Asociación Colombiana de Psiquiatría ACP

Revista Colombiana de Psiquiatría

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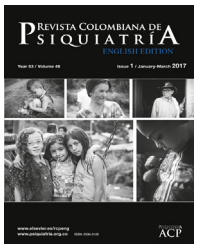

Review Article

Neural Foundations of Creativity: A Systematic Review

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ARTICLE INFO

Article history:
Received 9 October 2015
Accepted 4 June 2016
Available online 15 July 2016

Keywords:
Neuroscience
Creativity
Neural foundations
Neuroimaging

ABSTRACT

When considering the importance of the human cognitive function of creativity, we often overlook the fact that it is due to human creativity and to the constant search for new sensory stimuli that our world has, throughout the years, been one of innovation in every aspect of our existence —in the sciences, the humanities, and the arts. Almost everything that surrounds us is the result of human creativity, therefore it is not difficult to understand that although neuroscientific research has led to valuable perceptions into the probable underpinnings of this multifaceted ability, the precise neurological substrates that underlie creativity are yet to be determined. Despite the establishment of a strong link between creativity and divergent thinking, other brain networks have been implicated in this mental process. The following review underlines recent studies on the neural foundations of creativity. A comprehensive analysis of the upmost important facts will be presented, with emphasis on concepts, tests, and methods that have been used to study creativity, and how they have outlined a pathway to the key understanding of this unique human ability.

Fundamentos neurales de la creatividad: una revisión sistemática

Palabras clave:
Neurociencias
Creatividad
Fundamentos neuronales
Neuroimagen

RESUMEN

Al considerar la importancia de la creatividad en la función cognitiva humana, sucede con frecuencia y pasamos por alto el hecho de que es precisamente debido a la creatividad humana que a través de los años nuestro mundo ha estado en constante innovación en cada aspecto de nuestra existencia: en la ciencia, las humanidades y las artes. Casi todo lo que nos rodea se debe a la creatividad humana; por lo tanto, no es difícil entender que, aunque la investigación neurocientífica ha conducido a percepciones valiosas sobre los fundamentos probables de esta capacidad multifacética, estos estudios no han permitido conclusiones

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claras y tienen todavía mucho por determinar para comprenderla mejor. A pesar de que se ha establecido un fuerte vínculo entre la creatividad y el pensamiento divergente, científicos han identificado otras redes cerebrales implicadas en este proceso mental. La presente revisión subraya los estudios recientes sobre los fundamentos neuronales de la creatividad. Se presenta un análisis comprensivo con énfasis en los conceptos, las pruebas y los métodos que se han utilizado para estudiar la creatividad y la forma en que han proyectado una vía para la comprensión fundamental de esta capacidad humana única.

Introduction

In the last decade, although studies in neuroscience have provided important insights about the neural basis of creativity, these studies have not yet led to clear assumptions regarding the neural correlates due to the complicated construct of the topic.[1] Neural correlates in the fundamental human capacity of creativity have become increasingly important in research,[2] nonetheless hard to document or replicate due to its abstract and multiform definitions that likely involve other cognitive brain processes.[3] Therefore, although specific neural processes are assumed to mediate creativity, their scientific exploration has been extremely challenging.[4] There is no single measure method that can apprehend the multifactorial complexion of this cognitive function. Research in creativity is puzzling for a number of reasons; more specifically, the study of creativity becomes complicated when identifying tasks that will be able to measure creativity without other cognitive processes that can trigger brain responses.[5] For example, rather than being yes or no answer tasks,[6] creativity tasks involve verbal or written/drawing responses that may lead to brain activity related to working memory, attention and language.[7] Furthermore there is also a problem due to the conceptual meaning of creativity and the difficulties overcoming the fact that creativity isn't predicable and can't be prompted volitionally.

