Neuroscience and Art

A Collection of Essays

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CHAPTER

2

The Creative Brain

INTRODUCTION

"You see things; and you say 'why' but I dream things that never were; and I say 'why not'."

—**George Bernard Shaw**

These few lines of George Bernard Shaw beautifully illustrate the basic concept of creativity which essentially is an abstract phenomenon. It is a complex neuro-psycho-philosophical concept which is difficult to define literally. Creativity can be defined as a mental and social process involving the generation of new ideas or concepts, or new association of the creative mind between existing ideas and concepts. Creativity is fueled by the process of either conscious or unconscious insight. An alternative conception of creativeness is that it is simply the act of making something new (*http://www.wikipedia.com*). Recently, Meyers and Gerstman[1] compiled the "unconventional wisdom from 20 accomplished minds" in their book, "Creativity". Here, while a famous American playwright (Edward Albee) comments that "the only thing that separates the creative from the noncreative is the fact that creative people are not content merely to have the experience, but insist on commenting on it"; one famous architect (Daniel Libeskind) writes "I think creativity is something eternal, because it is an encounter with a moment of time—creativity is not only the search for the new, it can be a rediscovery on the newness of thousands of years ago, which is still unsurpassed in some way"; according to a famous author (Erica Jong), "creativity is mysterious... a creative person is someone who sees the world differently, and does not accept that structures that most people unthinkingly accept"; a musician feels "you cannot quite write directions on how to be creative—it is something that just happens because that is what creative people are all about"; and lastly a contemporary artist of much fame (Chuck Close) feels "...The most exciting thing in the visual arts is to see something that actually does not look like art". So you see the divergent views about creativity even among creative people. The reason probably is that creativity (like intelligence) is often domain specific.

The present author particularly likes the concept proposed by Bronowski.[2] Creativity is finding unity in what appears to be diversity. Great art works have a myriad of colors and forms and great musical works have a large variety of melodies and rhythms, but in both paintings and symphonies, the artist is able to develop a thread that unites diverse elements and displays order. Creative scientist such as Copernicus was able to see order in what appeared to be a disorderly solar system and Einstein was able to see the thread that unites matter and energy. Establishing the root of this novel orderly relationship through the eyes of a neuroscientist would be the prime objective of this chapter. In doing so, the author would first make a critical review of proposed concepts of creative cognition, suggest some new ones which the author would try to prove to be essential in the genesis of the cognitive process and would then try to hypothesize on an all embracing conceptual construct for creative cognition and output.

CREATIVITY THEORY

Years ago, Graham Wallas[3] suggested that creativity has four stages—preparation, incubation, illumination, and verification. Preparation is the acquisition of the skills and knowledge that allow a person to create. Einstein developed superb skills in physics and mathematics before he made his discoveries and Pablo Picasso learned to draw forms and mix colors (first from his father and then at art schools in La Coruna, Barcelona and Madrid and later with the older painters of Montmartre, Paris) before he painted his masterpieces. Rabindranath Tagore, though had little formal school education, was educated at home by eminent scholars in Calcutta and later in London and was an avid reader of Indian and Western literature and an astute observer of everything that he saw during his worldwide travels even up to late in his life. That was his "preparation". Interestingly, he never received any formal art training but emerged later in life as a most successful and creative painter (nearly 2000 paintings to match his 2000 songs and innumerable poetries). It was only possible for his keen observation of works of other artists (Indian, Western, and even aboriginal). His "preparation" phase was lifelong.

Is such a preparation phase always needed for creative innovation? Chance discoveries in science are, however, not too uncommon. However, it appears that the scientists (e.g., Archimedes or Sir Isaac Newton) who made such discoveries must have been prepared mentally and intellectually to grasp the significance of these accidental events or chances. It indeed is the "prepared mind"[4] that enables creators to perceive the importance of the phenomenon they observed. It is highly likely that an "incubation phase" of ideas is needed for this "preparedness". The observation and grasping of its significance constitute what is described in psychological literature as the "Aha!" experience. Historically, the author would prefer to call this the "Eureka" experience. This is what—Wallas[3] termed illumination. In science, the hypotheses arrived at need to be proved by experimentation and that is the stage of verification of Graham Wallas.[3] It must be remembered of course that in science, not many discoveries are made accidentally (hence may lack the "Aha" or "Eureka" experience) but result from a series of conscious steps (not just subconscious incubation). Thus, the categorical staging system does not work well in all aspects of the abstract concept of creativity and a general term like "creative innovation" (as proposed by Heilman et al.)[5] may be more easy to understand. The author would try to re-examine the involved issues so far noted and suggest new thoughts.

