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Journal

Topics in Cognitive Science

ISSN

1756-8757

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Publication Date

2026-05-26

DOI

10.1111/tops.70058

Can Childhood be Used as a Model to Understand the Effects of Psychedelics?

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Word count: 7,174

Keywords: "Cognitive Flexibility", "Psychedelics", "Cognitive Development"

Abstract

Psychedelic drugs have shown promise as a novel therapeutic for a variety of health conditions, yet the mechanisms underlying their clinical benefits remain unclear. A leading hypothesis suggests that psychedelics may enhance cognitive flexibility, a trait impaired in many of these conditions. While existing data from self-report and qualitative-interview studies support this hypothesis, data from experimental studies are limited and inconsistent. Here, we propose a novel cognitive development model that allows us to more precisely define cognitive flexibility as a mechanism underlying the effects of psychedelics. Considering children—a population known to be more cognitively flexible than adults— as a proxy psychedelic group, we identify three specific behaviors that could be used to empirically test this account: (1) changing the strength of, or reliance on, one's priors; (2) changing one's search and sampling strategies; and/or (3) changing one's allocation of attentional resources. Finally, we highlight preliminary findings from a pilot study supporting this framework and providing guidance for future work.

Can Childhood be Used as a Model to Understand the Effects of Psychedelics?

Recently, there has been a resurging interest in studying psychedelic drugs, which have shown promise as a novel therapeutic for a variety of conditions (Sessa, 2020). *How* these drugs lead to the observed clinical benefits remains an open question. Emerging evidence from clinical interviews (Noorani, Garcia-Romeu, Swift, Griffiths, & Johnson, 2018) and survey studies (Davis, Barrett, & Griffiths, 2020) suggests a promising cognitive-behavioral account—specifically, that psychedelics increase cognitive flexibility. However, experimental studies using behavioral tasks have yielded inconsistent results (Kuypers et al., 2016; Mason, Mischler, Uthaug, & Kuypers, 2019, 2021) and provide little insight into the underlying cognitive processes (Hass, 2017). To better test this account, it is necessary to examine specific behaviors indicative of increased cognitive flexibility. We propose that identifying these behaviors may stem from an unlikely source: children. Here, we provide an overview of a novel cognitive development model that we believe may provide a mechanistic explanation of the therapeutic effects of psychedelics, and preview findings from a pilot study that offer preliminary support for this model.

What are Psychedelics?

Around the turn of the century, there began a so-called "psychedelic renaissance" (Sessa, 2012), with clinical trials investigating the therapeutic potential of psychedelic therapy. The emphasis of this research has largely been *whether* psychedelics can be clinically effective, rather than *how* this occurs, and has resulted in a surge of findings indicating unprecedented clinical efficacy for a variety of indications. Psychedelics have been successful in eliciting clinically significant reductions in anxiety and depression (Grob et al., 2011; Ross et al., 2016;

Carhart-Harris et al., 2016, 2021; Daws et al., 2022; Doss et al., 2022; Goodwin et al., 2022, 2023; Gukasyan et al., 2022, Raison et al., 2023, Becker et al., 2022), and in some cases complete remission (Griffiths et al., 2016), facilitating a reduction or complete cessation of cigarette (Johnson, Garcia-Romeu, & Griffiths, 2017; Noorani et al., 2018) and alcohol consumption (Bogenschutz et al., 2015, 2022; O'Donnell et al., 2022), reducing the frequency and intensity of cluster headaches (Schindler et al., 2021, 2022) and other chronic pain conditions (Ramachandran, Chunharas, Marcus, Furnish, & Lin, 2018), as well as alleviating body dysmorphia and eating disorders (Peck et al., 2023; Schneier et al., 2023), among others.

Although these indications may initially seem rather broad, they are also all characterized by pathologically rigid cognition (e.g., Chamberlain, Fineberg, Blackwell, Robbins, & Sahakian, 2006; Lee & Orsillo, 2014; Palm & Follette, 2011; Todd, Forstmann, Burgmer, Brooks, & Galinsky, 2015). For example, high trait anxious individuals are more reliant on their preconceptions and established beliefs, failing to update their predictions about the world in response to changes in evidence (Browning, Behrens, Jocham, O'Reilly, & Bishop, 2015; Kraus, Niedeggen, & Hesselmann, 2021). Individuals with depression and anxiety exhibit exogenous attentional biases, such that they tend to narrowly fixate on negative or seemingly threatening stimuli (Abend et al., 2018; Mennen, Norman, & Turk-Browne, 2019). They also show both increased negative and decreased positive interpretation biases, which are resistant to disconfirming information (Everaert, Bronstein, Cannon, & Joormann, 2018). These attentional and interpretation biases can create negative feedback loops, whereby people inappropriately generalize from negative experiences when interpreting novel stimuli, limiting exposure to new information that might result in a revised interpretation of events. These "learning traps" (Rich & Gureckis, 2015) have been proposed to underlie a variety of pathologies (e.g., Teodorescu &

Erev, 2014; Dymond, Dunsmoor, Vervliet, Roche, & Hermans, 2015). For example, following a negative social interaction, an individual with social anxiety may form the inaccurate belief that all social interactions are low value and become even more withdrawn. As a result, they miss future opportunities for positive social interactions, which could change their beliefs. In fact, both cognitive behavioral therapy and exposure therapy—the conventional nonpharmacological treatments for depression and anxiety—specifically target cognitive rigidity and learning traps by exposing patients to evidence they would not otherwise receive.

