The creative brain

Some insights into the neural dynamics of flexible and persistent creative processes

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Publication date
2018

Document Version
Other version

License
Other

Link to publication

Citation for published version (APA):
Boot, N. C. (2018). *The creative brain: Some insights into the neural dynamics of flexible and persistent creative processes*.

CHAPTER 1

General Introduction

Over hundreds of years, humans have continuously improved their quality of life by inventing clever solutions to everyday problems. They have painted beautiful pictures that awe thousands of people, composed symphonies while being unable to hear, and made groundbreaking scientific discoveries. This exceptional human ability to imagine and create fascinates scientists and non-scientists alike. How do people come up with such unlikely ideas? Why are some people more creative than others? Are these people born this way or can everybody learn to be creative? Some researchers have gone to great lengths to study what makes creative people so inventive. In 1955, pathologist Thomas Harvey removed the brain of Albert Einstein – one of the most brilliant scientists of our times – from his body several hours after his death, without permission from Einstein's relatives (Burrell, 2005). It cost Harvey his job, but this did not stop him from cutting the brain into over 200 pieces that ended up traveling to laboratories all over the United States, being stored under a beer cooler in Harvey's lab, or getting lost. When 30 years later the first scientific report on Einstein's brain was published, it claimed that his brain was characterized by a higher cell density in frontal parts of the brain compared to other brains (Diamond, Scheibel, Murphy, & Harvey, 1985), while more recent analyses pose that it had an unusual shape and thicker connections between the two hemispheres of the brain (Falk, Lepore, & Noe, 2013; Men et al., 2014). However, these studies have been criticized on several methodological grounds and, despite all outrage, the question of whether Einstein's brain differed from less extraordinary brains remains unanswered (Hines, 2014).

Fortunately, we now have alternative, less sinister methods for studying the creative brain to our disposal and we no longer have to wait for the exceptionally creative to pass away. However, this has not necessarily resulted in a better understanding of what characterizes the creative brain (Arden, Chavez, Grazioplene, & Jung, 2010; Dietrich & Kanso, 2010). Creativity is a complex construct that can be defined as a process in which people use cognitive abilities to transfer their knowledge and expertise into outcomes (i.e., ideas, solutions, products) that are both original and useful (Amabile, 1996; Baas & van der Maas, 2015). The first things that come to mind when one thinks about creativity may be famous works of art, such as Van Gogh's Sunflowers, J.K. Rowling's fabulous stories of magical creatures, or that one friend's theme party outfits that outshine yours every time. However, creativity can also be (and is actually much more often) expressed in more subtle, everyday ways by each and every one of us: in the way we use analogies to explain complicated concepts to our students, in puns and witty remarks, in clever solutions to the daily problems we encounter, such as using a knife to fix a screw when a screwdriver is not available. The creative processes that underlie such everyday creativity are the focus of the research presented in this dissertation.