The problem can be approached at the level of large-scale systems using neuroimaging methods and standardized psychometric tests.[8,9]. Brain imaging methods including positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and electroencephalography (EEG and event related potentials [ERP]) have provided important implications regarding the neural basis of creativity.[10,11] Notwithstanding the lack of consensus, developing literature and neuroimaging studies have led to suggest that divergent thinking is neural correlate of creativity and a central component of the ability.[12] Specifically these studies yield information about the role of the prefrontal cortex, the default mode network and central executive processes associated with internally directed attention and spontaneous cognition.[13]

This review discusses definitions and evidence about the neural basis of creativity in an attempt to explain the neural mechanisms underlying this mental process, elucidating the current difficulties, the need to study other approaches and to reveal how functionally linked neural areas may cooperate in its production. By reviewing creativity, this article hopes to clarify that this cognitive process is one that cannot be completely apprehended by current theoretical proposals.

An Approach to Unravelling the Meaning of Creativity

Over the years there has been many definitions of creativity. Wallas[14] proposed that creativity was a mental process that included phases such as preparation, incubation, illumination and verification. Torrance[15] defined creativity as "a process of becoming sensitive to problems, deficiencies, gaps in knowledge, disharmonies; identifying the difficulty; searching for solutions, or formulating hypotheses about the deficiencies: testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results." Bronowski[16] defined creativity as the ability to find unity in what appears to be diverse or finding the thread that unites. On the other hand, Boden[17] formalized a mathematical Creative Systems Framework based on creative conceptualization and process. Heilman[18] defined creativity as "the ability to understand, develop and express in a systematic fashion, novel orderly relationships." Lastly, Schmidhuber[19] proposes a model based on intrinsic motivation and creativity based on maximizing intrinsic reward for active creation of innovating sequences that allow prediction.

It's noteworthy to understand that creativity is influenced by the development of new social institutions, economic growth[20] and time. The creative potential exists in everyone, but it's greatly influenced by experiences, social and environmental contexts.[21] Curiosity, experience and the senses are all key in the construct of creativity.[22] Experience can be considered as a basis by which humans influence the world we live in more effectively by constantly creating new and different ways of sensing our environment.[23] Considering the relationship between sensory-driven information and mind-driven information[24] it can be stated that creativity is a multimodal process that comprises sensory areas such as visual, tactile, olfactory, auditory, gustatory, physical and also cognitive, emotional and verbal information.[25]

There is a general agreement that creativity is a multifaceted phenomenon[26] that involves the ability to create or work on something that is innovative, beneficial, practical and generative.[27] However, creativity can be also observed, considered, and studied as a part of a process, rather than an only ability.[28] Creativity in the brain does appear to work in a series of networks of cognitive functions such as attention, flexibility,

and cognitive control.[29,30] As mentioned, an increasing body of research around divergent thinking proposes an interest in the cognitive basis of creative thought. Defined as the ability to generate a variety of solutions to an open ended problem (Guilford, 1967), divergent thinking was taken up to pinpoint one of the main problems regarding creativity's complex and multi-layered nature.[12]

Cognitive Neuroscience in Creativity: Psychometric Standardized Tests

One of the challenges to investigating creativity lies in the widespread use of qualitative approaches. This led to the development of several metrics in an attempt to investigate brain correlations in a quantitative or semi-quantitative manner.[31,32] At this moment it is important to understand the terms of convergent and divergent thinking and their definitions.[20] While convergent thinking leads to conventional ideas and solutions, divergent thinking leads to originality, which —we can now agree— is the central feature of creativity.[33] Taking this into account, most measures involve divergent thinking, and look at fluency, originality, flexibility, and elaboration.[34,35] Fluency considers the ability and fluency of an individual to give a large number of organized ideas. Originality is based on innovation and in frequency. Flexibility leads to diverse ideas and elaboration to an associative pathway followed by an individual.[33] What follows is a further overview on some of the most commonly used measures for creativity research.