This through line linking the conditions most responsive to psychedelic treatment may provide a clue to the mechanism underlying the observed clinical benefits. Indeed, both neural and psychological accounts of the efficacy of psychedelics seem to converge on the same conclusion: that treatment results in increased flexibility, and this flexibility is associated with clinical benefits (e.g., Kuypers, 2018; Davis et al., 2020, 2021; Doss et al., 2021).

The Role of Flexibility

Neural Accounts of Flexibility

While the neural effects of psychedelic drugs are widespread, neural accounts of the mechanisms underlying their clinical benefits have largely focused on changes to the default mode network (DMN) and salience network (SN). The DMN is composed mainly of the medial prefrontal cortex, posterior cingulate cortex, parahippocampal cortex, and parts of the inferior parietal lobe (IPL), while the SN is primarily composed of the anterior cingulate cortex (ACC) and anterior insula (Buckner, Andrews-Hanna, & Schacter, 2008; Fox et al., 2005). Both the DMN and SN are large connector hubs, comprising among the highest number of

cortico−cortical connections in the brain (Hagmann et al., 2008), and composed of brain areas with particularly dense expression of 5-HT2A receptors.

Magnetic resonance imaging (MRI) and molecular imaging methods (e.g., positron emission tomography) have demonstrated the impact of psychedelics on these networks, causing changes in structural connectivity by way of increased neural plasticity and flexibility. In line with this account, increases in neuritogenesis (formation of new neurites), spinogenesis (development of new dendritic spines), and synaptogenesis (formation of new synapses between neurons) have been reported after administration of psychedelics both in vivo and in vitro (Ly et al., 2018). Psychedelics have also been shown to increase brain-derived neurotrophic factor expression, a protein integral for these processes (Vaidya, Marek, Aghajanian, & Duman, 1997).

In addition to these changes in structural connectivity, the effects of psychedelics on neural activity and functional connectivity have also been demonstrated. Functional MRI (fMRI) scans taken during acute drug effects have shown notable decreases in the activity and functional connectivity within the DMN and SN (Carhart-Harris et al., 2012, 2017; Hermle et al., 1992; Preller et al., 2020; Tagliazucchi, Carhart-Harris, Leech, Nutt, & Chialvo, 2014). Elsewhere, though, there are overall increases in functional connectivity, including between the DMN and SN (Roseman, Leech, Feilding, Nutt, & Carhart-Harris, 2014) and in sensory areas (Preller et al., 2020). Curiously, fMRI scans taken post-acutely reveal increases in within-network DMN functional connectivity as well (Carhart-Harris et al., 2017; Sampedro et al., 2017; Smigielski, Scheidegger, Kometer, & Vollenweider, 2019). These functional changes have been found to persist at 1-week and 1-month post drug administration (Barrett, Doss, Sepeda, Pekar, & Griffiths, 2020), demonstrating increased “communication” between brain regions that are typically more distinct, which is believed to be characteristic of increased neural flexibility

(Pang, Dunkley, Doesburg, Da Costa, & Taylor, 2016; Siegel et al., 2024). These acute decreases followed by later increases in within-network DMN connectivity have been likened to a "reset" mechanism, whereby acute disintegration affords post-acute reintegration and connectivity increases beyond baseline, leading to overall improvements in functioning (Carhart-Harris et al., 2017). These changes to neural connectivity and activity provide a compelling descriptive, implementation-level account of the role of increased flexibility in producing the clinical benefits of psychedelics. But by focusing on brain-specific changes, this evidence provides little insight into how or in what ways an individual's subjective experience is changed as a result of taking these drugs.

Psychological Accounts of Flexibility

Psychedelics have been found to elicit spontaneous, dose-dependent insight experiences (Carbonaro et al., 2018, 2020; Davis, Xin, Sepeda, Garcia-Romeu, & Williams, 2021), which are correlated with clinical benefits after treatment (Roseman, Nutt, & Carhart-Harris, 2018). Additionally, qualitative analyses of interviews with patients who received psychedelic treatment revealed that these patients attributed their clinical benefits to the vivid insights gained from their treatment (Noorani et al., 2018). However, these effects are mediated by survey measures designed to assess psychological flexibility (Davis et al., 2020, 2021), suggesting that changes in psychological flexibility may underlie these insight experiences. Further, psychedelics have been shown to increase the personality domain of openness (MacLean, Johnson, & Griffiths, 2011), which is also associated with greater flexibility (Silvia, Nusbaum, Berg, Martin, & O'Connor, 2009).

By focusing on the mind, rather than the brain, psychological accounts can complement the existing neural accounts. However, as these psychological accounts are typically assessed in the context of correlational studies, they cannot provide causal explanations. Further, although psychological studies successfully capture the ways in which participants' subjective experiences are changed, they fail to characterize the cognitive processes resulting in those changes.

