11-30-2015

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Neurobiology
Fall 2015 Term Paper
30 November 2015

The Neurobiological Basis of Creativity – An Exploration of the Contributions of Intelligence, Integrated Circuitry, and Circuit Modulation by Neurotransmitters

Many scientists claim that true creative ability is the unique trait which sets humans apart from all other animals (DeFelipe, 2011). Those who wonder how Felix Mendelssohn composed the Overture to a Midsummer Night's Dream at the young age of 17, how Stephen Hawking developed his theory of Hawking Radiation and disproved an entire generation of physicists, or how Charles Babbage invented the computer are yearning to understand the concept of creativity. But in reality, creativity need not be defined by remarkable artistic accomplishments or revolutionary scientific discoveries. Instead, examples of creativity can be seen dating back to ancient times when our ancestors transformed rocks into tools, used berries as dyes, and developed a system of hieroglyphs with which to communicate, one of the first forms of written language. Creativity has been defined as "the ability to produce work that is both novel and appropriate," (Sternberg, 1999). By this definition, creativity could potentially take on many different forms, and yet some experts in the field claim that the trait is quite rare and even requires a number of other attributes such as intelligence, unconventionality, and the ability to think in unique ways, among others (Sternberg, 1999). Then again, many others dismiss this elitist view and claim that creativity is a part of all human intelligence (Vartanian, 2013). It seems more valid to accept the inclusive view of creativity and perhaps concede that humans simply have differing creative abilities. In this case, it would be relevant and interesting to decipher the biological source of human creativity, and the goal of this paper will therefore be to unite the many seemingly disparate types of creativity into one conceptual neurological model.

The study of creativity has historically been an underrepresented topic in both psychological and neuroscientific research until the late 20th century, but there are now numerous competing theories, explanations, and studies which all point to various contributing or even, as some may claim, causal precursors to creativity. Drawing from the framework of a more holistic approach to the problem, authors have argued for the importance of certain personality traits including motivation, perseverance, openness and high levels of imaginative capability (Sternberg, 1999). These perspectives are the results of studies that fall under the umbrella of the psychological approach to creativity, one that focuses on the interplay between personality traits, attitude, and intelligence. The field of neuroscience, however, provides a completely different approach to the creativity question. While this approach is complementary to the psychological method and incorporates many of the same experimental ideas, the results of neuroscientific studies of creativity offer something very different than those of studies based in psychology, namely a biological explanation of creative thought. These studies succeed in using various neuroimaging and pharmacological techniques to determine what happens in the brain during moments of creativity. The ability to take such an abstract concept, one that involves genius and imagination and varies in every single person, and to convert it into a biological mechanism is a novel accomplishment. In this paper I will incorporate both psychological and neuroscientific approaches to argue that creativity requires the contribution of intelligence, integrated functional circuitry, and circuit modulation by various neurotransmitters, namely dopamine and norepinephrine. The outline of this paper will follow the general model provided in figure 1.
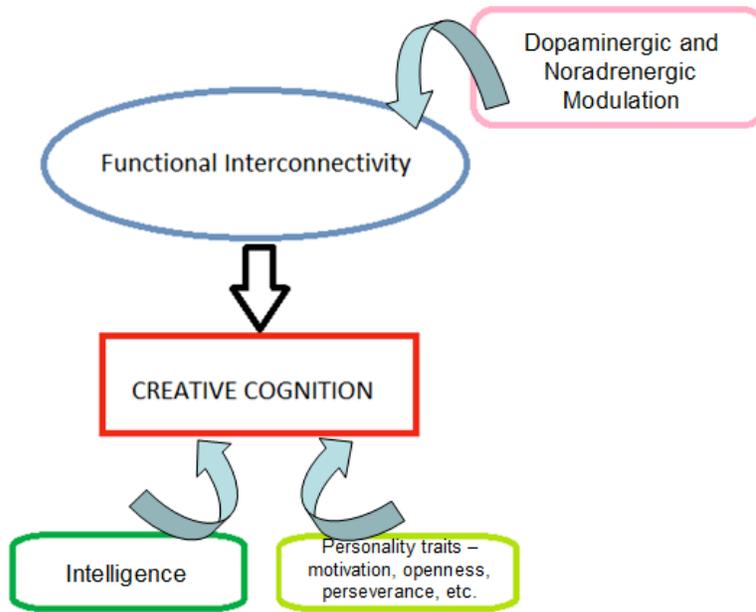
Figure 1. General model for the contributing factors to creative cognition. Intelligence and personality traits give a psychological foundation for creative potential (the dependence on intelligence is more firmly established). Creative cognition, however, is largely determined by the functional integrity of internetwork connections which are in turn modulated by the dopaminergic and noradrenergic systems which act to streamline creative network activity. (Created by Abby Scurfield).

