Creativity and Its Neural Correlates

Koryna Lewandowska

Institute of Economics and Management
Jagiellonian University in Krakow
Krakow, Poland

ABSTRACT

Creativity, understood in terms of the ability to generate original, adequate, potentially useful and feasible solutions for ill-defined and complex problems, is being considered as a very important aspect of human functioning. The growing belief that we are entering the „Conceptual Age", in which creativity will be valued even more, leads to the question of how it can be enhance. Resulting from seeing this ability in an egalitarian way, many training programs were formed, but the knowledge about biological basis and neural mechanisms underlying creative process is fragmentary and rarely taken into consideration. Among scientists there is a consensus that the prefrontal cortex (PFC) is mainly responsible for the creativity. The results of studies conducted using functional magnetic resonance technique (fMRI) also indicate differences derived from training and stimulation with e.g. ideas of others in the pattern of brain activity during performance of tasks requiring creative thinking. Thus, the knowledge from neuroscientific area seems to be useful for developing methods that have a potential to enhance the level of creativity.

Keywords: Creativity, Brain Functioning, Neural Correlates, Creativity Enhancement

INTRODUCTION

The functioning of the human brain can be understood in terms of complex adaptive system (Chan, 2001), which is *characterized by apparently complex behaviors that emerge as a result of often nonlinear spatiotemporal interactions among a large number of component systems at different levels of organization*. Such a dynamic system is able to learn, adapt and evolve. Probably the most striking example of this ability is creativity – process that governs individuals, groups, nations and whole human population to innovative problem solutions and therefore to civilizational, social and cultural progress. Scientific breakthroughs, technology inventions, works of art, new ways of exploring reality and simple amenities of everyday life are all the fruits of human creative mind. Many words were spoken and written about this remarkable feature of our kind, but still some answers are missing. We may intuitively know what creativity stands for but how this process is reflected in brain activity? Or maybe the inverse question - what are the biological, neural mechanisms that generate creativity? – would be the proper one leading to in-depth understanding of this process. What should be noted in the very beginning, just after the question was made, is that there is an obstacle in studying this ability. Creativity itself is a very heterogeneous construct – consisting of many elementary and complex cognitive processes, and resulting in various forms of expression. Nevertheless, these attributes makes it probably the most visible and ultimate sign of human brain viewed through the prism of complex adaptive system that acts as a dynamic whole with capacity to change in reaction to the information coming from its environment. Growing body of literature on neural correlates of creativity reflects its heterogeneity – methods of investigation are strongly differentiated what results in differentiated conclusions. In other words, *test diversity makes it impossible to interpret the different findings across studies with any confidence* (Arden et al., 2010). However, some answers were given and the aim of this article is to present hypothetical and partly unraveled brain mechanisms that underpin creativity – answers that may contribute to further development of techniques that enhance this ability.

THE CONCEPT OF CREATIVITY

As Eric Hoffer said, *Creativity is the ability to introduce order into the randomness of nature*. This quotation is mirrored in the psychological definition of this process, stating that creativity is the ability to generate original, adequate, potentially useful and feasible solutions for ill-defined and complex problems (Sternberg and Lubart, 1996; Lubart, 2001). It is also almost a synonym for the ability to exceed obvious patterns and schemas of thinking, what is reflected in the concept of divergent thinking created by Guilford (1950, 1967). The core idea of divergent thinking is the cognitive process leading to generation of many ideas and potential solutions in spontaneous and unorganized manner, usually in rather short time. The quality of divergent thinking is assessed in relation to four factors of which it is composed: fluency (measured by the number of generated ideas), flexibility (shifts in direction of thinking, explored categories, etc.), elaboration (tuning details of an idea) and originality (new, surprising ideas). The last factor, originality, seems to be creativity *sine qua non* resulting from unusual combination of remote concepts, thoughts and ideas (Mednick, 1962). The divergent thinking is often juxtaposed with convergent thinking understood as a sequence of logical steps leading to only one and correct solution. Although divergent thinking is typically associated with creativity, also convergent thinking plays its role in the emergence of creative behaviour – formulated ideas must be rephrased into one cohesive and clear proposal that is appropriate for the effective problem solution and situational context (Jaarsveld et al., 2012). The interplay of divergent and convergent thinking is clearly present in the creativity process descriptions. For example, in the classical theory of Wallas (1926), convergent thinking seems to be dominant in the first and last phase of the process - preparation (gathering information, defining problem) and verification (evaluation of solution), while divergent thinking is dominant during middle phases - incubation (unaware problem contemplation) and illumination (finding a solution).