Cognitive Flexibility

While both the neural and psychological accounts reviewed above seem to implicate increases in flexibility as a potential mechanism underlying the effects of psychedelics, there exists a "mind−brain gap" in the evidence supporting this theory. Specifically, both approaches fail to explain the cognitive mechanisms underlying the observed clinical benefits. To address this gap, help to link the observed neural changes with psychological survey outcomes, and afford more definitive causal claims, it is necessary to investigate flexibility at the cognitive level.

Cognitive flexibility is a term that was originally used to characterize one's ability to selectively change their conceptual systems in response to exogenous input (Scott, 1962). This was usually described in terms of switching behaviors, for example, learning/adopting new rules in a task and simultaneously maintaining internal representations for multiple concepts or categories, which are related to greater cognitive control and more developed executive functions (e.g., Berg, 1948; Bigler & Liben, 1992; Zelazo, 2006). Notably, though, psychedelics have been found to acutely impair executive functions (Barrett, Carbonaro, Hurwitz, Johnson, & Griffiths, 2018), which should decrease this type of flexibility. This creates a conceptual puzzle. If cognitive flexibility primarily reflects executive control, and psychedelics acutely impair

executive function, then psychedelics should reduce flexibility rather than increase it. Yet, several lines of evidence suggest the opposite pattern—that these experiences can increase openness to alternative interpretations and novel insights. This apparent contradiction suggests that the type of flexibility relevant to psychedelic effects may differ from the classic executive-control account. Rather than reflecting improved task switching or rule maintenance, psychedelics may influence forms of flexibility related to exploration, hypothesis generation, and attention, which result from weaker cognitive control and reduced top-down constraint (e.g., Thompson-Schill, Ramscar, & Chrysikou, 2009; Gopnik, 2024). In this sense, increased exploratory flexibility may come at the cost of executive control: the same reduction in top-down constraint that impairs task switching may enable broader hypothesis search and exploration. This leads to individuals being less influenced by prior knowledge (Gopnik et al., 2017), considering a wider range of possible solutions to a problem (Colantonio et al., 2025), choosing to explore even when aware of the costs of doing so (Liquin & Gopnik, 2022), and having better memory for information outside the scope of directed attention (Deng & Sloutsky, 2016). Our proposed framework refers to this search and attentional cognitive flexibility that is afforded by less developed (or decreased) executive function (Gopnik, 2024).

As cognitive flexibility encompasses several overlapping functions (Miyake et al., 2000), multiple brain areas and networks are involved in these processes. These include the regions described above that are most impacted—in terms of activity and functional connectivity— by the use of psychedelics. For example, activity in the prefrontal cortex (PFC) is generally involved in switching behaviors, with specific types of switching recruiting different areas of the PFC (Kim, Johnson, & Gold, 2012). The IPL is associated with the determination of saliency of new information, relative to existing mental models (Filipowicz, Anderson, & Danckert, 2016).

Finally, the ACC is associated with conflict monitoring and cognitive control (Kerns et al., 2004).

Others have previously proposed theoretical models of cognitive flexibility to explain the effects of psychedelics, largely focusing on the role of reduced top-down control (Carhart-Harris & Friston, 2019; Kuypers, 2018). These models have generated preliminary support from both animal studies (Torrado Pacheco, Olson, Garza, & Moghaddam, 2023) and clinical trials with humans (Doss et al., 2021). However, results from experimental work using behavioral tasks have been mixed. These studies have mainly implemented tasks measuring aspects of creativity (i.e., divergent thinking), which are treated as a measure of cognitive flexibility. In these tasks, divergent thinking is operationalized using summary score metrics like fluency (number of responses generated) and originality (overall frequency of generated responses) (Hass, 2017). Some studies found increases in cognitive flexibility during acute drug effects, but only in some tasks administered (Kuypers et al., 2016). Others found an increase on the day after drug administration, which subsided a week later (Mason et al., 2019). While others still found decreases in cognitive flexibility during the acute effects, no changes post drug administration, and evidence of practice effects among participants in their control group (Mason et al., 2021).

Cognitive Development as a Model for Cognitive Flexibility

As noted above, existing experimental evidence for the effects of psychedelics on cognitive flexibility is both limited and inconsistent. Further, by utilizing coarse measures of flexibility—like summary score metrics which quantify people's responses, rather than the processes leading to the production of those responses—these measures provide little insight into the underlying cognitive mechanisms which may afford these changes. Here, we argue that to

truly test this account, we must examine the specific behaviors that are known to be indicative of increased cognitive flexibility.

How could such behaviors be identified? One approach is to look to populations known to be more cognitively flexible than baseline adults. If such a population could be identified, it would support testable predictions for the specific ways in which psychedelics might result in increased cognitive flexibility. Fortunately, such a population exists, is widespread, and (relatively) easy to access. Those people are children.

As described above, the most salient neural changes that psychedelics engender are overall increases in global functional connectivity, with specific local decreases within the DMN and SN, increases in neural plasticity, and decreased activity in DMN and prefrontal regions. Children (ages 7–9) have been shown to have lower within-network DMN functional connectivity and fiber density relative to baseline adults, as well as decreased gray matter volume (Supekar et al., 2010). Across a number of studies, these connectivity differences show a distinct linear trend, such that connectivity increases with age between 7 and 35 years (Fair et al., 2007; Sherman et al., 2014; Uddin, Supekar, Ryali, & Menon, 2011). Infancy and early childhood are also periods of development that are characterized by very high degrees of neuroplasticity, including increased synaptogenesis and spinogenesis (Huttenlocher, 1990). These plasticity changes are heterogeneous, with sensory cortices reaching peak shortly after birth and steadily declining over development, while the PFC takes much longer to peak and start declining (Huttenlocher & Dabholkar, 1997). Thus, children also have less developed frontal regions and corresponding executive functions (Thompson-Schill et al., 2009).

