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REVIEW

Neuro-Scientific Studies of Creativity

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Creativity has historically been investigated in psychological and educational aspects, and developed by psychologists and educationists. Recent progress of computational and cognitive science has opened new horizons in the neuro-scientific approach, bridging the concept of creativity and specialized brain function. This review discusses the psychological and educational theories of creativity, and focuses on the recent works in neuroscience dealing with creativity in view of divergent thinking. We also summarize the brain areas and their networks found by the neuroimaging studies, especially functional magnetic resonance imaging.

Key Words creativity, neuroscience, network.

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INTRODUCTION

As Homo sapiens, humans have successfully evolved by incarnating sophisticated communications distinctive from other animals, meta-cognition, and conscious behavior, in order to effectively cope with the pressures of the world where the law of the jungle prevails, and the brutal nature where only the fittest survives. As a result, humans take a lead in the development of civilization and the technical innovations as befits "possessor of the wisdom", obtaining firmly the title of 'lord of all creation'. Creativity is suggested as a driving force for the successful construction of the individual cultural system and cooperative social structure of human beings, in spite of infinite competition for survival in the jungle of humans. The creative thinking for adapting an original idea to a real-life setting enables human beings to create civilizations different from other animal worlds. In order to succeed in the struggle for existence and thrive in the socio-cultural system systemically, there is no choice but to be creative at every moment.

The study on creativity has been dominantly conducted psychologically in the field of social science. However, since the brain is suggested as a center for cognitive function including creativity, and as rapid development of computer engineering and cognitive science arises, the brain neuroscientific approach for creativity has recently come into spotlight in the foreign academic society.[1,2] To organize scientific reports and theoretical discourses on creativity, it is necessary to investigate how creativity emerges through the brain. In this review, we collectively review studies on divergent thinking using functional magnetic resonance imaging (fMRI), starting with the definition of creativity and the core of related theories.

DEFINITION OF CREATIVITY AND ITS THEORIES

Creativity has received attention from the academic community since Guilford[3] mentioned its importance as an upcoming core research agenda in psychology during his presidential addresses in 1950 at the American Psychology Association. There were a lot of literature about creativity, including over 9000 articles published between the late 1960s and 1990, and over 10000 articles between 1999 and 2009, in terms of an interdisciplinary view, and about 21000 books registered are

now available at Amazon.com.[4]

There are three stages in the history of the development of theories on creativity.[5,6] First one is the He-paradigm summarized as a 'lonely genius', a traditional view of the creative study. It emphasizes the biogenetic characteristics of great men who generates an outstanding creative thought. This is called creativity for society (H-creativity) compared to creativity for the person (P-creativity). Recently, H-creativity is called "Big-C", meaning a breakthrough creativity changing a specific field at the moment, while P-creativity is called "Little-c", implying a normal level of creativity in daily life. The He-paradigm for creativity arouses the researchers' interest in the life journey and psychological profile of a creative person, highlighting the innate characteristics of creativity and contributing to the expansion of elitism of a small number of geniuses.

The second step of development for creativity is the I-paradigm, summarized as a "creative individual". This perspective emphasized the development of creativity for everyone, rather than for the few gifted. This notion was facilitated in the socio-political context when the United States strengthened its world superpower status under the Cold War system after World War II. The I-paradigm induced scientific approach, facilitating the development of a psychometric device for measuring creativity. In addition, it contributed to democracy in research on creativity, by examining the creativity of normal people. However, it is criticized in that it concentrates on the mental and inner properties of creativity so it leads to reductionism and causes non-historicity and non-contextuality.

The third step of the developmental trend of creativity study is the We-paradigm which underscores distributed and cultural psychological property of creativity. We-paradigm argues that culture and cognition are interrelated. Thus, creativity as a cognitive process is influenced by the social context. This cultural psychological approach argues that He-paradigm and I-paradigm immoderately concentrate on identifying the genetic property and personal construct, leading to a failure to notice the social, historical, and cultural influences on creativity and failing to explain the interdependency between a person and context. In addition, it is suggested that a comprehensive study is necessary, which covers the relationships between self and others, interdependency about the physical and symbolic application of tools, and interactions in the context in order to see social dynamics in creative processing. This implies that creativity does not solely exist in the individual mind, but is distributed and extended outside the mind, and resides in the socio-cultural context and in a relationship with the world.

