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# The Neural Foundations of Creativity in the Default Mode Network

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**Abstract.** Network neuroscience research is providing increasing specificity on the contribution of large-scale brain networks to creative cognition. This study reviews several neural processes that underlie creativity by examining the functional connectivity of multiple brain regions as identified by functional magnetic resonance imaging (fMRI) scanning, often utilizing divergent thinking tasks. Many of these processes will be based primarily in the interaction between the default mode and executive control networks and will closely parallel cooperation between controlled and spontaneous cognition. This paper will also review two other neural mechanisms, one of which links creativity to the Big Five Personality Factor Openness to experience and the second will involve the salience network.

**Keywords.** Network neuroscience, creative cognition, neural mechanisms

## 1. Introduction

Creativity and creative people are often high in demand, not only in conventionally creative fields, such as the visual arts, but also in non-artistic disciplines such as business and education. Creativity breeds innovation, invention, and growth which are all necessities to developing any field. Understanding the neural basis of creativity may allow for a reliable method to predict one's creative capacity. Even though there is no universal agreement as to the neural basis of creativity, the central executive processes and the default mode network have been consistently implicated in an abundance of neuroscientific studies (Beaty et al., 2019).

However, due to the seemingly opposing nature of the functions of the networks, the degree to which they work together and the precise mechanism they use to support creative thought is still uncertain. The default mode network is an association of brain regions including the posterior cingulate cortex, medial prefrontal cortex, lateral temporal cortex, anterior temporal cortex, hippocampus, and the posterior inferior parietal cortex (Jacque & Thomson, 2017). It is most often activated during the resting state, and it is involved in internal mental processes, such as mind-wandering and future thinking. (Beaty et al., 2015) The DMN has also been shown to integrate external information and internal memories and beliefs in order to facilitate shared communications (Yeshurun et al., 2021).

Sure enough, lesions of the medial prefrontal cortex (MPFC) within the default mode network (DMN) impaired remote concept generation. (Bendetowicz et al., 2017) The executive control network, consisting of the frontoparietal regions, such as the DLPC, ACC, OFC, and the lateral posterior parietal cortex, (Jacque & Thomson, 2017), is involved in executive functions like working memory and relational integration, response inhibition and task-set

switching (Beauty et al., 2015). This paper can be roughly divided into three sections: the first summarizing the role of the DMN and the ECM on creativity, the second looking specifically at the role of cognitive control (IFG) and the DMN, and the third looking at two other hypotheses associated with the DMN and creativity.

## **2. The Default Mode Network and the Executive Control Network**

Current behavioral and neuroimaging research suggests that creativity involves some degree of cooperation between the default mode network and the executive control network (Beauty et al., 2019). This aligns with recent functional MRI studies which suggest that the cognitive direction of semantic and episodic memories contributes to the capacity for divergent thinking in Alternative Use Tasks (AUT). During the study, participants generated more responses on the AUT following, Episodic Specificity Induction (ESI), or brief training in recollecting the details of a past experience but did not do so for the object control task. When observed through an fMRI, there was significantly greater blood oxygen level dependent activity for both the AUT and the OAT in both specified and control inductions in parts of the both the default and executive networks, and in the case of the medial temporal lobe, part of the default mode network, following ESI. The neural effects of episodic retrieval materialize in tasks involving divergent thinking, indicating that episodic memory is involved in the creative process (Madore et al., 2017).

One assumption regarding creative thought is the involvement of idea generation and evaluation, with the default mode network being responsible for the former and executive control network for the later (Beauty et al., 2019). A study involving the spontaneous generation of poems found that regions of both the default mode and executive control network were activated, and that there was greater correlation during the following revision process (Liu et al., 2015). This theory is also supported in the domain of visual arts. Although the idea generation process was mainly associated with the default mode network, the ensuing evaluation involved both brain regions (Beauty et al., 2016).