Over decades of research, behavioral scientists have obtained many important insights into the cognitive processes that are involved in creativity, the situational factors that facilitate or hinder creative processes, and the personality traits that distinguish more creative from less creative people (e.g., Carson, Peterson, & Higgins, 2003; De Dreu, Nijstad, & Baas, 2011; Feist, 1998; Guilford, 1950; Hommel, 2012). This knowledge helps us to better understand how creativity works, how to measure it in the laboratory, and even how to facilitate it in daily life. One model of creativity that has strongly influenced how creative processes are defined and measured throughout this dissertation is the Dual Pathway to Creativity Model (DPCM; De Dreu, Baas, & Nijstad, 2008; Nijstad, De Dreu, Rietzschel, & Baas, 2010). This model proposes that creative outcomes (problem solutions, stories, original examples) may result from two qualitatively different types of creative processes: flexible or persistent processes. Flexible creative processes include effortless switching between different perspectives, the combination of information that is not obviously related, and divergent thinking (the generation of multiple solutions to open-ended problems; Guilford, 1967). These processes may result in original ideas relatively quickly and effortlessly, because this flexible approach enables people to consider many different conceptual categories of ideas, including more original ones. Flexible creative processes are often measured using some type of divergent thinking task, such as the Alternate Uses Task (Guilford, 1967). This task requires people to generate as many new, original uses for a common object, such as a brick, within a few minutes. In addition to simply counting the number of ideas that people generate, one can score people's performance in terms of flexibility (the number of conceptual categories that ideas fall into) and originality (the extent to which an idea is uncommon). Persistent processes, on the other hand, include more analytical processes, such as the deep exploration of possibilities along a certain line and convergent thinking (the recombination of familiar and closely related information into novel ideas according to certain rules; Cropley, 2006). Persistent processes are characterized by sustained goal-directed effort and focused attention over extended periods of time (Lucas & Nordgren, 2015; Nijstad et al., 2010; Roskes, De Dreu, & Nijstad, 2012). Rather than switching between different categories of ideas, people who rely on persistent creative processes tend to come up with ideas that fall into the same conceptual category. While such processes will only lead to the most obvious, unoriginal ideas at first, ideas will become more original after those unoriginal ideas have been considered and discarded. The DPCM explains how situational and personality factors relate to creativity by linking them to flexible or persistent processes. In reality, creative outcomes most likely result from a combination of flexible and persistent processes, rather than one or the other.

A Neuroscientific Paradigm to Study Flexibility and Persistence

Studying the neural mechanisms that underlie these creative processes is complicated, because the neuroscientific study of cognitive processes is constrained by several requirements that seem to be incompatible with some of the defining characteristics of creativity (Abraham & Windmann, 2007; Fink, Benedek, Grabner, Staudt, & Neubauer, 2007). For example, one needs to be able to measure the cognitive process of interest at exactly the same time point in a large number of instances to filter out task-unrelated noise from the brain signal of interest (Cohen, 2014). The generation of creative ideas, on the other hand, is a complex combination of processes that are hard to predict in terms of timing. Therefore, it is necessary to come up with new ways to measure creativity that meet the requirements of neuroscientific research – a challenge that has been taken up by several research groups. The resulting empirical studies have invalidated some popular ideas on the neural substrates of creativity, such as creativity being 'located' in the right half of the brain (Dietrich & Kanso, 2010; Gonen-Yaacovi et al., 2013). Other findings from studies using functional magnetic resonance imaging (fMRI) indicate that creativity importantly, but not exclusively, relies on parts of the prefrontal cortex (Gonen-Yaacovi et al., 2013).

Several electroencephalography (EEG) studies suggest that alpha oscillations play a major role in creative idea generation in general, and in divergent vs. convergent thinking in particular (e.g., Fink & Benedek, 2014; Jauk, Benedek, & Neubauer, 2012). Overall, however, neuroscientific studies of creativity have been criticized as being uninterpretable due to large variability in methods across studies (Arden et al., 2010; Dietrich & Kanso, 2010). As a result, the literature is highly fragmented and researchers can always find papers that support their claims, regardless of what those claims are. Thus, more carefully designed new paradigms are required if we wish to understand more about the neural basis of creativity. I present such a paradigm in Chapter 2 of this dissertation.