In spite of the accumulation of various studies and development of theoretical approaches about creativity, there is no brief and clear definition of creativity due to the complexity of psychological constructs. According to several key studies, the core constructs of creativity are defined by 'novelty or originality' and 'usefulness or appropriateness'.[7] Even if a person's idea is original (e.g., it is worth 1000) but its usefulness, in reality, is zero, then creativity does not exist (1000×0). Also, if the idea has a high practicality (e.g., it is worth 1000) but it is not differentiated from the existing idea (resulting value is 0), then too creativity does not exist (1000×0). This indicates that both originality and appropriateness are necessary in the creative process. In addition, another substantial variable is contexts defining creativity. Although an idea is at the zenith of originality and usefulness, if unaccompanied by social receptibility and feasibility of environmental conditions, then creativity does not emerge. In other words, it can be summarized into an equation where creativity (C) is defined by multiplying originality (O) and appropriateness (A) in contexts (Fig. 1)[8] as follows.

$$C=[O\times A]_{context}$$

A conventional way to systemically understand a complex structure of generation and a developmental pathway of creativity is the 4P theory. Each factor of 4P represents a variety of views about the development of theory on creativity. Rhodes, an advocate of 4P theory, did not underline the mutually exclusive properties of the individual P (i.e., People, Processes, Products, environmental Press),[9] while from a view of a holistic approach he argued that according to the situation the four Ps are inter-related, depending on their functional properties and roles. Traditionally, the creative study is interested preferentially in quantifying variables representing psychological factors (e.g., attitude, value, motivation, etc.) of an outstanding creative person (Person). This person's observable product (Product) becomes the focus of psychometric approach. In addition, a socio-cultural approach underscoring the conditions of external environment for the development of individual creativity (Press) is receiving attention, and researches are being conducted on organizational creativity and creative environment scales.[10,11]

Among the 4P factors, many questions require to be addressed regarding the process of generation of creativity (Process), such as through which pathway creativity is generated, or which procedure it emerges through. In psychology, the process of creativity is indirectly measured by two most fre-

$C=[O\times A]_{context}$

Fig. 1. Creativity can be expressed as a function of originality and appropriateness, depending on the context. A: appropriateness, C: creativity, O: originality.

quently used tools: Torrance Tests of Creative Thinking (TTCT)[12] and Remote Associate Tests (RAT).[13] RAT assumes that an original idea is farthest from the associative pathways, and it measures creativity by examining solutions to problems including conventional word association test (e.g., "falling, actor, dust": the answer is "star") and insightful word association test, which can only be solved by few extraordinary people. While the RAT is a single type test, TTCT is composed of verbal and figural types, and both have two parallel forms: A and B. For example, the verbal TTCT consists of six activities, namely asking questions, guessing causes, guessing consequences, product improvement, unusual uses, and supposing. Each activity measures the most important properties of creative thinking in terms of fluency (the number of responses), flexibility (the number of category of responses), and originality (scarcity of the responses). Rather than these psychometric approaches, the neuroscientific approach has been increasingly used for a study on creative processing.[14] The neuroscience perspective of creativity is covered in the following chapter.

NEUROSCIENTIFIC BASIS OF CREATIVITY: fMRI STUDIES ON DIVERGENT THINKING

Major advances in brain imaging techniques have given rise to a rapid growth in neuroscience by providing structural and functional brain images. Creativity has also been investigated by using the brain imaging techniques, producing functional brain image or electrical signals to uncover neural correlates of creative processing by investigating specific brain areas activated during the creativity task. The most frequently used tools are positron emission tomography (PET), electroencephalography (EEG), and fMRI. PET measures oxygen in the blood and consumption of glucose by using a gamma ray, while EEG measures electrical signals generated by neurons in the brain. In fMRI, the regional paramagnetic properties of oxygenated and deoxygenated hemoglobin are detected, measuring the blood flow of the brain associated with neural activity. Compared to PET and EEG, fMRI has advantages in that it is free from radiation exposure and enables repeated scan in seconds, with a higher spatial resolution in millimeters.[1]