In addition to these neural similarities between typically developing children and psychedelic-treated adults, behavioral research also shows that when the adult brain is “made

more child-like" in terms of its structural and functional makeup (via injury or a temporary change), they also perform better on tasks requiring cognitive flexibility. For example, while divergent thinking decreases into middle and older adulthood (Jaquish & Ripple, 1985), adults with PFC damage exhibit increased performance compared to controls on these tasks (Reverberi, Toraldo, D'Agostini, & Skrap, 2005). Further, adults who receive transcranial direct current stimulation over their PFC exhibit increased creativity (Chrysikou et al., 2013).

One of the more consistent findings reported in cognitive development research is that children's performance on cognitive tasks tends to be "noisier" than adults' (Sobel, Tenenbaum, & Gopnik, 2004; Kushnir & Gopnik, 2007; Bonawitz, Denison, Griffiths, & Gopnik, 2014). Children's immature PFCs result in less developed executive function, inhibition, and constraint (Munakata, Casey, & Diamond, 2004; Carlson, 2005; Davidson, Amso, Anderson, & Diamond, 2006). This behavioral variability has historically been viewed as suboptimal or irrational, dating back to Piaget (Inhelder & Piaget, 1964). Critically, however, these conclusions are only reasonable if children have the same goals and utilities as adults. Recent work suggests this is not the case: Whereas adults tend to prioritize reward maximization (Sumner, Steyvers, & Sarnecka, 2019a), children tend to prioritize exploration of the environment (Sumner et al., 2019b). This protracted period of exploratory learning has been proposed to facilitate humans' unique cognitive capabilities (Gopnik, 2020), and converging evidence from research with birds and nonhuman mammals suggests that the length of immaturity is correlated with intelligence and relative brain size across species (Bennett & Harvey, 1985; Snell-Rood, 2013; Weisbecker & Goswami, 2010).

Consistent with this proposal, several studies have found that children tend to outperform adults on tasks that benefit from more exploratory or flexible forms of reasoning (e.g., Gualtieri

& Finn, 2022; Gopnik et al., 2017; Plebanek & Sloutsky, 2017; Sumner et al., 2019b). The variability observed between children and adults has, therefore, been reconstrued as both systematic and rational, given the differences in exploratory strategies and cognitive flexibility that are afforded by differences in executive function (Denison, Bonawitz, Gopnik, & Griffiths, 2013; Gopnik, 2020; Gelpi, 2021).

In sum, neural and behavioral data suggest that, when compared to baseline adults, both adults treated with psychedelics and children exhibit many of the same differences. Indeed, these differences have been previously noted by both developmental psychologists (e.g., Gopnik, 2016; 2018; in press) and psychedelic scientists (e.g., Carhart-Harris & Friston, 2019). Further, the field of cognitive development has generated a vast body of literature highlighting the differences between the cognition of adults and children, with several examples of children outperforming adults on tasks that require flexible thinking. Therefore, if children are treated as a proxy psychedelic group, the known cognitive differences between children and adults can be leveraged to guide predictions about specific ways that psychedelics might impact cognition that results in increased flexibility.

What, then, are the specific behaviors and cognitive features that allow children to be more flexible and more exploratory? Much of what is understood about these features has been informed by computational approaches to cognition—specifically, those applying the principles of probability theory to characterize human learning. Below, we provide a brief, high-level overview of probabilistic models of cognitive development, before introducing these target features.

Probabilistic Models of Cognition

In the context of cognitive development, probabilistic models have been used to describe how infants and young children leverage their limited observations to build abstract, structured, causal theories (e.g., Gopnik et al., 2004; Gopnik & Schulz, 2004; Gopnik & Bonawitz, 2015; Perfors, Tenenbaum, Griffiths, & Xu, 2011; Kushnir, Xu, & Benson, 2012). These early developing "intuitive theories"—like scientific theories—allow even the youngest learners to explain, predict, and act on the world (Gopnik, 2012). As we navigate the environment, there are often many potential explanations—or hypotheses—for the phenomena we observe. Probabilistic models apply Bayes' Rule to formally specify the probability that any particular hypothesis is true. Briefly, the prior probability of a hypothesis (i.e., the a priori probability of the hypothesis being true, prior to observing the data) is weighted by the likelihood of that hypothesis (i.e., the probability of the observed data being generated if the hypothesis were true). Since these probabilities are constantly updated in light of new information, differences in learners' experiences lead to differences in the hypotheses that are privileged. As such, these models make specific quantitative predictions about how people generate and revise their hypotheses over time (see Gopnik & Wellman, 2012, for detailed evidence supporting this account). Taking this approach also points to specific characteristics of learning in childhood that might lead younger learners to be relatively more flexible than adults (Gopnik, Griffiths, & Lucas, 2015, 2017; Gopnik, 2016; Gualtieri & Finn, 2022).