Dopaminergic Modulation of Flexibility and Persistence

One of the pictures that does emerge from several lines of research on the neural substrates of creativity is that the neurotransmitter dopamine seems to modulate creative processes. Dopamine is probably best known for its role in reward processing and the addictive properties of recreational drugs (Ikemoto, 2007; Volkow, Wang, Fowler, Tomasi, & Telang, 2011a), but it also plays a crucial role in the cognitive control of goal-directed behavior. In some situations, adaptive behavior requires us to focus on a certain task over extended periods of time while ignoring distractions, such as when trying to finish a dissertation. At other times, however, behavior benefits from the ability to explore alternative options in the environment and to switch to different activities that are more likely to result in desirable outcomes, such as when a colleague interrupts our goal-directed focus with some juicy gossip. Both these flexible and stable cognitive processes, and the interplay between them, are strongly influenced by dopaminergic functioning in a network of fronto-striatal brain areas (Cools & D'Esposito, 2011; Cools, Sheridan, Jacobs, & D'Esposito, 2007; Frank, Loughry, & O'Reilly, 2001; Hommel & Colzato, 2017; McNab & Klingberg, 2008). While dopamine in the prefrontal cortex seems to support the maintenance of goal representations in the face of distractions, dopamine in the striatum is involved in switching between task strategies and the updating of goal representations. Accumulating evidence suggests that dopamine in different brain areas similarly modulates flexibility and persistence in creativity (e.g., Chermahini & Hommel, 2010; De Manzano, Cervenka, Karabanov, Farde, & Ullén, 2010; Mayseless, Uzefovsky, Shalev, Ebstein, & Shamay-Tsoory, 2013; Zhang, Zhang, & Zhang, 2014a). In the striatum, dopamine seems to modulate flexible creative processes, such as having a broad attentional scope (perceiving global rather than detailed features, allowing more remotely related information to enter working memory) and divergent thinking (Chermahini & Hommel, 2010; Zhang et al., 2014a). In the prefrontal cortex, on the other hand, dopamine may modulate more analytical, convergent creative processes, and the ability to persist when creative ideas do not immediately come to mind (Mayseless et al., 2013; Zhang, Zhang, & Zhang, 2014b). As, in reality, creative ideas result from a combination of flexible and persistent processes, it seems likely that creativity requires a delicate balance of dopaminergic functioning in fronto-striatal brain areas. Although these hypotheses have not been directly tested, they are indirectly supported by evidence from genetic studies (Reuter, Roth, Holve, & Hennig, 2006; Zhang et al., 2014a), indirect measurements and manipulation of dopamine availability in the brain (Chermahini & Hommel, 2010; Colzato, De Haan, & Hommel, 2014), and from studies linking personality factors to creativity (Baas, Roskes, Sligte, Nijstad, & De Dreu, 2013; Depue & Collins, 1999). I will review this evidence in Chapter 3 of this dissertation.

Creativity in ADHD

The dopaminergic system may also be an important factor in the link between several mental disorders and creativity (Acar & Sen, 2013; Baas, Nijstad, Boot, & De Dreu, 2016; Johnson et al., 2012). Symptoms of mental disorders that are characterized by dopaminergic hyperactivity in the striatum, such as schizophrenia and bipolar disorder, seem to be related to enhanced creativity (Acar & Sen, 2013; Baas et al., 2016; Johnson et al., 2012). For example, people who experience mild schizotypal symptoms (e.g., having odd, magical beliefs and strange perceptual experiences) seem to be more creative than people who do not experience such symptoms (Acar & Sen, 2013). This may also be the case for another disorder that is associated with dopaminergic imbalance in various brain areas: attention-deficit/hyperactivity disorder (ADHD) (Sagvolden, Johansen, Aase, & Russell, 2005; Swanson et al., 2007). ADHD is characterized by symptoms of distractibility, hyperactivity, and impulsivity. Because people with ADHD tend to process more task-irrelevant information and take more risks (presumably as a result of impaired dopaminergic functioning in several brain areas; Sagvolden et al., 2005; Sonuga-Barke, 2003), they may be able to come up with more original ideas than people without the disorder (Baird et al., 2012; Feist, 1998; Toplak, Jain, & Tannock, 2005). The idea that people with ADHD are more creative than others is popular outside of the scientific world and has received some support in recent empirical studies (White & Shah, 2011, 2016). However, while people with (symptoms of) ADHD seem to be more creative in everyday life (White & Shah, 2011; Zabelina, Condon, & Beeman, 2014), they do not consistently outperform people without the disorder on laboratory tasks of divergent thinking (Abraham, Windmann, Siefen, Daum, & Güntürkün, 2006; Barkley, Murphy, & Kwasnik, 1996; Murphy, Barkley, & Bush, 2001). In Chapter 4 and 5 of this dissertation, we investigate several potential explanations for these mixed findings. First of all, the relationship between ADHD and creativity may depend on individual differences in the (degree of) specific ADHD symptoms that people experience and on the specific (flexible or persistent) creative processes under investigation. These possibilities are examined in Chapter 4. Alternatively, factors such as the motivation for performing creative tasks may explain whether and when people with ADHD are more creative than others (Volkow et al., 2011b). Generally, people with ADHD experience decreased motivation during tasks that are not perceived as interesting or immediately rewarding (Barkley, 1997; Shaw & Giambra, 1993; Volkow et al., 2011b), but evidence indicates that providing rewards such as money or praise can improve cognitive (and possibly also creative) performance by increasing motivation in people with ADHD (Geurts, Luman, & Van Meel, 2008; Kohls, Herpertz-Dahlmann, & Konrad, 2009). This possibility is tested in Chapter 5.