Nevertheless, creative mind needs some input information in order to express the outcome of processing. This thought is highlighted by Bogousslavsky (2005), who distinguished three stages of artistic work creation: (1) perception processing related to sensory activity; (2) extraction (delineating major features) and abstraction (synthesizing what has been extracted) related to cognitive activity; (3) execution related to motor activity. This simplified theory emphasizes holistic functioning of the brain. The author, however, pointed out that the frontal lobe is the most important for creativity as the connection between prefrontal (PFC) and tertiary sensory cortices is the biological base for extraction and abstraction, and frontal-anterior subcortical loops underlie motor skills (Kalbfleisch, 2004). Bogousslavsky also depicted the dual role of the frontal lobe in the creativity – both proactive and inhibitory, claiming that disinhibition of frontal cortex is probably crucial for novelty appearance. Visible signs of such disinhibition might be noted in behaviour – more spontaneous and free from conventional restraints. Moreover, unusual perceptual experience, hypomanic traits and impulsive nonconformity are related to the level of creativity (O'Reilly et al., 2001).

But how this novelty is created? Dietrich (2004) proposed interesting theory in which cognitive processes underlying creativity are linked with specific brain structures. Insights leading to creation results from combination of two modes of thought: deliberate or spontaneous, and two types of information: emotional or cognitive. Thus, there are four basic types of mechanisms: (1) deliberate mode combined with cognitive information; (2) deliberate mode combined with emotional information; (3) spontaneous mode combined with cognitive information; (4) spontaneous mode combined with emotional information. In general, process of creativity related to prefrontal activity (mainly to dorsal prefrontal cortex (DLPFC) involved in working memory) operates on knowledge stored in the temporal, occipital and parietal lobes involved in perception and long-term memory.

In deliberate mode of thought, this process is rather rational, organized and in concert with belief system and individual values. Deliberate-cognitive insights emerge when frontal network is activated in order to search task relevant information in memory storage resulting in subsequent recruitment of related neural structures. This kind of insight, most visible in representatives of science, is strongly dependent on expertise and is domain-specific. The hippocampus, due to its role in declarative memory consolidation (Squire, 1992; Squire and Alvarez, 1995), is thought to be recruited in this process. Deliberate-emotional insights are also initialized by frontal network but this time source of information is located in emotional structures storing affective memory – thus, they are not domain-specific due to universality of emotions. This kind of insight can occur during psychotherapy. What is interesting, although amygdala is involved in affective memory formation (Phelps and LeDoux, 2005), the author claims that because of its poor direct connection with DLPFC, insights derived from basic emotions cannot be deliberate. Thus, rather ventromedial prefrontal cortex (VMPFC) and cingulate cortex, related to complex social emotions, are recruited.

In opposition to the deliberate mode, spontaneous insights emerge in a mental state characterized by defocused attention (Bransford and Stein, 1984; Eysenck, 1995). In other words, processed information are not actively selected by the frontal network and therefore are more random. Spontaneous-cognitive insights occur during associative unconscious thinking (thus in phases of incubation and illumination in Wallas' theory). The author marks two structures as probably involved in this process – basal ganglia due to their involvement in implicit and procedural learning, and in action selection and action gating (Chakravarthy et al., 2010) as well as DLPFC, which activity underpin working memory. Spontaneous-emotional insights emerge when strong emotional experience enters consciousness – this experience might be sometimes described in terms of revelation or epiphany and can be subsequently expressed in work of art.