PREREQUISITES OR PREPARATION

General Intelligence

Intelligence is supposed to be domain specific just like creativity in general. Domain-specific intelligence is difficult to assess. A cricketer who innovated the reverse swing or the reverse sweep or innovates a batting stroke for an odd ball, which is not described in cricketing books, is certainly creative. But he need not have been a "bright" boy at school. However, if you define intelligence as a measure of a person's ability to acquire the knowledge and skill that will allow them to adopt to their environment,[6] a basic level of intelligence would be a prerequisite for any creative endeavor; of course, the relationship may not be a linear one. Barron and Harrington[7] found a weak relationship between creativity of architects and their IQ. They concluded that above an IQ of about 120, the IQ does not predict creativity as much as it does if the IQ is below 120. This suggests that there is an IQ threshold. A person needs to be above the threshold to be intelligent enough to learn and have sufficient knowledge about the domain of their activity. Thus, intelligence is a necessary but not sufficient component of creativity.

Knowledge and Special Talents

A person may have a specific cognitive disorder, e.g., a learning disorder like dyslexia or even autism, but can have creative talents in another field even to the level of a creative genius. Such people are often referred as "savants" and while the possible brain mechanisms of savants would not be discussed at this stage, some concrete examples from history would highlight the point. Writings of Leonardo da Vinci, examined recently,[8] suggest that he probably had developmental dyslexia. However, the world has yet to see such an expression of multidomain creativity as observed in Leonardo. Both Picasso and Einstein most likely suffered from learning disorders.

Thus, general intelligence (which may be unaltered in dyslexia) or what Spearman[9] called the "g" factor alone cannot explain specific disabilities or specific talents and several theories have placed more emphasis on special factors called the "S" factor.

Weisberg[10] concluded that domain-specific knowledge is a prerequisite for creativity. This knowledge in human is generally stored in the posterior neocortex in the region of the inferior parietal lobule (Broadman areas 39 and 40) and the posterior portion of the temporal lobe (area 37). Lesional studies confirm that these areas are important in mediating many higher cognitive activities such as literary skill, mathematics, and spatial computation.

BRAIN STRUCTURE–CREATIVITY RELATIONSHIP

Is it true that larger a particular brain area devoted to a function better if that function performed? Norman Geschwind[11] and his coworkers demonstrated that the left temporal planum, which mediates language, is larger than that on the right and other anatomic asymmetries exist between the right and left brains. Early in the 20th century, it was noted that several mathematicians and physicists had large parietal lobes but little research was done to document this observation until the works on Einstein's brain. Einstein himself thought that the best way to learn brain mechanisms in creativity would be to examine the brains of creative people. So, in accordance with his will, his brain was removed soon after his death in 1955 and was photographed and preserved. The brain subsequently was cut into several (as many as 240) pieces and sent to various institutions in USA and Canada. However, most pieces were lost, and reports from only two centers are available.

Fortunately, the brain was photographed before sectioning, and only in 1999 (that is 44 years after Einstein's death), the findings were made available by Witelson et al.,[12] working at McMaster University in Hamilton, Canada. The photographs show a striking feature. The posterior ramus of the sylvian fissure instead of turning upward behind the postcentral sulcus to divide the inferior parietal lobule into supramarginal and angular gyri actually got continued with the caudal end of the postcentral sulcus. Consequently, Einstein had a large undivided inferior parietal lobule—the area which specializes for mathematical skills and spatial computation. However, this work was criticized by Foundas and her coworkers[13] and thus Einstein's exceptional creativity cannot solely be accounted for by the undivided large inferior parietal lobule. Histological studies on the brain, however, were available earlier (1985).