Weaker Prior Beliefs

Across a variety of learning problems, both adults and children tend to favor hypotheses that best explain the observed evidence, in ways broadly consistent with Bayesian models of inference (e.g., Bonawitz, Denison, Gopnik, & Griffiths, 2014; Denison et al., 2013; Gopnik &

Wellman, 2012; Tenenbaum, Kemp, Griffiths, & Goodman, 2011). However, children and adults differ in how much their prior knowledge guides their inferences. According to Bayes' Rule, the stronger one's priors, the more their inferences are guided by this prior knowledge, and the less sensitive they become to current evidence. This is true even if the incoming evidence contrasts with their existing hypotheses. In fact, part of what makes adults such powerful learners is that we develop strong, context-specific priors, which allow us to make predictions based on what we have experienced in the past. In many cases, adult predictions are broadly consistent with the predictions of resource-rational models, which assume that people make approximately optimal decisions given constraints on time, information, and cognitive resources (e.g., Griffiths, Lieder, & Goodman, 2015; Lieder & Griffiths, 2020).

Given that children have comparatively less knowledge than adults, they necessarily have weaker prior beliefs. As a result, children's inferences are more sensitive to incoming evidence, leading to a more flexible process of belief revision. Indeed, there is growing empirical support for this claim: while adults tend to rely more heavily on their priors and are less likely to update their beliefs, children readily and flexibly update their beliefs in response to counterevidence (e.g., Gopnik et al., 2015; Kimura et al. in prep; Lucas, Bridgers, Griffiths, & Gopnik, 2014; Seiver, Gopnik, & Goodman, 2013). In one such study, Lucas et al. (2014) had children and adults make causal inferences about a novel machine. Participants were told that this machine is activated by objects placed on top of it, but only by specific types of objects called "blickets" (a hidden property). Two sets of participants were shown unambiguous training data, which implied that the machine operated according to a general rule: either disjunction (individual objects are causal, which is the default high prior assumption for adults; e.g., Cheng, 1997; Griffiths & Tenenbaum, 2005) or conjunction (multiple objects combined are causal). A third set of

participants were not shown any training data and could thus only rely on their prior beliefs. Next, participants were shown ambiguous test data that was consistent with both their default high prior disjunctive theory and the initially less likely conjunctive theory. They were then asked to identify which objects from the test data were blickets. For one critical object, it is ambiguous from the test data alone whether or not it is a blicket. This judgment is thus informed by the rule that participants infer for how the machine operates. Participants were also asked to try to activate the machine themselves using the available objects, to see whether they choose a single or multiple objects—which would also be informed by this inference.

Across several experiments, when participants were shown training data that was consistent with a conjunctive cause, the proportion of people who correctly labeled the critical object as a blicket and chose multiple objects decreased with age. Importantly, there were no differences between the children and adults who were not shown any training data: people of all ages inferred that the machine operated according to a disjunctive rule. This implies that the developmental differences observed do not result from differences in prior beliefs, but from how strongly they are weighted relative to new information. That is, children are more willing to switch to an initially unlikely hypothesis when presented with counterevidence (Lucas et al., 2014). These findings are robust and have been replicated in a variety of additional studies (Gopnik et al., 2015, 2017; Walker, Rett, & Bonawitz, 2020).

If we apply these findings to our current framework, it is possible that psychedelics produce their clinical benefits by lowering how strongly adults' prior beliefs are weighted, making other, initially lower-likelihood alternatives comparatively more plausible. This could explain the success of psychedelic-assisted therapy for conditions like depression and anxiety that had previously been unresponsive to treatment (Grob et al., 2011; Ross et al., 2016; Carhart-

Harris et al., 2016, 2021; Becker et al., 2022; Daws et al., 2022; Doss et al., 2022; Goodwin et al., 2022, 2023; Gukasyan et al., 2022, Raison et al., 2023), as well as conditions characterized by obstinate mental models, such as obsessive-compulsive disorder and eating disorders (Moreno, Wiegand, Taitano, & Delgado, 2006; Peck et al., 2023; Schneier et al., 2023). It also provides behavioral evidence for previously proposed cognitive models of the effects of psychedelics, such as the relaxed beliefs under psychedelics (REBUS) model (Carhart-Harris & Friston, 2019). Importantly, however, the findings reviewed here can be explained either by the fact that children have weaker priors or because children employ a broader sampling strategy. These possibilities are not mutually exclusive.

Hypothesis Sampling

While probabilistic models of cognition provide a computational-level account describing how Bayes' Rule could be used to make inferences, the process of Bayesian inference is computationally costly, and the space of possible hypotheses to evaluate is intractably large (Gittins & Jones, 1979; Griffiths, Vul, & Sanborn, 2012; Sanborn, Griffiths, & Navarro, 2010). In practice, therefore, people are thought to approximate Bayesian inference by stochastically sampling candidate hypotheses to evaluate from a probability distribution over possible hypotheses (e.g., Griffiths et al., 2015; Lieder & Griffiths, 2020; Sanborn, 2017; Sanborn & Chater, 2016; Thomas, Dougherty, Sprenger, & Harbison, 2008; Vul & Pashler, 2008). Importantly, this sampling process is not random. Instead, hypotheses are sampled with frequencies proportional to their probability. After sampling and evaluating a hypothesis, its probability will be updated, the probability distribution over all hypotheses will be adjusted, and a new hypothesis can then be sampled from this updated distribution.