Guildford's Divergent Thinking Test 1967 (DTT)

During this test individuals list as many possible uses for common objects. Scoring is comprised of four basic components: originality, fluency, flexibility and elaboration.[36]

Structure of the Intellect (SOI) Divergent Production Test

This test is based on Guildford's (1967) DTT and takes an individuals' potential at divergent creations in numerous areas for example semantic systems, figural systems and symbolic units. The test has a scoring criteria also based on fluency, flexibility, originality and elaboration.[26]

Wallach-Kogan Test of Creative Thinking (WKCT)

WKCT is based on the associative notion of creativity; this task's performance is then scored on the number of related responses and uniqueness generated under several contexts.[26]

Torrance Tests of Creative Thinking (TTCT) (1966)

This test provides a tool that can evaluate an individual's creative potentialities and can accommodate to their demographic properties. The test has a figural and verbal component each with different tasks. The first one, scores an individual's originality and elaboration potential, picture completion, fluency and flexibility. The verbal task scores for fluency, flexibility and originality.[37]

Remote Associate Test (RAT)

The RAT is a test of creative potential and is based on associations and convergence. The questions presented consist of three common stimulus words that can be linked to a fourth word. This test is a verbal task of certain complexion involving creative thought and intelligence.[38]

Consensual Assessment Technique (CAT)

CAT was developed to evaluate creativity perceived in finished items or pieces. During this test, creativity researchers rate a set of products that include stories, poems, and other objects.[39]

Brain Imaging in Creativity

There are several cognitive neuroscience methodologies that provide basis for the understanding of the neural correlates of creativity.[40] Brain imaging technologies are essential to identify the areas of the brain associated with creativity and the processes related to it.[8] Many of these studies shed light and uncover information on the areas of the brain involved in divergent thinking and the relationship with the Default Mode Network.

Electroencephalography

EEG measures electromagnetic electric fields generated by neuronal activity through sensors that are placed on the patients scalp.[8] The method detects neural activity in the dendrites and an electromagnetic field is created if a sufficient number of neurons are receiving signals at the same time.[41] EEG is usually used to measure an event related potential, this means that information is recorded after the presentation of a stimulus. These studies have revealed that brain patterns are due to different types of cognitive thinking tasks such as mathematical or language processing tasks.[27] EEG can be measured in many different techniques that have been effective in creativity studies.[31] The data is reported in ranges of frequency: Delta activity associated with deep sleep and reflects a low neuron firing rate; Theta waves associated with drowsiness; Alpha activity can be evidenced with minimal arousal; Beta waves occur during active thinking, and finally, Gamma activity is associated with perceptual information.[12] EEG studies in neuroimaging of creativity include tests and tasks such as insight problems from the RAT,[12] stories from GDTT,[42] Divergent Thinking with eyes closed,[43] and mentally create a drawing while looking at a white wall.[44]

Functional Magnetic Resonance Imaging

Neuronal activation results in a local increase in blood supply to the active area of the brain, which induces a change in the relative concentration of oxyhemoglobin and deoxyhemoglobin.[45] fMRI uses magnetic field to measure these relative changes in concentration of oxy- and deoxyhemoglobin, by using a technique known as blood oxygen level dependent signal (BOLD). Sites with increased activity receive

more blood, which in turn increases the BOLD signal.[46] fMRI captures these signals and provides images of brain activation zones.[8] There are several studies in neural correlates of creativity using fMRI and tasks such as the three-word remote associates test[47] match problems, divergent thinking,[48] story generation task[49] processing novel metaphors[50], and Rorschach-ambiguous figures.[51] On most of these studies, the significant associations are in brain regions unique to each study due to the sensitivity of functional imaging and the differences in experimental design structure.

Positron Emission Tomography

When neurons are firing rapidly there is an elevated neuronal activation leading to an increase to their blood supply that matches the increase in oxygen demand.[8] By introducing a radioactive tracer into the blood stream, PET measures the differences in regional cerebral blood supply (rCBF). Where there is more blood flow to a specific location, a larger amount of the radioactive tracer accumulates in the vascular beds of the tissue resulting in increased radiation emissions from that particular location.[8] The patient is given a cognitive task and the associated brain regions then activate. The scanner is able to measure brain activity.[8] There has been several tests conducted using PET. Some of these include Creative Functioning Test,[6] that involves creating a story using easy or hard words presented on a screen[52] and Creative and two control task.[53] These studies presented some evidence that, when undertaking cognition tasks involving creativity, creatives show greater activation in bilateral prefrontal regions. Less creative subjects presented rises in the left prefrontal region when doing a creative cognition task.[45] Concordantly, studies using PET evidence the activation of the prefrontal regions during creative tasks.