It is speculated that creativity requires directing and monitoring spontaneous activities from the default mode network by inhibiting unoriginal ideas that would undermine the creative thought process. This could indicate that the greater functional connectivity between the inferior prefrontal cortex and default mode regions of creative individuals may relate to a greater ability to govern their imaginations. The findings suggest that highly creative people have the ability to simultaneously engage large-scale brain networks of cortical hubs within various brain regions, including the default and executive networks. Cross-validation analysis shows that neural models can reliably predict the creative quality of ideas generated by novel participants within a given sample.

## **3. Creativity and the Cognitive Control**

The DMN is also shown to be associated with a specific region of the brain: the inferior frontal gyrus (IFG). Top-down control over the DMN's activities can also be attributed specifically to the IFG, which is implicated in executive processes like controlled memory retrieval and prepotent response inhibition. Two studies found greater functional connectivity between the DMN and the IFG in individuals with greater creative capacity, albeit at different regions of the IFG depending on resting or active state. (Marstrand-Joergensen et al., 2021) Specifically, the left IFG and the entire default mode network showed increased connectivity, while the right IFG showed increased connectivity with the bilateral inferior parietal cortex and the left dorsolateral prefrontal cortex in highly creative individuals. This suggest that creative idea generation is correlated to increased functional connectivity between the inferior prefrontal

cortex and the default network, pointing to a greater collaboration between brain regions associated with controlled and imaginative cognition (Beatty et al., 2014).

fMRI scans also imply ideas generation and practical creative behavior in emotionally provocative contexts share cognitive processes. The reappraisal generation task (RGT) and AUT have been found to activate similar brain regions in particular the left prefrontal regions, indicating they involve similar executive processes such as inhibition of prepotent responses, cognitive flexibility and controlled memory retrieval. This has been consistent not only across these two different tasks but across various creative domains. Among these two tasks, however, there are differences, including the negative correlation between AUT performance and activation of the left IFG implied that better AUT performance occurred when the IFG was less activated. This may hint that less controlled memory and lower response inhibition indicates higher creativity or that higher creativity is related to higher neural efficiency.

On the other hand, RGT-specific activation was found in a rather right-lateralized network, including the right superior frontal gyrus and middle frontal gyrus, the right middle temporal gyrus and the right precuneus, the right SFG and bilateral angular gyri. Successful reappraisal generation involves the prefrontal regions and its executive functions, indicating that the lateral prefrontal cortex associated with the top-down regulation. This could imply that the creative process requires resolution between dominant emotional responses and top-down implementation of creative reappraisal ideas. Together, these studies once again support the notation of creativity stemming from the collaboration of brain regions related to cognitive control and spontaneous thought. (Perchtold et al., 2017)

#### **4. Creative individuals and brain activity**

The above research implies that creativity is hinged upon certain brain activation patterns and functional connectivity. However, in order to observe more real-world applications of the neural basis of creativity, several studies have observed the brain activities of those in professional creative occupations, such as the arts, or have otherwise distinguished themselves as creative individuals. According to Chrysikou et al. (2020), eminent creative thinkers from a diverse array of fields with higher CAQ scores, had higher activity in the right supramarginal gyrus and the right transverse temporal gyrus than non-eminent thinkers of similar age and education.

However, non-eminent thinkers had higher activities across a wider range of regions across the DMN and ECN, like the left lingual gyrus, the left frontal pole, the anterior cingulate gyrus, the left parietal cortex, and the posterior cingulate cortex. This indicates that creativity is not linked to an exceptional cognitive process, but rather that the ability to efficiently engage the needed processes and brain regions.

These conclusions parallel another study by Japardi et al. (2018), in which groups of individuals with Big-C type creativity and those of similar IQ and parental education underwent fMRI scans during convergent and divergent thinking tests. Though their task performance did not differ much between groups, there were fMRI differences between the two groups during the divergent thinking task. The Big-C groups had less activation than SCG in frontal pole, right frontal operculum, left middle frontal gyrus, and bilaterally in the occipital cortex. The Big-C group could further be divided.

Specifically, those scientifically inclined (the SCI) showed less frontal and parietal activation, while those visually inclined (the VIS) showed less frontal activation than both the SCI and SCG. However, the VIS showed more activation in the right inferior frontal gyrus and left supramarginal gyrus relative to the SCI. More specifically, these results deemphasize the role of cognitive control during divergent thinking.