The process of searching and sampling from a hypothesis space might unfold in a variety of different ways: Search can be narrow, “exploiting” high likelihood hypotheses that only differ incrementally, or broad, “exploring” the entire space and potentially arriving at novel solutions that are ultimately better than local alternatives. In the context of computer science, balancing exploitation and exploration is particularly relevant for optimization. Efforts to resolve this tradeoff between finding the best solution while spending the fewest resources have led to several potential algorithmic accounts, all of which have a property in common: Effective exploitation of an environment’s reward structure requires first understanding that reward structure. Thus, exploration is initially prioritized and reduces over time as information is accumulated (Kirkpatrick, Gelatt, & Vecchi, 1983). It has been proposed that similar changes in search strategies occur across human development (Gopnik, 2020, 2024; Meder, Wu, Schulz, & Ruggeri, 2021), and development itself has been framed as a process of parameter optimization (Giron et al., 2023).

Adults tend to privilege efficiency and seek to maximize their utility (Dennett, 1989; Gergely, Nádasdy, Csibra, & Bíró, 1995; Jara-Ettinger, Gweon, Schulz, & Tenenbaum, 2016). Guided by all the information they have accumulated throughout their life, adults initially sample a high prior hypothesis and strategically modify it such that successive samples are all relatively similar. As a result, adults tend to base their decisions on just a few samples (Goodman, Tenenbaum, Feldman, & Griffiths, 2008), and it is often the case that taking a single sample is the optimal strategy (Vul, Goodman, Griffiths, & Tenenbaum, 2014). These exploitive strategies lead to quick, “good enough” solutions. However, they leave one susceptible to being stuck in a local optima, whereby their current hypothesis may be better than all local alternatives but much worse than alternatives that are further away (Gopnik, 2020).

Children, on the other hand, tend to engage in directed and systematic exploration (e.g., Schulz, Wu, Ruggeri, & Meder, 2019; Meder et al., 2021), even when this behavior is associated with greater cost (Liquin & Gopnik, 2022). These developmental differences in search behavior are ultimately guided by different goals: exploration of unfamiliar options typically results in poorer short-term performance, supporting long-term information gain, while exploitation of known options leads to maximizing immediate rewards at the cost of acquiring new knowledge.

This behavioral pattern in which adults are more exploitative and children are more exploratory has been documented in causal inference tasks (e.g., Gopnik, 1996, 2012; Lapidow & Walker, 2020), as well as in general reinforcement learning paradigms, where one freely acts in an environment and can choose to continue exploring or exploit known rewards (Blanco & Sloutsky, 2020, 2021; Liquin & Gopnik, 2022; Schulz, Konstantinidis, & Speekenbrink, 2018; Sumner, Steyvers, & Sarnecka, 2019a; Sumner et al., 2019b). Schulz et al. (2019), and later Giron et al. (2023), utilized a spatially correlated multiarmed bandit paradigm (Wu, Schulz, Speekenbrink, Nelson, & Meder, 2017) to investigate developmental differences in search strategies and the factors that influence them. On a series of trials, participants were presented with an 8×8 tile grid, where each tile had an initially unknown reward value. By clicking to reveal and earn a hidden tile's reward, or selecting a tile with a known reward, the goal was to earn as many points as possible given a limited number of clicks. The authors were specifically interested in three components of search behaviors—random exploration, directed exploration, and generalization—and examined how each of these components may be related to developmental changes in search strategies. Across experiments, children engaged in more directed exploration than adults—placing a higher value on resolving uncertainty—and generalized less often, with no differences observed in random exploration behavior (Schulz et

al., 2019; Giron et al., 2023). Thus, the differences in explore−exploit behaviors outlined above likely reflect a developmental change in the process of belief revision via changes in search strategies, rather than a change in the weighting of the priors alone.

Again, applying these findings to our novel framework, psychedelics may serve to modify adults' search strategies, making them (at least temporarily) broader and more exploratory. If so, they may be more likely to escape the negative feedback loops and learning traps that occur as a result of rigidly held mental models. This could also explain how psychedelic treatment leads to increases in creativity (Harman et al., 1966; Spitzer et al., 1996) and insight experiences (Carbonaro et al., 2018, 2020; Davis et al., 2021), which are correlated with improvements in symptoms of depression (Roseman et al., 2018) and addiction (Noorani et al., 2018).

Exogenous Attention

The cognitive features discussed so far describe differences in how children and adults "search" their internal environment, or hypothesis space. However, prior work has also provided evidence for differences in how children and adults search their external environment, via differences in exogenous attention. Specifically, adults rely on selective attention, a top-down process that narrowly concentrates attentional resources on goal-relevant aspects of a task (Deng & Sloutsky, 2016). As a consequence, they learn to ignore goal-irrelevant input, a phenomenon known as learned inattention (Heckler, Kaminski, & Sloutsky, 2006). This behavior is thought to be an indicator of learning, as adults optimize allocation of their attentional resources to input they believe will best facilitate learning and success (Yim, Best, & Sloutsky, 2011). However, learned inattention can also be costly when goal switching, or in cases in which the goal-relevant

input is misinterpreted. Children, on the other hand, show much more diffuse allocation of attentional resources (Gopnik, 2009). This allows them to pick up on various relevant cues in their environment that adults may miss (e.g., Blanco & Sloutsky, 2020; Plebanek & Sloutsky, 2017; Rich & Gureckis, 2015; Tandoc, Nadendla, Pham, & Finn, 2024).