If the specific biological underpinnings of creativity are to be explored, it is first important to establish a brief history of creative thought. To do this we must turn towards evolutionary principles which can speak specifically to the evolution of the human brain and how it differs slightly yet significantly from that of all other species. The most significant development has been that of the neocortex which has grown continually in thickness over time within the *H. Sapiens* species and is the thickest compared to that of all other species (DeFelipe, 2011). The makeup of the neocortex is, however, nearly identical to that of the rest of the brain. There are interneurons and projection neurons, extrinsic and intrinsic fibers, neurotransmitters, excitatory and inhibitory synapses, along with vast amounts of glia and vasculature (DeFelipe, 2011). However, it is well-established that the neocortex houses the most important of our neural

functions, namely those that make us human. Therefore there must be some underlying characteristic responsible for our creativity, imagination, desires, and forethought that has not yet been unveiled.

Based on studies by Franz Nissl and Constantino Von Economo, many believe that a "general connectivity" (GC) ratio can be used to describe cortex density. Von Economo (1926) postulated that the more connections a single neuron possessed, the higher the degree of separation form neighboring cells; this would allow for the formation of more synaptic inputs and neuronal interactions (as cited in DeFelipe, 2011, p. 9). The GC ratio, equal to the average number of synaptic inputs to each neuron, is therefore believed to be positively correlated with intelligence (DeFelipe, 2011). While exceptions to this theory have been illustrated in terms of differences between cortical layers and variability in number of axon terminals, it is a generally accepted predictor of neural ability. Additionally, this theory has been investigated with a focus on dendritic spine volume, another direct correlate of cortical connectivity. The number of densities reflects the potential for excitatory inputs, and the size of the spines can predict the intensity of each signal. It is the variations in these neural components that lend the level of cognitive complexity with which we as humans are so familiar (DeFelipe, 2011).

Now that the evolutionary and gross corticostructural basis for higher intelligence has been discussed, I will next investigate the dependence of creativity on general intelligence. In a discussion on the building blocks of creativity, it makes sense to assume that a baseline level of intelligence is required for creative potential. There have, however, been a number of competing theories regarding the exact role that intelligence plays as a predictor of creative ability. Some researchers have conducted studies that show a positive correlation between intelligence quotient (IQ) and creative ability, essentially a continuum between increasing IQ and heightened creative

ability (Preckel, Holling & Wiese, 2006). Then again, the majority of studies have argued for the existence of a threshold above which intelligence is no longer correlated with creative ability.