Creativity is developed systemically by parallel processing of both divergent thinking (emphasizing on "originality") and convergent thinking (emphasizing on "utility"). Originality is a representative feature of creativity and can be cultivated by divergent thinking, which flexibly generates a novel idea distinguishable from the existing thinking system. Utility is one of the crucial factors of creativity and is organized by convergent thinking which considers applicability and adaptability of a novel idea in a real life, compared to that of the existing one. In this complex character of creativity, originality is the most important component, in that it facilitates a generation of an idea for problem discovery as a start point of problem-solving. In this context, divergent thinking tasks have been employed to promote originality in neuroscientific experiments about creativity. In addition, the high reliability and predictive validity of creative activity has allowed the divergent thinking tasks as proxy measures of creativity, over the past 50 years in psychology.[15]

In the present investigation, we covered five fMRI studies using divergent thinking tasks.[16-19] For a study of the verbal form of creativity, Fink et al.[16] employed four verbal tasks, and observed left frontal cortical activation during the task. Benedek et al.[17] invited generation of ideas based on the given word stimuli. Results showed that divergent thinking was correlated with distributed bilateral brain activation in the left prefrontal cortex and the right medial temporal lobe with deactivation of the right temporoparietal junction, while the generation of new ideas compared to the retrieval of old ideas showed increased activation in the left hemispheric region located in the inferior parietal cortex. For a study of the figural form of creativity, Huang et al.[18] employed the figural TTCT. During visual creative thinking, they observed increased activation in the left middle and inferior frontal lobes with decreased activation in the right middle frontal lobe and the left inferior parietal lobe. In addition, Ellamil et al.[19] recruited students majoring in art and asked the participants to design a book cover. They found that creative generation was associated with activation in the bilateral medial temporal lobe regions, while creative evaluation correlated with bilateral regions in the rostrolateral prefrontal cortex, insula, and temporopolar cortex.

These studies show no consistent results, except for the finding that both the left and right hemispheres of the brain engage in divergent thinking. The discrepancies among previous studies might be due to the difference in tasks and experimental procedures employed in each study. This limitation seems to be inevitable, considering it is almost impossible to approximate an exact human cognition in the setting of the experiment.

The implication of the previous studies is that it provides empirical evidence based on neural correlates of creative processing. Most neuroscientific studies on creativity have focused on biological changes in specific areas of the brain such as frontal, temporal, and subcortical regions. This approach is attributed to the localization of mental function, which is based on phrenology claimed by Franz J. Gall,[20] a German neuroanatomist and physiologist. This view proposed that a

specific activity or ability of a human is localized in certain brain areas, a theory which is reinforced by the split-brain research by Roger W. Sperry.[21] This perspective strengthened a common notion that the left hemisphere is organized for logical thinking while the right hemisphere processes sensible and artistic functions. In addition, the neuroscientific studies suggest that creativity arises in the right brain in terms of divergent thinking or insight which is one of proxy measures of creativity and differentiated from the left-brained measure such as adaptive thinking or convergent attitude, which is gaining interest in the academic society.[2]

In fact, the view of localization on cognitive function is valid in part: the left and right hemisphere dominate language and spatial perception, respectively. However, a recent theory has arisen in the academic society, which suggests that the emergence of cognitive function interconnected with complex psychological constructs in the cerebral cortex (such as creative thinking) are not confined in a certain brain area, but recruit distributed brain areas.[3,4] In other words, cognitive processing can be achieved by cooperative activity among distributed brain networks, including the executive attention network (prefrontal cortex and posterior parietal lobe), the default mode network (medial prefrontal cortex and posterior cingulate or precuneus), and the salience network (ventral cingulate and anterior insula) rather than only by the right hemispheric function, as suggested by aforementioned fMRI studies.

CONCLUSION

The importance of creativity is being emphasized not only as a representative intangible asset contributing to the enhancement of quality of individual life, organizational growth, and national advancement, but also as the spirit of the times which guarantees the sustainable development of the history of mankind. In spite of a great interest in creativity by people of all social strata, scientific reports on the neural mechanism of creative processing are rare. In particular, the domestic academia immersed in the psychometric approach by investigating the complex relationship among factors[22-24] and assessing the validity of a task,[25] yielding relatively insufficient researches on the neural basis of creativity. Considering creativity is a cognitive function as a result of the functioning of the brain, a neuroscientific study on creativity is necessary to secure empirical evidence and to establish a theoretical basis.