Diamond et al.[14] performed a histological analysis of both right and left Broadman's area 9 (superior frontal gyrus) and area 39 (angular gyrus) of Einstein's brain and found that compared to controls, area 39 of Einstein's brain contained a higher glial cell-neuron ratio. They thought that this unusual ratio was a response by the glial cells to greater neuronal metabolic need which could have been related to Einstein's unusual conceptual power. This report was severely criticized for methodological reasons. Kantha[15] posited that Einstein had developmental dyslexia and hypothesized that the abnormality reported by Diamond et al.[14] may have been related to Einstein's dyslexia rather than his genius. Heilman and his coworker[5] much later suggested that the high index of glial cells found in Einstein's brain might have indicated a high degree of connectivity. This, as we shall examine later in the article, is closely related to creativity.

PHENOMENON OF PARADOXICAL FUNCTIONAL FACILITATION

Geschwind and Galaburda[16] suggested that the delay in development of left hemisphere (as occurs in dyslexia) may allow the right hemisphere, that mediates spatial computation, to become highly specialized. Einstein's creativity was heavily dependent on spatial reasoning and abnormal development of left hemisphere may have allowed the right hemisphere to become highly specialized for spatial computation. De novo development of artistic or musical skills (which resides in the right hemisphere) has also been described in several patients with left hemispheric dysfunction including frontotemporal dementia.[17] This somewhat paradoxical observation can be explained on the basis of the theory of paradoxical functional felicitation proposed by Kapur.[18] This, Kapur[18] thought, occurs as a compensatory augmentation occurring as a specific manifestation of central nervous system (CNS) plasticity. The present author wishes to call this "Reverse Diaschisis". In diaschisis, as first described by von Monakow in 1914, reduced function of one brain area leads to reduced function of a remote brain area to which it is anatomically connected. The reverse occurs here. Dysfunction of the left brain leads to disinhibited functioning of the right brain.

FURTHER OBSERVATIONS ON BRAIN STRUCTURE AND CREATIVITY RELATION

We do not know whether all creative people harbor specific anatomic differences in areas needed for specialized knowledge. However, specialized knowledge might also depend on a region's cellular organization and neurochemicals found in this region. It may be hypothesized that more neurons that a person is endowed with, greater their ability to learn and store knowledge. However, on the other hand, experimental animals, who were put in an enriched environment and who could learn better, had a thicker cerebral cortex with an increase in number of the dendritic spines[19] that are critical for neuronal connectivity and storage of knowledge. Connectivity thus seemed the most important prerequisite for the creative brain to develop. As we age, our creativity generally diminishes—not so much because of reduction in number of nerve cells but due to reduction in number of synapses, thereby reducing connectivity. The prerequisites discussed in this section prepare the brain for creative concepts and output which in turn is dependent on several factors accounting for creative innovation (incubation and illumination stages of creativity of Graham Wallas).[8]

CREATIVE INNOVATION

Several factors may contribute:

- *Divergent thinking*: Thinking "out of the box" is a major part of creative conceptualization. Novel understanding of a problem and seeking and expressing an orderly relationship is the hallmark of creative conceptualization. Simply speaking, a creative person needs to take a different direction from the prevailing modes of thought or expression, which is called divergent thinking.

  Oliver Zangwell[20] suggested that frontal lobe dysfunction would disrupt divergent thinking. There might be two components to divergent thinking—disengagement and developing alternative solutions. In order to find a creative solution to a problem that has remained unsolved, a person must alter the way by which people have previously attempted to solve the problem. The frontal lobes are essential for this disengagement and shift to new avenues for solution. Cognitive perseveration, the inability to set or change the form of an activity, is often observed following frontal lobe injuries or frontal lobectomies.[20] How the frontal lobes accomplish this, however, remains unknown. Pandya and Kupers[21] demonstrated that the frontal lobes have strong connection to the polymodal and supramodal regions of the temporal and parietal lobes. Perhaps, these connections are important for inhibiting the activated networks that store semantically similar information while exciting or activating the semantic conceptual networks that have been only weakly activated or not activated at all. Activation of these remote networks might be important in developing the alternative solution, so important in divergent thinking.