Jauk, Benedek, Dunst, and Neubauer (2013) conducted a study to definitively reject or accept the threshold theory of the creativity/intelligence relationship. They recruited 300 subjects, 60% of which had at least 12 years of schooling, and 24% of which held a university degree. To assess intelligence, the researchers used four subsets of the Intelligence Structure Battery. Creative potential was measured by having subjects complete alternate use or three instances tasks which either asked them to state alternate uses for common objects or to provide uncommon solutions to given problems. To analyze the data, the researchers used a linear regression analysis which allowed them to test whether or not there was a significant shift in the correlation pattern. This analysis revealed a significant shift in the correlation between intelligence and creative potential at an IQ of 104 and a shift at an IQ of 119 when researchers investigated overall idea originality (Jauk et al., 2013). These results revealed that the Threshold Hypothesis is in fact valid, but the correlation cutoff point depends on how creativity is measured. Specifically, it is crucial to measure the quality of ideas, not simply the quantity, because the Threshold Hypothesis is best applied to these types of measurement. The hypothesis does not argue for a correlation between intelligence and the number of ideas produced on creativity tasks, but rather the quality of the ideas produced, ones that are deemed truly "creative" (Jauk et al., 2013).

When applied to the idea of creativity in general, these results allow us to hypothesize specific determinants of creative potential; here it is clear that intelligence is an influential factor only until a certain point, specifically an IQ between 100 and 120. Past this point, other factors come into play, likely including personality traits such as openness self-confidence, ambition,

and motivation, among others (Sternberg, 1999). Jauk et al. (2013) also argue that the intelligence-creativity continuum depends on the level of sophistication of the measurement and that perhaps with the most advanced measurement techniques, the correlation could potentially continue through the entire spectrum.

The dependence of creativity, whether creative potential or achievement, on intelligence, personality traits, and motivation has been thoroughly examined, and yet the neurobiological underpinnings of this abstract idea remain somewhat elusive. Neuroscientists have now tried for years, using an array of complex neuroimaging methods, to pin down neural regions specifically associated with creativity. Many studies have revealed areas which show high activation levels during creative tasks, and these have provided the foundation for further investigations. The most commonly identified areas have been distributed regions in the prefrontal cortex, the temporo and frontoparietal junction, and the anterior cingulate cortex (Howard-Jones et al., 2005; Jung et al., 2010; Jung et al., 2009; Takeuchi et al., 2010). However, for the most part, researchers have largely fallen short of their goal to identify discrete neural regions for creativity. For almost all of the structure-centered studies that have been conducted, meta-analyses have uncovered very little result overlap, meaning that it has generally been extremely difficult to identify specific neural regions associated with creative cognition. This finding potentially indicates that the exact neural basis of creativity lies not within isolated brain regions common to every creative person, but perhaps within a different neural mechanism.

Since the relationship between IQ and creativity has been established, it would be logical to posit that the neurobiological basis of intelligence is in turn closely related to that for creativity. The next step, therefore, would be to investigate the underlying neural patterns associated with intelligence and then to relate these back to the likely determinants of creativity.

First it is important to separate intelligence into two subsets – crystallized intelligence (gC) and fluid intelligence (gF). Crystallized intelligence refers to the ability to draw from previous experiences and established skills (usually from long term memory) and apply them to formulate successful solutions to current problems, whereas fluid intelligence requires a higher level of adaptation to think logically and solve problems in novel situations to which previous knowledge cannot be applied (Cattell, 1963). Fluid intelligence is therefore more reflective of true creativity and this is what studies aim to quantify.

Previous experiments have suggested that crystallized intelligence is significantly dependent on structure whereas fluid intelligence is tied largely to neural function (Choi et al., 2008). Choi et al. (2008) carried out an MRI study in which they assessed 225 subjects for IQ and fluid reasoning ability using the Wechsler Adult Intelligence Scale (WAIS) and the Raven's Advanced Progressive Matrices Set II (RPM), respectively. Structural MRI results indicated a significant correlation between cortical thickness and WAIS scores, reflecting hypotheses regarding the GC ratio and intelligence set forth by DeFelipe (2011). When the researchers performed fMRI scans on subjects during a fluid reasoning task, they noted a highly distributed pattern of activity with slightly more intense activation in the prefrontal cortex and frontoparietal region than in other areas. fMRI also revealed a higher covariability with gF than gC. gC was instead highly correlated with measures of regionalized cortical thickness. Furthermore they found that the structural activity correlates were mainly localized to the left hemisphere, indicating a dependence on language and semantic information processing, whereas functional correlates were symmetrically distributed across the cortex, creating a type of cortical network. From these results they gathered that, while there is interplay between structural and functional

measures, gC is dependent on structural properties and gF is dependent on integrated functional activity connecting numerous regions of the frontoparietal cortex (Choi et al., 2008).