The present study overviews the core concepts of theory on creativity, and discusses the fMRI studies examining neural correlates of creativity. The core finding of the previous fMRI studies is that divergent thinking emerges through dynamic interactions between the left and right hemisphere. This is considered as evidence supporting the fact that the brain functions via parallel processing in the frontal cortical regions, and refuting conventional wisdom that the creative process appears based on the right-hemispheric activity. Considering creativity is a complex built up from psychological constructs (e.g., originality, fluency, flexibility, etc.) which are not mutually exclusive, further strict research is needed to uncover how creative processing emerges in the cerebral cortex, based on various problems and different task structures.

Conflicts of Interest

The authors have no financial conflicts of interest.

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REFERENCES

1. Dietrich A, Kanso R. A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychol Bull* 2010;136:822-848.
2. Sawyer K. The cognitive neuroscience of creativity: a critical review. *Creat Res J* 2011;23:137-154.
3. Guilford JP. Creativity. *Am Psychol* 1950;5:444-454.
4. Kaufman SB, Gregoire C. *Wired to Create: Unraveling the Mystreies of the Creative Mind*. New York: Penguin Publishing Group, 2015.
5. Glăveanu VP. *Distributed Creativity: Thinking Outside the Box of the Creative Individual*. London: Springer, 2014.
6. Glăveanu VP. *Thinking through Creativity and Culture: Toward an Integrated Model*. New brunswick: Transaction Publishers, 2014.
7. Runco MA. Creativity. *Annu Rev Psychol* 2004;55:657-687.
8. Beghetto RA, Kaufman JC, Baer J. *Teaching for Creativity in the Common Core Classroom*. New York: Teachers College Press, 2015.
9. Rhodes M. An analysis of creativity. *Phi Delta Kappan* 1961;42:305-310.
10. Amabile T. *Creativity in Context: update to the Social Psychology of Creativity*. Boulder: Westview Press, 1996.
11. Csikszentmihalyi M. Society, culture, and person: a system view of creativity. In: Sternberg RJ, editor. *The Nature of Creativity: Contemporary Psychological Perspectives*. New York: Cambridge University Press, 1988:325-339.
12. Torrance EP. *The Torrance Tests of Creative Thinking: Norms-Technical Manual Figural (Streamlined) Forms A & B*. Bensenville: Scholastic Testing Service Inc., 1998.
13. Mednick SA. The associative basis of the creative process. *Psychol Rev* 1962;69:220-232.
14. Yoruk S, Runco MA. The neuroscience of divergent thinking. *Act Nerv Super* 2014;56:1-16.
15. Runco MA, Millar G, Acar S, Cramond B. Torrance tests of creative thinking as predictors of personal and public achievement: a fifty-year follow-up. *Creat Res J* 2010;22:361-368.
16. Fink A, Grabner RH, Benedek M, Reishofer G, Hauswirth V, Fally M, et al. The creative brain: investigation of brain activity during creative problem solving by means of EEG and FMRI. *Hum Brain Mapp* 2009;30:734-748.
17. Benedek M, Jauk E, Fink A, Koschutnig K, Reishofer G, Ebner F, et al. To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *Neuroimage* 2014;88:125-133.
18. Huang P, Qiu L, Shen L, Zhang Y, Song Z, Qi Z, et al. Evidence for a left-over-right inhibitory mechanism during figural creative thinking

in healthy nonartists. *Hum Brain Mapp* 2013;34:2724-2732.
19. Ellamil M, Dobson C, Beeman M, Christoff K. Evaluative and generative modes of thought during the creative process. *Neuroimage* 2012;59:1783-1794.
20. Zola-Morgan S. Localization of brain function: the legacy of Franz Joseph Gall (1758-1828). *Annu Rev Neurosci* 1995;18:359-383.
21. Sawyer RK. Biology and creativity. In: Sawyer RK, editor. *Explaining Creativity: the Science of Human Innovation*. 2nd ed. New York: Oxford University Press, 2011;157-161.
22. Cho S. Verification of the dynamic interaction among components of creative problem solving. *J Think Dev* 2013;9:47-69.
23. Kang YJ, Lee SM. Construct validation of Torrance tests of creative thinking. *Korean J Psychol* 2010;29:461-488.
24. Sung EH, Kim MS. Gender differences in divergent thinking and creative personality among college students. *Korean J Woman Psychol* 2003;8:71-86.
25. Suh MO. The study of cultural influence on originality scores in TTCT-Figural Form A. *Asian J Educ* 2009;10:171-189.