As it can be seen from above-mentioned theories, creativity comprises many different cognitive and emotional processes and properties that work in concert, such as working memory, sustained attention, cognitive flexibility, decision making, judgment of propriety, conflict resolution and others – all ongoing under cultural pressure in specific situational and social context, and in the frame of internalized belief system (Bogousslavsky, 2005; Dietrich, 2004). Thus, this complex process of novelty creation, in most probable way requiring holistic brain functioning, is difficult to capture with scientific methods. Nevertheless, in the next section, reports from studies on neural correlates of creativity are briefly referred.

NEURAL UNDERPINNINGS OF CREATION

Anatomical Structure of Creative Brain

There are only few investigations that concentrates on anatomical brain structure in relation to creativity. In two of them, researchers were interested in gray matter volume. In the first one, three different measures of divergent thinking (drawing fluency, drawing with pre-specified lines and Alternative Uses Test summarized in Composite Creativity Index) and the Creative Achievement Questionnaire were adopted to assess the level of participants' creativity (Jung et al., 2010b). Analysis of structural scans obtained with the use of magnetic resonance imaging (MRI) revealed that Composite Creativity Index is negatively associated with gray matter cortical thickness in the lingual gyrus and positively associated with thickness of right posterior cingulate. It seems that such result might be the effect of used creativity measures, which strongly involve visuospatial processing. In addition, scores in Creative Achievement Index were negatively correlated with the thickness of left lateral orbitofrontal region (OFC; involved in regulation of emotion influence on decision-making; Hooker and Knight, 2006) and positively correlated with thickness of right angular gyrus (involved in visuospatial attention; Seghier, 2013). Second investigation, conducted by Takeuchi et al. (2010a), showed positive correlation between creativity measured in terms of divergent thinking and gray matter volume in right DLPFC, bilateral striata and regions covering substantia nigra, tegmental ventral area and periaqueductal grey. As authors emphasized, such results indicate that creativity is related to the functioning of dopaminergic system. Moreover, results of another experiment (Chermahini and Hommel, 2010) showed that the average level of spontaneous blinking, which is considered to be a clinical marker of dopamine concentration in the brain, is associated with better performance of tasks requiring divergent thinking. In this study, the lowest level of spontaneous blinking was associated with an effective convergent thinking.

Another two investigations were devoted to define relation between creativity and white matter. In both of them diffusion tensor imaging (DTI) was used. Jung et al. (2010a) found an inverse relationship between creative cognition and fractional anisotropy (FA) within left inferior frontal white matter. Interestingly, Takeuchi et al. (2010b) showed positive correlation between FA within bilateral prefrontal cortices, corpus callosum, bilateral basal ganglia, bilateral temporo-parietal junction (TPJ) and the right inferior parietal lobule (IPL). Such result stands in line with the concept of creativity arose on remote ideas integration via white matter tracts passing through association cortices and corpus callosum. In addition, earlier study of Moore et al. (2009) showed positive association between the size of the corpus callosum responsible for interhemispheric communication, and creativity.

Summarizing, results of these four studies lead to subsequent questions. The team of Jung showed that in the case of creativity less is more, especially in the left hemisphere. On the contrary, the team of Takeuchi found that thicker gray and integrated white matter are related to the higher level of creativity, especially in some parts of right hemisphere. Although these results are compatible to some extent, what is the reason for the difference? May it be the characteristic of experimental groups, as the research teams come from different cultures?