Cognitive theory has also provided the field of neuroscience with a significant foundation on which to discern the building blocks of creativity in a stepwise fashion. A significant first step was to establish the mechanisms that allow us, as humans, to hold such complex cognitive ability. Many researchers believe the answer to this mystery lies within cell assembly networks that work together in parallel processing to integrate information across many functional domains (Hebb, 1949). It has long been known that there is some degree of localized functional representation in the brain, namely regions for memory, language, and sensation processing (olfactory bulbs, auditory and visual cortices). There are, however, so many sophisticated human cognitive abilities that have not yet been assigned structural foundations or other neuromechanistic explanations. The neuron assembly phenomenon has been demonstrated multiple times in studies of language and visual processing (Wennekers et al., 2006; Eckhorn et al., 1990), and this has led other researchers to implicate the idea in models of cognition. Pulvermuller, Garagnani, and Wennekers (2014) postulate that the answer to sophisticated human thought lays within the interconnectivity between previously discrete cognitive systems. Functional units of neurons relate information to one another in what are known as distributed neuronal networks (DNAs) or thought circuits (TCs). These circuits interlink information from very disparate brain regions and in turn reduce concept representation overlap as a byproduct. This highly efficient method of information integration is what allows us to develop finely tuned representations for highly specific concepts (Pulvermuller et al., 2014).

The aforementioned studies have established that both intelligence and general cognition are dependent on functional connectivity between seemingly separate brain regions. This finding

indicates that the interconnectedness of many regions is what allows for ingenuity in formulating novel ideas. A logical next step would be to directly relate regional interconnectivity to more precise measures of creativity, and this would require a method of looking at both structure and function simultaneously. This very goal can be accomplished with a technique called diffusion tensor imaging (DTI) which is the only non-invasive method of characterizing the microstructure of neural tissue. Combining this technique with a more general neuroimaging method such as fMRI allows researchers to more closely approach the true neurobiological basis of creativity down to the level of fiber dynamics. Because of the different diffusion properties of water in white matter (anisotropy), the tissue is easily imaged and maps of fiber orientation or continuous trajectories can be constructed (Jones & Leemans, 2011). This neuroimaging method allows for the visualization of circuitry that remains undetectable with other methods such as MRI, PET, or EEG. The ability to relate structural integrity to functional efficacy is crucial to developing an understanding of differential patterns of neural activity for various states of task-based neural demand.

One study discusses the role of 'connectomes,' which are networks with specific structural properties that directly effect functional properties involved in memory and attention-demanding tasks (Hermundstad et al., 2012). To study these 'connectomes,' researchers have combined data gathered from both DTI and fMRI, allowing them to reveal the interplay between structure and function that is so difficult to accomplish. When researchers investigated the dependence on cognitive state using attention and memory-demanding tasks, new patterns arose in which overall functional connectivity increased during attention-dependent tasks and decreased during memory-dependent tasks. Long intrahemispheric connections showed low rsFC even though they were similar in length and number to interhemispheric connections with high

rsFC (Hermundstad et al., 2012). Results demonstrated that both connection length and number are directly correlated to functional connectivity and that spatial location of connections impacts the function of many circuits, both indicating that structural-functional relationships are not static, but vary depending on a number of factors including region and tissue microstructures (Hermundstad et al., 2012).