- *Is subtle frontal lobe dysfunction a necessity for creative innovation?—a hypothesis*: As discussed earlier, frontal dysfunction is detrimental to the creative process. However, the present author feels that some degree of perseverative behavior is needed for creative output as creative scientists and artists are found to produce voluminous output of thematically similar works. However, the dysfunction must be of a subtle nature.

  Claude Monet made some thirty odd paintings of one cathedral in Rome in different weather and lighting conditions.

  Furthermore, especially for creative artists and men of letters, some disinhibition of thought process is often needed. Often, emotions and feeling lose all boundaries in writings and use of colors, which become more and more vibrant and brush strokes more and more bold. When Tagore wrote "I shall flood you with the waves of love" or even "death is like divine to me"—surely these are examples of disinhibited emotion of love and surrendering to God (the present author's translations).

  Thinking a little broadly, it seems likely that subtle frontal dysfunction would be conducive toward divergent thinking and toward novelty seeking behavior and suppression of latent inhibition, as we shall discuss later.

  The other side of the coin is of course, the disinhibited character and manners seen in many poets and artists. Alcoholism, drug use, unkempt appearance, and sexual promiscuity, resulting from disinhibited behavior, are unhelpful to the society. It seems to the present author that the relationship between frontal disinhibitory behavior and creativity is in the form of an inverted "U".
- *Latent inhibition*: It may be described as the capacity of the brain to filter from conscious awareness stimuli previously perceived as irrelevant[22] as measured by various behavioral tests in humans and animals. This construct figures prominently in numerous theories of schizophrenia and it has been demonstrated that reduced latent inhibition is associated in psychotic states or psychotic susceptibility as well as high dopamine (DA) levels.[23] Much of the phenomenology of psychoses includes the formation of association between unrelated or irrelevant stimuli and this has led some researchers[24,25] to speculate that creativity, which involves "original recombinant ideation", may

involve a reduction in latent inhibition. In essence, looking a little broadly, reduced latent inhibition might enhance divergent thinking.

- *Novelty seeking*: Creative people are in general novelty seekers. However, creativity should not be equated always with novelty. If one wears a red shoe in one foot and a green shoe in the other, that is novel but not creative. As the result would be an eyesore and not an esthetic one. Still, novelty in concept is a result of divergent or "out of box" thinking. As mentioned earlier, creative artists, writers, and composers/musicians show a high incidence of alcoholism.[26] On one hand, this suggests a frontally disinhibited behavior and socially looked down upon. However, there is a finer neuro-psycho-pharmacologic side as well. There is some evidence that exposure to novelty activates the mesolimbic DA system of the brain.[27] Increased DA activity is highly rewarding and contributes to the illumination (Aha !) stage of creativity. The densities of DA receptors and transporters in the amygdala (the seat of emotions in humans) are low in alcohol abusers.[28] Hence, alcoholics use alcohol to stimulate DA release from such reduced number of receptors to get the "kick". In the same way, novel ideas stimulate the same receptors to generate the "Aha"! or "Eureka" sensation or feeling.

  Support for the DA hypothesis might come from the case described by Schrag and Trimble[29] where a man with Parkinson's disease (a DA-deficient state) developed previously nonexistent poetic talents (leading to publication and prizes) soon after starting a DA agonist treatment. In other words, he became creative. Moreover, as this patient had left dominant parkinsonism, it seems he had a right dominant pathology. Hence, stimulation of the right brain produced poetic creativity by disinhibiting the left brain which houses the language function. This is similar to the cases described by Miller and others[30] where left brain pathologies like frontotemporal dementias disinhibited right brain function like artistic talents.

- *Connectivity and creativity: Hemispheric dichotomy or harmony*—Creative conceptualization and creative output (incubation and illumination) have already been mentioned in relation to the observations made in Einstein's brain. The brain is organized in a modular fashion—several modules (neural networks) house different talents and capacities. Thus, the understanding, development, and expression of orderly relationship (that is what creativity is all about) might require communication between these modules.

  The strongest evidence for brain modularity is hemispheric localization of functions. The left brain stores language function, motor control of skilled movements, categorical processing, and arithmetic skills. The right brain houses spatial cognition, spatial imagery, face and object recognition, coordinates coding and emotional communication.[31] If you look at any creative work, you may find a harmonious and coordinated functioning of both the hemispheres. Take the simple example of a car driver in a narrow, congested busy road. He needs to be a skillful driver (a left brain function) to have his car unscratched and at the same time have a good spatial concept of the street plan (a right brain function), to choose the path of least resistance to reach his destination in time.