In one study highlighting developmental differences in the allocation of attentional resources, Plebanek and Sloutsky (2017) showed participants a series of overlapping shapes. Each image contained one shape that was cued and another that was uncued. Within a trial, participants would first see a target stimulus for 1000 ms, followed by a mask for 500 ms, and then a test stimulus for 1000 ms. In the test stimulus, either the cued shape changed from the target stimulus, the uncued shape changed, or the test stimulus was identical to the target. After each trial, participants made familiarity judgments for the cued shapes. They also made change detection judgments for the test stimuli, where they were asked whether or not the test stimulus was identical to the target. The authors found an interaction between age and trial type. While adults had greater change detection accuracy for trials where the cued shape changed, children had greater change detection accuracy for trials where the uncued shape changed. That children outperformed adults on trials where the uncued shape changed indicates that they were allocating their attentional resources more broadly than adults (Plebanek & Sloutsky, 2017).

This difference in the allocation of attentional resources is related to differences in inhibition and control afforded by PFC development (Thompson-Schill et al., 2009). However, it may also be influenced by adults' higher weighted priors, and/or their tendency to engage in more local perceptual sampling (Gelpi, 2021). By broadening the allocation of one's attentional resources, similarly to broadening one's hypothesis sampling strategies, psychedelics may serve to increase exposure to new evidence that could result in belief revision. Like the other features

of flexibility outlined above, such a change in exogenous attention may provide an avenue to bypass or overcome learning traps, leading them to positive outcomes.

Pilot Study

The currently proposed model for the effects of psychedelics leverages what is known about the cognitive differences between children and adults to make specific, testable predictions for how psychedelics may affect cognition to increase flexibility. To summarize, psychedelics may (1) reduce the weighting of one's priors; (2) change one's search and sampling strategies, making them broader and more exploratory; and/or (3) change one's allocation of attentional resources, making them more diffuse. In each case, we would expect that adults treated with psychedelics would exhibit more of these characteristics relative to baseline.

To illustrate how these hypotheses can be tested experimentally, we briefly describe a small pilot study designed to adapt several developmental paradigms for use in psychedelic research. We have begun to empirically test these specific hypotheses in this pilot work. In an initial study, data from nine adult participants were collected in the context of a larger clinical trial examining psilocybin's ability to alleviate chronic phantom limb pain (Hurwitz, 2024). Here, participants with chronic phantom limb pain were enrolled and randomly assigned to receive either a high dose of psilocybin (25 mg p.o.) or a niacin control (100 mg p.o.). Niacin (Vitamin B3) was used as an active control because it mimics some of the physiological sensations associated with the onset of the effects of psilocybin, including body temperature changes and a tingling sensation. All cognitive flexibility tasks were conducted the day after the experimental drug session, and all but one of the tasks implemented the same experimental paradigms that had previously been used to identify differences between children and adults

described above (Lucas et al., 2014; Gopnik et al., 2017; Plebanek & Sloutsky, 2017; Schulz et al., 2018; Giron et al., 2023; Liquin & Gopnik, 2022). We also included one novel paradigm developed for the pilot study. Below, we preview some of the key findings from a subset of these tasks. A full overview of the experimental design and analyses from all cognitive flexibility tasks administered can be found elsewhere (Hurwitz, 2024). Although the small size of this pilot study precludes drawing conclusions from behavioral data (psilocybin, n = 5; niacin control, n = 4), these preliminary findings provide guidance for which hypotheses may be most promising to pursue in larger preregistered experiments.

First, participants in the psilocybin condition appear to be more sensitive than niacin controls to incoming evidence that contrasts with their strongly held beliefs. Using the blicket detector paradigm developed by Lucas et al. (2014) and explained above, participants in the psilocybin condition (2/5), like children in the original work, were more likely than controls (0/4) to identify the critical ambiguous object as a "blicket." Participants in the psilocybin condition (5/5) were also more likely than controls (1/4) to choose multiple objects when prompted to activate the machine themselves. Together, this suggests that participants in the psilocybin condition successfully inferred and applied the less intuitive conjunctive rule, while those in the control condition did not. Although additional data were needed, these preliminary findings are at least consistent with the predictions of the proposed framework: that psilocybin reduces the weighting of one's priors.

Second, using a novel serial production task (Hurwitz, 2024), participants in the psilocybin group exhibited broader and more exploratory search strategies relative to the control group. In this task, participants complete multiple trials where they attempt to guess a secret target word. They are initially given no information as to what the target word might be and

generate a series of guesses to try and identify it. Participants receive feedback after submitting each guess on how similar their guess is to the secret target word in semantic space, as measured by the cosine between any two word vectors generated by the Global Vectors for Word Representation (GloVe; Pennington, Socher, & Manning, 2014). Given this design, participants must, therefore, continuously update the constraints (imposed by their own previously generated guesses) on their subsequent guesses. Search strategies are quantified by the average similarity between sequentially generated responses—with higher average similarity corresponding to local, more exploitive, search strategies, and lower average similarity corresponding to broader, more exploratory, search strategies. Participants in the psilocybin condition ($M = 0.40$) had a lower average sequential response similarity than those in the niacin condition ($M = 0.44$), indicating that they were employing more exploratory search strategies. These search strategies were also related to participants' self-reported clinical benefits, with more exploratory search behavior associated with lower pain at 1 ($\beta = 49.3$), 2 ($\beta = 45.7$), and 4 weeks ($\beta = 28.7$) after their experimental drug session. Here, the positive slopes indicate that as the average sequential response similarity increased (i.e., greater cognitive rigidity), phantom limb pain increased in turn.