Functioning of Creative Brain

Existing body of literature on brain activity during creative cognition clearly differs in used measures, methods and referred results and therefore is difficult to interpret (Arden et al., 2010). However, among researchers there is quite a consensus that creativity depends on inter- and intrahemispheric connectivity as well as on activity of the frontal lobe (Takeuchi et al., 2010b). This conclusion finds its confirmation in the results of some studies. For example, a near-infrared spectroscopy (NIRS) study of divergent thinking measured in relation to schizotypal personality, showed association between creativity and bilateral PFC activation (Folley and Park, 2005). Interestingly, the effect was even stronger for the right PFC in schizotypal group. In another study, conducted with the use of functional magnetic resonance imaging (fMRI), participants were asked to generate stories in creative or non-creative manner in response to presentation of unrelated words (Howard-Jones et al., 2005). When subjects tried to think creatively right PFC was activated. Interestingly, in comparison to non-creative thinking, an increase in activity in the prefrontal areas, including bilateral medial frontal gyrus and left anterior cingulate cortex (ACC) was detected. In study of Carlsson et al. (2000), comparison between highly creative and non-creative individuals was made by analyzing measured regional cerebral blood flow (rCBF). Creative individuals showed increased or unchanged activity in anterior prefrontal, frontotemporal and superior frontal areas, while non-creative group showed mainly decreases. Another interesting investigation was conducted in order to capture the phases of generating and evaluating ideas (Ellamil et al., 2012). In this study participants were designing book cover with the use of tablet compatible with MR scanner. Creative generation was associated with recruitment of parahippocampal gyrus, presupplementary motor area and bilateral IPL. In turn, ideas evaluation was related to increased activity in the dorsal ACC, DLPFC, medial prefrontal cortex (MPFC), TPJ, rostral part of PFC, insula and cerebellum.

Studies conducted with the use of electroencephalography (EEG) also revealed some aspects of neural mechanisms of creativity. For example, Jausovec (2000) reported that creative individuals present more inter- and intrahemispheric EEG coherence than those less creative. Jauk et al. (2012) showed that divergent thinking is characterized by an increase in power of alpha waves in comparison to convergent thinking. The originality of ideas is also accompanied by increase in alpha waves power corresponding to the activity of the left inferior frontal gyrus (Fink et al., 2009). In the experiment of Kounios et al. (2006), the increased power of alpha waves preceded the experience of insight, what corresponded precisely to the ACC activation. Finally, experiments of Jung-Beeman et al. (2004) showed gamma burst in the right anterior temporal lobe preceded by alpha burst in right posterior parietal area related to solving insight problems. It is worth noticing, that increased synchronization of frontal alpha waves is sometimes considered to be a manifestation of increased top-down control and inhibition of processing stimuli that are not task relevant (e.g. Benedek et al., 2011; Fink et al., 2009). The ACC is believed to be involved in this kind of cognitive control enhancement (Lewandowska et al., 2012).

Fascinating conclusions can be also derived from the neurological case studies. For example, in patients with lesions in the MPFC, impairment in originality was observed (Shamay-Tsoory et al., 2011). In turn, lesions in the left posterior parietal (PC) and temporal cortex were related to elevated level of originality in a linear manner – thus, the greater area was damaged, the higher was the level of originality. What is more, reports about the patients suffering from the development of progressive aphasia resulting in enhanced level of creativity expressed in paintings indicate that degeneration of left frontal cortex is combined with increased grey matter volume in right posterior neocortical areas (Seeley et al., 2008). These mechanisms of neural degeneration in left hemisphere and growth in right one seems to be responsible for the liberation of visual creativity that may be observed in these patients.

As it can be clearly understood, it is difficult to interpret all of the above-referred reports in a holistic manner. Nevertheless, the important role of the frontal lobe and right hemisphere in creative cognition might be noticed.