Leonardo da Vinci, excelled in drawing and painting, needed the executive skill of drawing/painting (a left brain function) as well as spatial imagery (a right brain function). He made anatomical and architectural drawing (conceptualization needing right brain and skill needing left brain functions) and made arithmetic calculations (left brain) to support his engineering skills. Einstein was a brilliant mathematician (left brain) but built his theories (relativity and gravitational) on spatially imagined concepts (right brain). Tagore excelled in language (left brain) and in painting (skill from left brain and visual imagery from right brain). So, harmonious functioning of both hemispheres in unison is essential for creative output. Connectivity, thus, is of paramount importance, and the principal structure subserving this connectivity between the two hemispheres is the corpus callosum. Callosal disconnection destroys creativity.[32] However, in addition to having this interhemispheric connectivity, intrahemispheric connectivity is of no less importance. Rabindranath Tagore exhibited multidomain creative excellence. Not only did he excel in poetry and song writing, he showed exceptional talents in prose writing, music, and visual art. In retrospect, he certainly had highly developed domain-specific neural networks in his right brain (in addition to left brain language skills) which obviously were highly interconnected (intrahemispheric connectivity). Such types of individual would be very rare to find and hence no domain-specific lesional studies (within one hemisphere) are available. It is a pity that we have no knowledge about the networking morphology of Tagore's brain. Spearman[9] suggested that creative ideas result from the combination of two or more ideas that have been previously isolated. Or in other words, developing inter- and intrahemispheric connectivity. Novelty and divergent thinking result from utilizing a new neural circuitry than what had been previously used and it may well lie in the other hemisphere.

When Einstein could not solve the mass–energy relationship through detailed mathematical calculations (utilizing his left brain), he took recourse to spatial thinking and computation (right brain function) to solve the mystery and then went back to mathematics. Einstein's creativity was related to his enhanced intra- and interhemispheric connectivity.

SYNESTHESIA AND CREATIVITY: AN EXTENSION OF THE CONNECTIVITY CONCEPT

It is said that Richard Feynman, the Novel prize winning physicist and famous for his very novel and innovative concepts, often started with abstract visual representation of his ideas, which he subsequently translated into mathematical terms. Apparently, the architecture of the networks supporting his visual representation permitted him the manipulative freedom to escape conventional formulations, thereby providing the basis for creative innovation. To the present author, this phenomenon in Richard Feynman sounds very much like synesthetic thought processing. Synesthesia, a positive neurological phenomenon that occurs from early childhood, affects 4% of the population.[33] An otherwise healthy individual has automatic and involuntary experiences in one sensory modality when a different sensory modality is stimulated. It is different for each synesthetic, and examples of these long-term discrete pairings can be simple such as the day "Tuesday" or the letter "F" triggering the experience of light pink, or more complex such as the sound of a middle "C" played on a piano triggering the sensation of a long green solid block spanning in space or the taste of salty burnt chicken. Synesthesia had frequently been reported among poets, novelists, artists, and musicians such as Rimband, Baudelaire, Kandinsky, Nabokov, Scriabin, Messiaen, and Heckney.[33] Theories of its neurological basis include hyperconnectivity[34] or diminished feedback between unimodal sensory areas of the cortex and polymodal integration areas in the temporal lobe.[35] Interestingly, synesthetics perform better on tests of creativity similar to divergent thinking and those who pursue artistic lifestyle often report needing to communicate with these unusual visual experience, through another medium. Olivier Messiaen wrote "...whenever I hear music or even if I read music, I see colors."[36] The present author has a feeling that Rabindranath Tagore probably was a synesthetic as well. He did make a vague comment about it in his conversation with Rani Chanda (*Alapcharita Rabindranath*). Tagore took to painting quite late in life. All his life, he wrote poetry and songs. The present author argues that when he started painting, his own songs and poems continually "played" in his brain (and new songs/poetry as well, as he composed several new ones even while he was deeply engaged in painting) to give rise to color sensation. His paintings are hence so vibrant in color with bold brush strokes and bold borders. He has, of course, red–green color blindness (protanopic probably) and the color "true" red is conspicuously absent in his paintings.