Aside from general investigations of white matter integrity and its relationship to intelligence, further studies have been conducted in which researchers have specifically examined the correlation between white matter connectivity and creativity. Takeuchi et al. (2010) carried out one of these studies with a group of highly educated students at a Japanese University. The students were first assessed for general intelligence (measured with the Ravens Advanced Progressive Matrices test (RAPM)) and creative ability (measured with a total score from combined category scores of the S-A creativity test). All subjects then underwent DTI scans to elucidate the possible relationship between total scores on the S-A test and white matter integrity. This property was measured using fractional anisotropy (FA), where a result of 0 indicated isotropic diffusion (diffusion of water in all directions) and a result of 1 indicates unidirectional diffusion (Takeuchi et al., 2010). Data analysis revealed strong positive correlations between FA and S-A scores in many white matter regions, the most significant of which were bilateral regions of the frontal lobe and anterior cingulate cortex, regions in and surrounding the bilateral striatum, a stretch of white matter from the frontal lobe to the temporo-parietal junction, and throughout the corpus callosum (Takeuchi et al., 2010).

These results support a number of previous theories that creativity is associated with efficient information integration and diverse high-level cognitive functions (Thagard et al., 2011; Takeuchi et al., 2010). These functions are naturally a product of the frontal regions since the

frontal lobe/prefrontal cortex is the source of so many crucial functions, namely cognitive flexibility, attention, and fluency (the amount of ideas produced) (Eslinger et al., 1993). Aside from the high level of white matter integrity between frontal regions, of particular note is the high S-A/FA correlation in the regions spanning from the frontal lobes to the bilateral striatum because of the modulatory role of the dopaminergic system which will be discussed in more detail at a further point in the paper.

Instead of trying to visualize patterns of neural activity during 'creative tasks,' a better approach to discerning the neurological underpinnings of creative ability may be to study the creative brain at rest. This would provide a more generalized picture of the neural substrates of creativity. Beaty et al. (2014) conducted a study in which they investigated the correlation between divergent thinking ability and resting state functional connectivity with specific focus on individuals with high and low creative ability. The default mode network (DMN) is a pattern of neural activation seen when the brain is idling and includes the medial prefrontal cortex (mPFC), posterior cingulate cortex (PCC), and the bilateral inferior parietal lobes (IPL) (Fox et al., 2005). Questions are arising as to how this network is related to creativity, so that is what this study sought to elucidate. After administering divergent thinking tasks and separating subjects into high and low-creative groups independent of IQ, researchers performed fMRI scans on all participants during an eyes-closed resting state. Results reveal higher functional connectivity between the inferior prefrontal cortex (IPC) and regions of the DMN for the high-creative group compared to that for the low-creative group supporting the role for functional connectivity in people with high levels of creative ability. These results also suggest that cooperation between brain regions associated with controlled and spontaneous cognitive processes may be significantly involved in divergent thinking and, by extent, creativity (Beaty et al., 2014).

From these studies it is evident that creativity is not the result of single regional activation, but rather arises from the functional interconnectivity of many regions distributed throughout the prefrontal cortex as well the cingulate cortex, the striatum, and parietal regions (Takeuchi et al., 2010; Chavez-Eakle et al., 2007). One group of researchers has argued that the exact mechanism of this functional connectivity lies in the mathematical operation of convolution – an integral function that expresses the degree of overlap as one function is overlaid by another (definition from wolfram: http://mathworld.wolfram.com/Convolution.html). Thagard & Stewart (2011) use the original cell assembly hypothesis of Hebb (that cell assemblies are organized by their synaptic connections and are capable of generating complex behaviors) to posit that creativity occurs when cortical activity of old networks combines in just the right pattern to create what is known as the "Aha!" moment (Thagard et al., 2011). Once this occurs, a cascade of new ideas follows as the problem is seen in a new light after the reorientation of the entire pattern of cortical activity. The function of convolution in itself integrates two functions in a way that does not allow for simple deconstruction. In other words, the characteristics of the two original functions are not simply combined to create the new function; they are summated in a nonlinear fashion leading to the development of emergent properties in the resulting function, or in this case, neural network (Thagard et al., 2011). Using the Neural Engineering Framework of Eliasmith & Anderson (2003), Thagard et al., (2011) illustrate that two populations of neurons generating input patterns will act on another group of neurons which then is activated in a way that represents the convolution of the two inputs. Therefore creativity, occurring most often during instances of the "Aha!" moment, can be modeled by the unique convolution of numerous discrete perceptual inputs (Thagard et al., 2011).

