as these faculties are differentially related to various ASC.

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