Pharmacological Manipulation of Creative Processes

The relationship between symptoms of ADHD and creative processes, as well as the dopaminergic model that we propose in Chapter 3, suggests that creativity may be influenced by stimulant drugs that are commonly prescribed to treat symptoms of ADHD, such as methylphenidate (also known as Ritalin) and amphetamines (Advokat, 2010). These drugs are believed to improve stable cognitive processes, such as the ability to focus over extended periods of time while ignoring distractions, by raising dopamine and noradrenaline levels in the brain (Arnsten & Dudley, 2005; Kuczenski & Segal, 1997). For this reason, an increasing number of healthy people now use such substances as *cognitive enhancers* to improve their ability to concentrate in situations that ask for prolonged cognitive effort (Greely et al., 2008). While these drugs may indeed facilitate sustained attention and working memory functioning (Linssen, Sambeth, Vuurman, & Riedel, 2014), they may negatively affect more flexible cognitive processes, such as those required for (flexible) creativity (Mohamed, 2016; Müller et al., 2013). Thus, the effects of these drugs seem to vary from task to task and may also differ across different individuals (Cools, 2015). For example, methylphenidate may improve more persistent, analytical creative processes in people who experience a relatively strong degree of ADHD symptoms (e.g., impulsivity or distractibility), whereas the effects may be opposite in people who do not experience such symptoms (Cools et al., 2007; Gvirts et al., 2016). Studying the individual differences that influence the effects of methylphenidate could have important implications for the use of these drugs by both people with and without ADHD. In Chapter 6, I describe a study in which we tested these effects.

Overview of this Dissertation

In the studies presented in this dissertation, my collaborators and I set out to answer some of the open questions regarding the neural mechanisms underlying creative processes. This dissertation is built around four empirical chapters and one theoretical chapter. In Chapter 2, I present a new paradigm that we developed to be able to directly compare the neural dynamics associated with convergent and divergent processes in creative idea generation in an EEG experiment. In the theoretical Chapter 3, I review accumulating evidence suggesting that dopamine in fronto-striatal brain areas modulates flexible and persistent processes in creativity. Based on this evidence, I present a model of dopaminergic modulation of creativity that opens up important avenues for future research. Both Chapter 4 and 5 focus on the link between creativity and symptoms of ADHD. Chapter 4 includes three empirical studies in which we addressed the relationship between ADHD and creativity in a sample of healthy students to assess whether and how specific ADHD symptoms are related to different types of creative processes. In Chapter 5, I describe two studies in which we extended these findings by investigating creativity in people with clinical ADHD and comparing their performance to the performance of healthy controls. In Study 5.1, we assessed whether people with ADHD are simply more motivated to generate original ideas than healthy controls and whether using medication to treat symptoms of ADHD affects creativity. In Study 5.2, we manipulated motivation by introducing competition between participants during an idea generation task to assess whether people with ADHD can be motivated to generate more original ideas. These chapters on dopamine and ADHD converge in Chapter 6, where I describe a study in which we directly manipulated dopamine (and noradrenaline) levels in the brain. We did so by administrating methylphenidate to a group of healthy participants to test how this affected their creative performance and whether these effects depended on individual differences in ADHD symptoms. Finally, in Chapter 7, I integrate the main conclusions of the preceding chapters and their implications. Moreover, I discuss some limitations of the current work and propose directions for future research.