I have now established that creative thought is largely dependent on the functional integration of distributed neural regions. This theory has been supported by countless psychological and neuroscientific studies, but there is still something missing, and that is the role of creative circuit modulation by endogenous neurotransmitters. The involvement of dopamine has long been implicated in creativity, imagination, and even psychosis (insert citations), and the role it plays in creativity is a significant one. Revisiting Takeuchi et al. (2010) reintroduces the idea of the stretch of white matter between frontal lobe regions and bilateral striatal areas. Previous studies have succeeded in enumerating the exact roles of dopamine and the functions of this corticostriatal network that it modulates.

Nagano-Saito et al. (2008) conducted a study in which they explored dopamine in the context of this frontostriatal network. Researchers used the Wisconsin Card Sorting Task (WCST) with nineteen subjects to investigate the dependence of task success on the presence of dopamine. The WCST has been used in multiple studies of cognition and functions as a model to elicit neural activity reminiscent of divergent thought which is one of the chosen models for creativity (Beaty et al., 2014, Guilford, 1950). Subjects were first either given a normal health drink or one that was heavily depleted in the dopamine precursors, tyrosine and phenylalanine. This treatment drink acted to decrease striatal dopamine levels by nearly 30%. All subjects then underwent fMRI scanning to deduce differences in functional connectivity while completing the WCST. In the control group, researchers saw that there was a significant increase in functional connectivity between the frontal lobes and striatum during the task compared to baseline, and this phenomenon was largely missing in the group of subjects who drank the dopamine precursor-deficient drink (Nagano-Saito et al., 2008). Even though the network was still activated in the dopamine-depleted condition, the functional connectivity was largely lost, and

this was seen in the increased response times of subjects performing this set-shifting task. Also of interesting note is the finding that control subjects exhibited a deactivation of medial frontal, posterior cingulated, and hippocampal areas, an effect that was not observed in the dopamine-depleted subjects (Nagano-Saito et al., 2008).

From these results, it is clear that dopamine plays a crucial role in the frontostriatal network. Although this particular study did not specifically investigate dopaminergic modulation of this network within the framework of creativity, the WCST is one that naturally recruits many of the same prefrontal areas that have previously been implicated in creativity studies (Takeuchi et al., 2010; Howard-Jones et al., 2005; Choi et al., 2008). Therefore, it is reasonable to postulate that during a creativity or high cognitive-demand task, dopamine acts to potentiate frontostriatal functional connectivity and simultaneously suppresses activity in areas that may compete for attention and potentially decrease performance.

From this previous study, it seems that dopamine may act to create just the right balance between activation and suppression to elicit peak performance on cognitive tasks. If investigated within the framework of a more creativity-geared task, this result is replicated for the most part, but becomes much more complicated. Chermahini et al. (2010) approached the creativity/dopamine relationship by measuring the eye blink rate (EBR) of university students and correlating this measurement to scores on both divergent and convergent thinking tasks. EBR is known to be indicative of striatal dopaminergic functioning (Karson, 1993), and divergent/convergent thinking tasks are established psychometric methods for measuring creative ability (Guilford, 1950). Researchers discovered that the relationship between dopamine and creativity was more complicated than previously perceived. After assessment for general intelligence, participants were then asked to perform an alternate uses task (AUT - used to

measure divergent thinking) and a remote associates task (RAT - used to measure convergent thinking). In the final experiment, researchers combined data from the first three experiments and normalized AUT, RAT, and EBR measurements to gather more powerful results. These analyses revealed that the relationship between convergent thinking and EBR showed a negative linear correlation, whereas the relationship between divergent thinking and EBR manifested as an inverted quadratic correlation (Chermahini et al., 2010).