But what may be the possible mechanism of association of synesthesia with creativity. Synesthetes have additional neural activation during the synesthetic experience over and above activation involved in typical mental imagery. For example, the angular gyrus shows greater activation in synesthetes[37] and consistent with its strategic location at the crossroads between the temporal, parietal, and occipital lobes, and is likely to serve in the function of cross-modal association. The synesthetic coactivation in different sensory modes creates a de-focus of attention from just the trigger sensation to another sensation. Broadened cortical activation is also correlated with an increase in ideation productivity and importantly a decrease in fixation that stunts creative thought in typical population.[38] This could explain how synesthetes, who experience an excess coactivation in different areas of cortex continually in everyday life, can have a propensity for high creative thinking abilities. This is significant to the understanding of synesthesia, and creative cognition, because the ability to use one network architecture to represent another is hypothesized to enable escape of constraints in the original network and lead to novel association, solutions, and subsequent pattern formation. The present author feels this is what Heilman et al.[5] referred to as "creativity by metaphor".

AROUSAL, MOOD, AND CREATIVITY

Several scientists have mentioned that they had had the experience of solving many complex scientific problems during sleep or when they were either falling asleep or on awakening. Ramanujam, the great mathematician, is known to having solved mathematical problems during sleep. Kekule, who described the hexagonal structure of the benzene ring, is said to have dreamt of a snake chasing its own tail and Crick is said to have dreamt of two interlocking snakes before he conceptualized the double helix structure of the DNA. How far these are true is not really known and neither it is known how Freud would have interpreted such dreams! The Spanish anatomist Ramon Y Cajal[39] in his book, "Advice for a Young Investigator" advised resting, if a difficult solution cannot be arrived at. High cortical arousal induced by stress is often associated with conscious attempts at problem solving. But this high arousal might suppress the emergence of remote associations which forms the neural basis of divergent thinking and creativity. Lower degree of cortical arousal might allow unusual association to become manifest facilitating creative thinking.[40]

Kraeplin in 1921 was perhaps the first to note that manic-depressive psychosis was often associated with enhanced creativity.[10] Several investigations have reported that many of our most creative writers, composers, painters, and scientists have suffered with depression either bipolar or monopolar. Among the eminent artists showing most probably manic-depression or cyclothymic symptoms were—E Dickinson, Ernest Hemingway, N Gogol, A Strindberg, V Woolf, Lord Byron, JW Goethe, Vincent van Gogh, F Goya, G Donizetti, GF Handel, O Klemperer, G Mahler, R Schuman, and H Wolf.[41]

During his blue period (starting in 1901), Picasso was also very depressed (blue is the color of depression). There are indications that he was looking for a more personal and intimate style, his finances were meagre, and he was worried about his future lest he has to face the miseries like Van Gogh or Cezzane.[42] Rabindranath Tagore suffered from depression from an early age. This is apparent in some of his writings, in his biographies (e.g., that by Prabhat Kumar Mukherjee) and his conversations with Rani Chanda (*Alapcharita Rabindranath*). He lost his mother early, lost his very close sister-in-law, then his own wife, one son and one daughter, his very favorite nephew Balendranath, and lastly in old age his dear grandson. He faced criticisms from his contemporaries, had severe financial difficulty for the educational institution he established, was much aggrieved by the sufferings of his countrymen under the British rule, and was worried for his differences of opinion with other national leaders like Gandhi. Yet he embraced his misfortunes, never blamed anybody and wrote "O cruel Almighty; whatever you have done is good for me; an incense stick does not emit any fragrance unless burnt; a candle does not give light unless lighted" (present author's translation). His life is a vivid example of creating in the midst of depression. How can arousal, relaxation, and depression be related to creativity? The possible link appears to be changes in level of neurotransmitters, and norepinephrine (NE) in particular which is reduced both during sleep, relaxation, and depression. How this may be related to the creative process is discussed in the next section.