## 5. Other Processes

Another explanation of creativity regards high openness to experience. A Big Five personality factor, openness was proportional to time the brain state had positive correlations among the default, salience, executive, and dorsal attention networks. It was established that the effect of openness was specific to the correlated brain states, and that people high in openness who are more likely to engage these networks at the same time at rest. Across two studies, the authors found that openness predicted increased global efficiency within a network composed of DMN nodes and edges, indicating that people high in Openness show greater efficiency of information processing within the DMN (Beaty et al., 2018).

Another resting-state fMRI study found that Openness is related to increased functional connectivity between DMN hubs and regions associated with cognitive control, consistent with task-based fMRI studies reporting functional interactions among these brain regions during tasks involving imagination and creativity. In two studies, openness predicted the global efficiency of a functional network composed of DN nodes and corresponding edges explaining 18% of the variance in DN functioning in one. These findings suggest a biological basis of Openness to Experience, and by extent creativity, lies in the neural networks (Beaty et al., 2015).

Another functional neural network involved in the creative process is the salience network, a region consisting of the anterior cingulate cortex, somatosensory cortex, hypothalamus, amygdala, and temporopolar cortex, and others, that integrates of internal and external stimulus (Jacque & Thomson, 2017). A study found that the creativity of divergent thinking responses was correlated to the functional coupling of the ventral ACC of the salience network and the left angular gyrus, regions involved in cognitive control and self-generated thought. Similarly, another study with a verb generation task corresponded with the activation of the medial prefrontal cortex, (a part of the default mode network), whose coupling with the ventral ACC increased with the semantic separation between the noun and the verb (Beaty et al., 2017). Furthermore, studies that assessed fMRI images during a divergent thinking task found that there was initially greater correlation between the default mode network and regions of the salience network, which facilitate the switch between the default and executive control networks by identifying candidate ideas and forwarding them to the executive control network. (Beaty et al., 2018) fMRI studies found that the PCC was more strongly connected to salience network regions during divergent thinking tasks, and later with executive network regions. Network edges that correlated positively to a high degree of creativity were mostly densely found in the default, salience, and executive control networks, which could be used to predict creative thinking ability.

## 6. Conclusion

Neural creativity research has brought the complicated cognitive mechanisms of the creative brain to light, often through analysis of connectivity of specific regions in relation to specific creative tasks. So far many have been determined, including the dynamic of the executive and default networks, the default network and the IFG, and in relation to personality traits and other major brain networks. Even within these subdivisions, there is still much to be determined about the precise relationship between different parts of the brain and how they activate within different creative contexts.

Whole brain functional connectivity may serve as a predictor for creative ability (Beaty et al., 2018), but there has also been precedent for the neuroscience of creativity being used in creativity training. For instance, the Applied NeuroCreativity program, or ANC, taught at

business schools in Denmark and Canada, integrates the cognitive concepts of creativity, which stem from functional connectivity analyses, before applying these concepts to relevant real world creative problem (Onarheim, B., & Friis-Olivarius, M., 2013).

However, the direct applicability of the role of specific brain regions has yet to be determined. Regardless, as long as there is a neurological basis for creative cognition, it could imply that a creativity could be specifically induced or become an objectively measurable value with a recognized standard of measurement based on the brain activity of specific regions. One limitation of these studies is that they, by nature, take place within an artificial, controlled setting. Though the biological reactions to creative demands may not vary much, the translation of these findings into predictors that produce tangible results as they react with other variables that may be found in more everyday settings, such as a workplace appears to be untested.

One possible resolution may lie in employing more natural tasks and stimuli, such as through the use of virtual reality paradigms, or the integration of collected data on creative individuals to extrapolate their cognitive processes (Nastase et al., 2020). Still, despite the perhaps inscrutable nature of creativity, both inside and outside the laboratory, there is no doubt that to understand this seemingly abstract concept is a prospect worth exploring.

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