CREATIVITY AS A RESULT OF TRAINING

The question about the differences between individuals performing creative professions such as musicians, designers and painters, and those who perform more prosaic works still remains open as well as the question about source of these differences. Studies conducted so far indicate that some differences may be observed at the level of neural activation. Investigation of Kowatari et al. (2009) showed that in individuals who have undergone professional training (graduates of academy of fine arts) less brain areas were activated than in amateurs during creative task performance. In this study participants were asked to design a pen. In both groups activation was found in right inferior frontal gyrus, prefrontal, visual, inferior temporal and inferior parietal cortices. What is interesting, in professionals activation was observed only in the PFC and PC of the right hemisphere, while in amateurs these regions were activated bilaterally. In addition, also ACC was activated only in amateurs. Furthermore, the level of originality in professionals was positively associated with bilateral activity of PFC, while in amateurs it was negatively associated with PC activation. These results suggest that in professional group increased neural activity characterized lower number of brain structures than in amateur group and the pattern of activity differed between the groups. In addition, the study of Gibson et al. (2008) showed that musicians presented higher level of divergent thinking accompanied by increased activity in frontal cortex than control group. Also experiment conducted by Berkowitz and Ansari (2008) indicated the differences between "creative" professionals and amateurs – during improvisation deactivation of TPJ in musicians was observed and this effect was not present in control group. The authors interpreted this result in terms of attentional shift inhibition.

Was it the long-term training that influenced the pattern of brain activity in professionals or rather innate predispositions characteristic for this group? Studies of Bengtsson et al. (2007) and Limb and Braun (2008) on musical improvisation in two groups of professionals: jazz and classical piano players, revealed a surprising contrast. In jazz musicians, mainly deactivation was found in the regions of lateral OFC, DLPFC and dorsal part of MPFC while the frontal part was activated. In addition, the increased blood flow in the areas of sensory-motor cortices was detected. In turn, in classical musicians increased activation of right DLPFC, premotor and auditory cortex was found. Interestingly, study of de Manzano and Ullen (2012) didn’t reveal any differences in neural activation in classical piano players between playing random notes and improvising. It is worth to notice, that in both cases ACC activation was detected, what wasn’t found in the study involving jazz musicians. These results may indirectly indicate the impact of long-term training – in contrast to the classical pianists, jazz pianists often improvise on stage, what is related to a different way of skills practicing and playing style.

It is rather obvious, that process of learning which took many years affects brain functioning. Proponents of an egalitarian approach to creativity are convinced that not only artists and designers (what is in the centre of elitarian approach), but also representatives of less creative professions can develop an ability to think and act creatively, just like any other ability can be trained and developed. But can the fashionable short creativity trainings cause a positive change? Metaanalysis of such trainings effects done by Scott et al. (2004) brings rather optimistic conclusions. Results of this study indicated improvement in divergent thinking, problem solving, task performance and attitude towards task after training. Interesting investigation was conducted with the use of fMRI technique by Fink et al. (2010). Participants were asked to generate as many alternative uses of presented object as possible. In one of the conditions, they were confronted with ideas of others - this technique is frequently used during creativity trainings and is the core idea of brainstorming. Such cognitive stimulation resulted in enhanced originality and increased activity of right temporo-parietal cortex, bilateral medial frontal and parietal cingulate cortices. Also simpler methods may provide increased originality. For example, bilateral eye movements inducing increased inter-hemispheric interaction (IHI) performed by individuals with strongly lateralized handedness may lead to originality enhancement (Shobe et al., 2009). This effect wasn’t observed in the group of mixed-handers, but they presented significantly higher creativity regardless the eye movement task performance. This report emphasizes the importance of IHI for creativity.

CONCLUSIONS

In the coming *Conceptual Age* (Pink, 2008), creativity is believed to be one of the most important abilities on which organizational human capital value will depend. Thus, activating the creative potential of employees that may result in innovations is becoming more and more important. Assumptions that creative individuals will be the ones most wanted in the labor market, as those on whom economic development is dependent, are arising from some time (e.g. Pink, 2008; Florida, 2010). At the same time, egalitarian approach to creativity became rather dominant in common opinion what can be seen in the amount of creativity trainings. Thus, identifying neural correlates of creativity and potential changes in brain activity patterns due to taken trainings seems to be valuable and in further perspective extremely useful knowledge, that may contribute to the development of efficient creative techniques used in everyday life.