Search strategies were also assessed using a spatially correlated multiarmed bandit paradigm (Wu et al., 2017). Following prior work (e.g., Schulz et al., 2019; Giron et al., 2023), computational models were used to characterize different components of exploration, including the extent to which participants preferentially sampled uncertain options, generalized information across the environment, and engaged in random sampling. Each component was formalized by a parameter in the models, and higher parameter values indicated participants exhibiting greater incidences of that behavior. Results suggested that participants in the

psilocybin condition adopted broader search strategies than those in the niacin condition. In particular, they showed greater directed exploration ($M_{psilocyin}$ = 0.22, M_{niacin} = 0.18) and reduced generalization across options ($M_{psilocyin}$ = 0.83, M_{niacin} = 1.13), a pattern that resembles the exploratory strategies observed in children in earlier studies using the same paradigm. Random exploration did not differ between conditions ($M_{psilocyin}$ = 0.03, M_{niacin} = 0.04). These preliminary findings are consistent with the proposed framework, suggesting that psilocybin shifts search behavior toward broader, more exploratory sampling of the environment.

Finally, there was no evidence that psilocybin impacted the allocation of attentional resources. Using a change detection paradigm (Plebanek & Sloutsky, 2017), where change detection accuracy was measured using A' (a nonparametric equivalent of d'), we found that participants in both the psilocybin and control conditions had similar accuracy for cued ($M_{psilocyin}$ = 0.96, M_{niacin} = 0.93) and uncued ($M_{psilocyin}$ = 0.77, M_{niacin} = 0.78) images. The performance of participants in both conditions was similar to that of adults in the original work. Given that the perceptual effects of psychedelics occur during acute drug effects, it is not necessarily surprising that no initial evidence for attentional shifts were found a day later. It is, however, possible that any effects on exogenous attention may occur solely during acute drug effects, which warrants further study.

Conclusion

Over the last decade, psychedelics have become an increasingly popular novel treatment option for a variety of clinical indications. There is a preponderance of evidence indicating that psychedelics can afford substantial clinical benefits, even resulting in complete remission in some instances, yet the mechanisms underlying these effects have received comparatively less

attention. Evidence from both neuroimaging and psychological survey studies suggests that cognitive flexibility may be key to understanding these effects. However, few studies have prospectively tested specific hypotheses for what may be driving the observed clinical benefits, and fewer still in ways that would afford causal conclusions to be drawn. To truly test this account, specific behaviors known to be symptomatic of increased cognitive flexibility must be examined. Here, we have proposed a cognitive development model, whereby children—a group known to be more cognitively flexible than adults—are treated as a proxy psychedelic group to generate predictions for such behaviors.

After providing an overview of three potential features of increased cognitive flexibility, we previewed the findings from our initial pilot data, formally testing these predictions. These pilot results are broadly consistent with the predictions of the proposed framework, suggesting that adults treated with psilocybin may exhibit more flexible patterns of behavior resembling those observed in children, such as reduced reliance on prior assumptions and more exploratory search strategies. However, given the small sample size, these results should be interpreted primarily as an illustration of how developmental paradigms can be adapted to test specific cognitive mechanisms in future preregistered experiments. By better understanding the mechanisms underlying psychedelic therapy, it will be possible to identify which individuals and clinical conditions may be most receptive to this therapeutic practice. Additionally, it will allow for the development of alternative treatments targeting the same mechanism for individuals who are not suited for psychedelic therapy.

While the analogy between childhood and the psychedelic state is useful for generating new hypotheses about how psychedelics influence flexibility, it is necessarily imperfect. Development unfolds over years, whereas the acute effects of psychedelics occur over hours,

with some residual effects lasting longer. Nonetheless, the comparison highlights a shared shift toward broader exploration and reduced reliance on prior assumptions. This perspective raises important questions about the mechanisms underlying such changes, including whether psychedelics alter how individuals pursue existing goals or instead shift the value placed on exploration itself. Clarifying these mechanisms, and identifying where the similarities and differences between these populations lie, will be essential for understanding how psychedelics reshape learning. Taken together, the framework and preliminary evidence outlined here provide a starting point for systematically investigating these questions in future work.

Acknowledgements

This project was directly inspired by Rummelhart awardee, Dr. Alison Gopnik. Her ground-breaking research served as the foundation for the ideas explored in this project. The authors would also like to thank Dr. Erik Brockbank and Dr. Elizabeth Lapidow for their input when developing the ideas for this project, Nildo Junior for their assistance in task design, and the members of the UCSD Center for Psychedelic Research and the Early Learning and Cognition Lab for critical contributions throughout the project.

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