CATECHOLAMINES AND CREATIVITY

The roles of two catecholamines have been discussed in relation to creativity—DA and NE. Both are related in the sense that NE is a product of DA metabolism. The possible role of DA had already been discussed in relation to novelty seeking.

As discussed in the previous section, to creativity as stress is associated with high brain NE level. On the other hand, sleep and relaxation being associated with a low NE state enhance creativity. Faigel[43] showed that students taking propranolol, a centrally acting β-blocker reducing effect of NE on neurons, improved performance of students taking the Scholastic Aptitude Test (SAT), which tests both crystallized knowledge and fluid reasoning, that NE modulates cognitive flexibility had also been shown in experiments. That NE modulates involving problem solving after pretreatment with ephedrine and propranolol,[44] and also comparing effect of propranolol and nadolol, a peripherally acting β-blocker.[45] Only central β-adrenergic blockade increased cognitive flexibility.

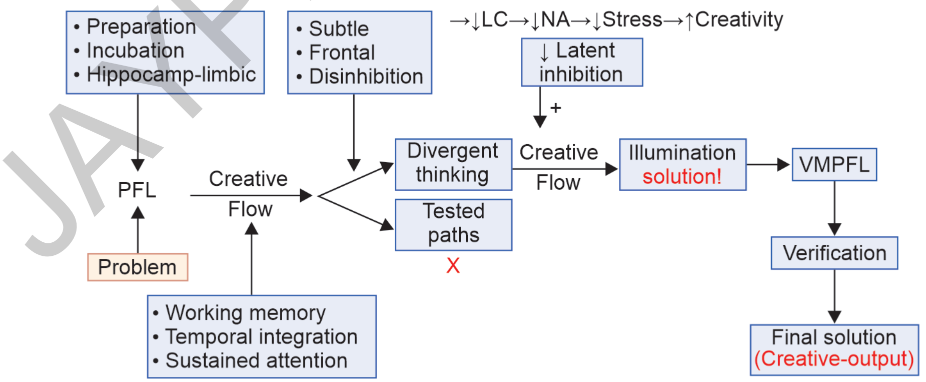
The locus coeruleus (LC) is the richest source which provides NE output to the cortex. Aston-Jones et al.[46] posited that high levels of tonic LC activity, which increases the levels of NE in the cortex, are important for "monitoring and attending to external stimuli and increasing behavioral responsiveness to unexpected and novel stimuli". It is thus needed for the "flight or fight" activities. It follows, therefore, that low levels of LC activity would enhance creative cognition and outputs.

The frontal lobes appear to be able to exert an inhibitory influence on the LC.[47] Hence, frontal disinhibitory behaviors would be nonconducive for creative activity. On the other hand, the author had already postulated that a subtle degree of frontal dysfunction is conducive for creative activity. How does one solve this puzzle? The present author feels that the relationship between frontal disinhibition and LC activity is inverted U-shaped. At low levels of disinhibition, LC activity diminishes providing reduced levels of NE to cortex which facilitates orderly distributed representations (thus enhancing creative thinking) and high level of frontal disinhibition would enhance LC activity with high NE level at cortex which is nonconducive for creativity. An analogy can be drawn from the relationship between mood and creativity concept of where the relationship is also in an inverted "U" form. Elevation of mood facilitates creativity to a certain point beyond which extreme increase has an adverse effect on achievements.[48] Perhaps, the same is true for depression as well.

CREATIVE COGNITION AND OUTPUT: AN ALL EMBRACING CONCEPTUAL HYPOTHESIS

The concept of creativity is an abstract one—a phenomenon of the mind, but it has to be a function of the brain. However, because of its abstract nature and for the fact that creativity is largely a domain-specific behavior, Jacksonian concept of cerebral localization of neurological function and phenomenon cannot be applied here. The seat of creativity is likely to remain undetermined. Neuropsychological tests for creativity can only give a very partial insight into man's creativity and such tests have not been applied to really creative people as we recognize them. Hence, approach to conceptualization has to be somewhat anecdotal as has been made in this chapter. However, based on known functions of different brain areas, a working model of flow of thought processing which ultimately leads to creative cognition and output can perhaps be hypothesized. The output in most forms of creative works is one of problem solving and thinking broadly artists and men of literature possibly make the same endeavor as well.