Nevertheless, knowledge about neural basis of creativity is still rather fragmentary. As it was highlighted before, creativity is a complex phenomenon lasting in time, going through the stages, employing many different aware and unaware cognitive and emotional processes, requiring differential skills and properties, and resulting in diversity of expressions, forms and novel solutions. Therefore, creativity seems to be the ultimate manifestation of brain functioning as a complex adaptive system in challenging environment. Moreover, this holistic vision of creative mind is supported by the notion about importance of balanced inter- and intrahemispheric communication leading to the novelty creation. Nevertheless, the need for further scientific meticulous exploration of this area is obvious. Studies that investigate the multidimensional differences between creative stages, types of creative insight, and creative professionals such as painters, musicians, writers, scientists and handymen can benefit in finding the core of creativity and efficient ways of elevating it. What is important and worth to emphasize, such multidimensional approach requires interdisciplinary perspective that combine at least neuroscientific, psychological and management view as well as synthesis of knowledge coming from theory and practice.

REFERENCES

Arden, R., Chavez, R.S., Grazioplene, R., Jung, R.E. (2010). “Neuroimaging creativity: A psychometric view”. BEHAVIOURAL BRAIN RESEARCH Volume 214. pp. 143-156

Benedek, M., Bergner, S., Konen, T., Fink, A., Neubauer, A. (2011). “EEG alpha synchronization is related to top-down processing in convergent and divergent thinking”, NEUROPSYCHOLOGIA Volume 49. pp. 3505-3511

Bengtsson, S.L., Csikszenmihalyi, M., Ullen, F. (2007). “Cortical regions involved in the generation of musical structures during improvisation in pianists”, JOURNAL OF COGNITIVE NEUROSCIENCE Volume 19. pp. 830-842

Berkowitz, A.L., Anasari, D. (2008). “Generation of novel motor sequences: The neural correlates of musical improvisation”, NEUROIMAGE Volume 41. pp. 535-543

Bogousslavsky, J. (2005). “Artistic Creativity, Style and Brain Disorders”, EUROPEAN NEUROLOGY Volume 54. pp. 103-111

Bransford, J. D., Stein, B. S. (1984). “The ideal problem solver”. New York: Freeman

Carlsson, I., Wendt, P.E., Risberg, J. (2000). “On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects”. NEUROPSYCHOLOGIA Volume 38 No.6. pp. 873–85

Chan, S. (2001), Complex Adaptive Systems; MIT, Research Seminar in Engineering Systems, Course Notebook: http://web.mit.edu/esd.83/www/notebook/Complex%20Adaptive%20Systems.pdf

Chakravarthy, V.S., Joseph, D., Bapi, R.S. (2010). “What basal ganglia do? A modelling perspective”. BIOLOGICAL CYBERNETICS Volume 103 No.3. pp. 237-253

Chermahini, S.A., Hommel, B. (2010). “The (b)link between creativity and dopamine: spontaneous eye blink rates predicts and dissociate divergent and convergent thinking”, COGNITION Volume 115. pp. 458-465

De Manzano, O., Ullen, F. (2012). “Goal-independent mechanisms for free-response generation: creative and pseudo-random performance share neural substrates”, NEUROIMAGE Volume 59. pp. 772-780

Dietrich, A. (2004). “The cognitive neuroscience of creativity”, PSYCHONOMIC BULLETIN & REVIEW Volume 11 No.6. pp. 1011-1026

Ellamil, M., Dobson, C., Beeman, M., Christoff, K. (2012). “Generative and evaluative modes of thought during the creative process”, NEUROIMAGE Volume 59. pp. 1783-1794