From this we can see that performance levels on the divergent thinking task are highest during mid-level dopaminergic modulation, and success in convergent thinking is reliant on low levels of dopaminergic circuit modulation, likely mirroring the idea of suppressing competing processes seen in the previous study. The inverted quadratic relationship seen between EBR and divergent thinking points toward the likelihood of an ideal level of dopaminergic modulation above and below which performance, and to extent creativity, is negatively affected. A perfect example of this has been documented for years, and that is the role of dopamine in Schizophrenia. Many studies have provided support for the classical dopamine hypothesis of Schizophrenia which states that the positive psychotic symptoms are caused by the hyperactivity of dopaminergic transmission at the D2 receptor, mainly present in the striatum (Abi-Dargham et al., 2000; Seeman et al., 2000; Bertolino et al., 2000; Van Rossum, 1966). This hypothesis makes sense when juxtaposed with studies of the relationship between dopamine and creativity, because the implications of dopamine in Schizophrenia support the quadratic relationship. Too much dopaminergic transmission or modulation can over activate frontostriatal circuits and cause psychosis (Van Rossum, 1966), clearly supporting an 'ideal level' model of dopamine activity.

Researchers have also investigated the role of the noradrenergic system in creativity and have found a significant modulatory role for norepinephrine. Beversdorf et al. (1999) examined

the involvement of this system in creative performance on cognitive tests. The researchers of this study recruited eighteen university students and administered either oral propranolol or ephedrine (a beta-blocker and stimulant, respectively) before asking subjects to complete tasks dependent on cognitive flexibility, one of the many psychometric measures of creative ability (Zabelina & Robinson, 2010). Data analysis revealed that the anagram task was the only one that showed significant differences in completion times between stimulant, beta-blocker, and placebo treatment groups. The researchers only analyzed data from the best problem solvers for this task to eliminate the floor effect introduced by the psychometric testing scale and found that task performance was significantly higher for the propranolol group than that for the ephedrine group (Beversdorf et al., 1999). They suggest that these results could be the effect of one of two possible mechanisms of noradrenergic modulation: either the drugs could be acting on the adrenergic receptors of the peripheral nervous system and modulating CNS activity by way of feedback mechanisms, or these two drugs could be acting directly on the CNS and modulating cortical activity (Beversdorf et al., 1999). In a follow up study, however, Beversdorf et al. (2002) suggest that, while PNS modulation may be involved, the noradrenergic modulation largely occurs though a CNS-mediated mechanism. Because cognitive flexibility tasks have been used repeatedly as psychometric measurements of creativity, this study succeeded in establishing a role for noradrenergic modulation of networks involved in creativity and further reinforcing the existence of peak performance neurotransmitter level conditions.

After examining the contributions of these two modulatory systems, it is possible to construct a simple model of their actions on general regions of multiple creativity networks. The PFC has been implicated in nearly every one of the studies examined, so the entire area is included in this model instead of separating the PFC into its constituent parts. The studies that

were discussed established both the dopaminergic and noradrenergic modulations of the PFC as

the likely mechanisms by which they influence creative performance (Nagano-Saito et al., 2008;