So we can assume facing a problem to be the trigger for creative cognition to begin. It may be suggested that this process starts in the prefrontal lobe. But surely, along with this, a curious phenomenon also occurs in the prefrontal cortex whereby there is simultaneous subtle suppression of frontal inhibitory behavior. The neural circuitry involved would be complex and it would be difficult to hypothesize on this at the present stage. The creative cognitive thoughts can thus flow uninterrupted because of disinhibition of frontal control on divergent (out of box) thinking and aided by suppression of latent inhibition, as highlighted earlier in this chapter. The latter makes room for the divergently thinking mind to choose from several different paths to problem solving (including unconventional ones) which were not available earlier to others due to frontal inhibitory behavior. This conceptual phenomenon leads to development of novelty—a core feature of most creative works. Continuing challenge from divergent thinking during the creative process would enhance intra- and interhemispheric connectivity (possibly through generation of neurotropic factors with establishment of new synapses) which would further augment divergent thinking and thus self-rewarding. The frontally generated creative cognitive flow would certainly be enriched by other brain areas (like from memory, emotion, output from areas for artistic and mathematical talent, etc.) and then would finally lead to creative output. This likely is also an essentially frontally governed phenomenon. **Flowchart 1** summarizes the present author's hypothetical view on the generation of creative output from thought initiation to the final result.



FLOWCHART 1: Creative flow: A hypothesis.

(PFL: prefrontal lobe; LC: locus coeruleus; NA: noradrenaline; VMPFL: ventromedial prefrontal lobe)

Source: Reprinted with modifications from Chakravarty A. The creative brain—revisiting concepts. Med Hypotheses. 2010;74(3):606-12.

CONCLUDING REMARKS

Why would a clinical neurologist be interested in the process of creativity which essentially is a mental phenomenon having no proved discrete cerebral localization not following the Jacksonian concept that all neurological phenomenon can be localized to a specific area of the brain? Thinking neurologically is a creative act in the same way that thinking artistically, musically, or scientifically is creative. The profession of clinical neurology is an intrinsically artistic endeavor. Finding unity among myriads of diverse symptoms is certainly a creative task as highlighted early in this article. Neurologists may not be able to say where the artistic process is located in the brain, but they can at least have the pleasure of feeling what it is to be creative.

Much of what we have learnt about creativity in general is based on hypotheses. It would be a daunting task even for a creative brain to unravel the mystery of creativity. The present author would tend to disagree with Albert Einstein's view that studying the brains of creative people at postmortem would be helpful. Lots lie in functioning rather than structure. A theoretical solution might be to perform functional imaging studies of creative people at work. This seems impractical at the present state of our knowledge and available technology. One cannot ask an artist to paint or a mathematician to solve a puzzle while lying inside the gantry of an MR scanner. There is certainly a limit to human understanding of the "Language of God".

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(*Reprinted with modifications from Chakravarty A. The creative brain--revisiting concepts. Med Hypotheses. 2010 Mar;74(3):606-12.*)

Neuroscience and Art
A Collection of Essays

Salient Features

- This unique book would be the first of its kind published from an Asian country while only a very few titles are available in the Western world.
- Art is an expression of human creativity that is not observed in any other living creature. The artist expresses his/her experience, idea, thought, and/or opinion on a subject crossing his/her mind or visually or auditorily perceived.
- Through art, it is possible not only to record or describe objects, events, and moments, but also to express feelings, opinions, and attitudes. Modern neuroscience has the privilege to investigate the processes of artistic performance in a healthy brain by means of advanced neuroimaging techniques.
- The first five essays in this book describe in detail but in simple language, the science behind creativity, the scientific basis of the techniques which the artists employ to enhance the aesthetic values of their artworks without having any knowledge about the structure or functions of the brain, and lastly the possible neural pathways involved in both creation and appreciation of visual artworks. An artist is essentially a neurologist or better a neuroscientist.
- The rest of the essays principally discuss the changes in art forms and creativity which happen when talented artists develop some form of neurological diseases including strokes, dementias, and Parkinsonism.
- The book also contains discussions on portrayal of some neurological diseases in art-related media such as literature and films.

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Printed in India

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ISBN 978-93-6616-714-5