Divergent Thinking and the Default Mode Network

Behavioural evidence of the cognitive processes related to divergent thinking has been supported by EEG and fMRI studies that report task related activation in regions of the brain associated with creative cognition.[34] Such studies compare neuronal activation and brain activity patterns in high vs. low creative individuals, yielding evidence that high creatives show stronger prefrontal brain activation.[31] Among the most strongly activated regions during divergent thinking is the inferior prefrontal cortex (IPC). Conversely, neuroimaging studies have also reported the activation in brain regions within the default mode network which includes the medial temporal lobe (MTL), the ventral and dorsomedial prefrontal cortex (PFC), the posterior cingulate cortex (PCC), the inferior parietal lobule and the hippocampal formation. Creativity researchers have hypothesized that the DMN underlies processes such as internally directed attention and selective retention processes during divergent thinking.[34]

Further evidence of the DMN's role in divergent thinking can be evidenced though resting state fMRI (rs-fMRI) that has enabled examination of functional communication between brain regions through investigation of their level of co-activation during rest.[12,13,34] Regions of the DMN show activation during resting states and their activation is reduced during cognitively demanding tasks. This has led researchers to suggest that divergent thinking reflects the shifting of attentional focus from spontaneous cognition (regions associated with the DMN) and cognitive control (PFC).[12,34]

EEG studies might support the notion that the DMN regions show activation during resting states and minimal arousal. A psychometric review in neuroimaging creativity by Arden et al,[45] reported that practically most all of the EEG studies in neuroimaging creativity used measures of divergent thinking. Also, most of these EEG studies indicate alpha band synchronization changes linked with creative task performance in the centro-parietal brain regions. This is a focus of interest since the increase in power and synchrony at this frequency wave indicates low levels of cortical arousal and defocused attention. Nevertheless, there is significant heterogeneity of outcomes across EEG studies of creative cognition.[45] This makes it somewhat difficult to obtain strong conclusions about the impact of alpha activity, power and the location of these factors within neural activity on a particular task.[45]

Conclusions

To conclude, a broad revision of literature indicates that important progress has been made in the last decade; however the neural basis of creativity is still puzzling. Although measures, tests and neuroimaging methods provide researchers with important information regarding creative underpinnings in the brain, it is key to understand that these methodologies have both weaknesses and strengths. Regardless of this fragmentation, we can draw some conclusions from the existing information:

1. There appears to be consent on the brain activity in the prefrontal cortex[45] during divergent thinking tasks, however its unclear which cortices are in involved. Studies have shown activation of the ventrolateral prefrontal cortex, the right ventromedial prefrontal cortex, right premotor region, left dorsolateral prefrontal area and supplementary motor area.
2. A growing body of evidence suggests that divergent thinking is related to regions associated with internally directed attention and spontaneous cognition, indicating a functional link to the DMN.[34,42,43]
3. Creativity cannot be localized to a single part of the brain due to its implicit and multifaceted nature. This means that the underlying characteristics of creativity are not dependent on a particular mental process or brain region, rather they depend on a network of different brain regions. Divergent thinking is broadly distributed, does not involve a specific set of processes and therefore a specific brain region. It is the construct of these processes that result in different patterns of brain activation that make creativity such a fascinating human skill.[54]
4. Although there is a tendency to believe creativity is a function strictly related to the right hemisphere, neuroimaging results indicate divergent thinking and therefore creativity require activation of different areas involving both hemispheres of the brain.[45]

The most direct inference that can be taken from this review is that there is no current notion that can capture the neural mechanisms underlying creativity. Such a broad pattern of processes needs a comprehensive framework in order to pursue greater understanding. There is a long road ahead in order to validate current models of measures and methods in creative processes. Further studies would prove valuable by examining whether involvement of neural substrates underpinning control processes also diverges as a function of the content of creativity.

Conflicts of interest

The author has no conflicts of interest to declare.

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