Chermahini et al., 2010; Beversdorf et al., 1999, 2002), as seen in figure 2. These modulatory

systems act to streamline creative cognition, ensure the avoidance of overstimulation, and

increase functional connectivity between disparate neural regions (Nagano-Saito et al., 2008;
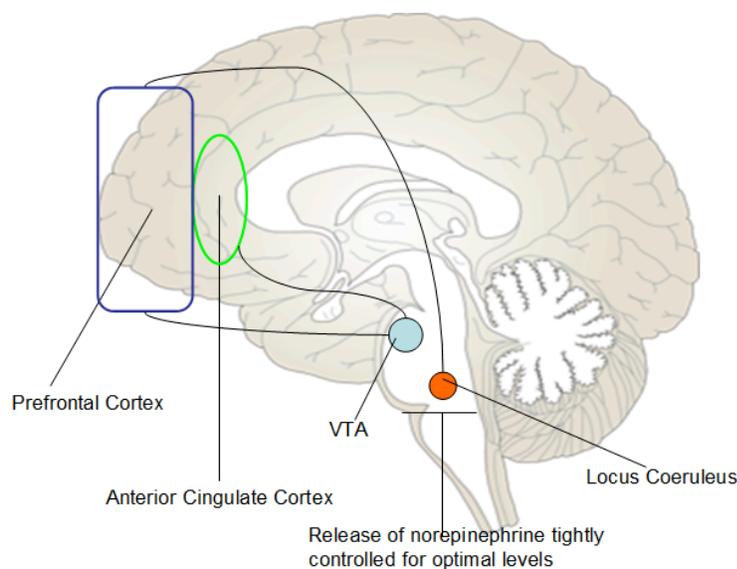
Chermahini et al., 2010; Beversdorf et al., 1999, 2002).

Figure 2. Generalized model of dopaminergic and noradrenergic modulation of creative networks. Dopamine from the Ventral Tegmental Area (VTA) neurons and norepinephrine released by the neurons of locus coeruleus are both directed toward prefrontal areas. Here and in other regions implicated in creative studies (such as the ACC), they selectively modulate creative networks to cause ideal levels of activation and peak creative performance. (Created by Abby Scurfield).

At this point, it is clear that creativity is not the result of neural activation in exactly one

region or even characterized by one specific pattern of activation. Instead, while there are many

regions which have been repeatedly implicated in creativity studies, it is more the functional

connectivity between these regions rather than the singular regional activities themselves that

leads to creative cognition. Intelligence most definitely plays an important role and is likely

positively correlated with creativity throughout the entire IQ spectrum, but authors do point out

that it is very important to distinguish between creative achievement and potential as there could be differing relationships for each (Jauk et al., 2013). Creative cognition is not the result of one mechanism common to every human, but rather the functional interplay between many activated neural regions normally involved in attention, memory, language, auditory, and visuo-spatial processing. Modulation of creative networks by dopamine and norepinephrine plays a significant role in establishing ideal levels of activation in network regions, allowing for peak performance on creative tasks.

While creativity research has come a long way since the 20th century, there remains much to accomplish, especially within a neuroscientific framework. As evident from the lack of discussion in this paper, research on the cellular mechanisms that contribute to creativity is greatly lacking. It would be extremely interesting to go a step further and deduce the cellular basis of imaginative thought, mind-wandering, and bursts of creativity, but the research technique is a limiting factor. Jung et al. (2009) suggests that methodology is in fact the main issue with creativity research. The essential considerations with creativity studies are numerous and include choosing a representative task, identifying a proper population, and using techniques that allow for specific identification of what is trying to be revealed, whether it is structural or functional in origin (Jung et al., 2010). The issue defining creativity carries over to the development of reflective tasks. These psychometric assessments that have been developed to measure creativity are so diverse that it has been nearly impossible to attain replicable or overlapping results when investigating the neurobiology of creativity. There is also still the question of whether supporting evidence for the functional connectivity explanation of creativity reflects truly interconnected networks or multiple isolated contributions to the same problem (Beaty et al., 2014). In the future, more analytical research should be undertaken to first establish

reliable assessments for creativity. Only then can selectively chosen neuroimaging techniques be used to elicit potentially conserved patterns involved in creative cognition and establish the neurobiological basis of creativity.

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