Eysenck, H. J. (1995). “Genius: The natural history of creativity”. Cambridge: Cambridge University Press

Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., Neuper, C., Ebner, F., Neubauer, A. (2009). “The creative brain: Investigation of brain activity during creative problem solving by means of EEG and fMRI”, HUMAN BRAIN MAPPING Volume 30. pp. 734–748

Fink, A., Grabner, R.H., Gebauer, D., Reishofer, G., Koschutnig, K., Ebner, F. (2010). “Enhancing creativity by means of cognitive stimulation”, *NEUROIMAGE* Volume 52. pp. 1687-1695

Florida, R. (2002), “The Rise of the Creative Class: And How it’s transforming work, leisure, community and everyday life”. New York: Perseus Book Group

Folley, B.S., Park, S. (2005). “Verbal creativity and schizotypal personality in relation to prefrontal hemispheric laterality: a behavioral and near-infrared optical imaging study”, SCHIZOPHRENIA RESEARCH Volume 80 No.2–3. pp. 271–282

Gibson, C., Folley, B.S., Park, S. (2008). “Enhanced divergent thinking and creativity in musicians: A behavioral and near-infrared spectroscopy study”. BRAIN AND COGNITION Volume 69. pp. 162-169 Howard-Jones, P.A., Blakemore, S.J., Samuel, E.A., Summers, I.R., Claxton, G. (2005). “Semantic divergence and creative story generation: and fMRI investigation”, COGNITIVE BRAIN RESEARCH Volume 25. pp. 240-250

Guilford, J.P. (1950). “Creativity”, AMERICAN PSYCHOLOGIST Volume 5 No.9. pp. 444–454

Guilford, J.P. (1967), “The nature of human intelligence”. New York: McGraw-Hill

Hooker, C.I., Knight, R.T. (2006), “The role of the lateral orbitofrontal cortex in inhibition”, in: The orbitofrontal cortex, Zald, Rauch (Ed.). pp 307-324

Jaarsveld, S., Lachmann, T., Van Leuven, C. (2012). “Creative reasoning across developmental levels: convergence and divergence in problem creation”, INTELLIGENCE Volume 40. pp. 172-188

Jauk, E., Benedek, M., Neubauer, A.C. (2012). “Tackling creativity at its roots: Evidence for different patterns of EEG alpha activity related to convergent and divergent task processing”, INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY Volume 84. pp. 219-225

Jausovec, N. (2000). “Differences in cognitive processes between gifted, intelligent, creative, and average individuals while solving complex problems: an EEG study”. INTELLIGENCE Volume 28. pp. 213–237

Jung, R.E., Grazioplene, R., Caprihan, A., Chavez, R.S., Haier, R.J. (2010a). “White matter integrity, creativity, and psychopathology: disentangling constructs with diffusion tensor imaging”. PLOS ONE Volume 5 No.3. pp. e9818

Jung, R.E., Segall, J.M., Bockholt, J.H., Flores, R.A., Smith, S.M., Chavez, R.S., Haier, R.J. (2010b). “Neuroanatomy of creativity”, HUMAN BRAIN MAPPING Volume 31 No.3. pp. 398–409

Jung-Beeman, M., Bowden, E.M., Haberman, J., Frymiare, J.L., Arambel-Liu, S., Greenblatt, R., Reber, P.J., Kounios, J. (2004). “Neural activity when people solve verbal problems with insight”, PLOS BIOLOGY Volume 2 No.4. pp. 500–510

Kalbfleisch, M.L. (2004). “Functional neural anatomy of talent”. THE ANATOMICAL RECORD PART B THE NEW ANATOMIST Volume 277. pp. 21-36

Kounios, J., Frymaire, J.L, Bowden, E.M., Fleck, J., Subramaniam, K., Parrish, T.B. (2006). “The prepared mind: neural activity prior to presentation predicts subsequent solution by sudden insight”, PSYCHOLOGICAL SCIENCE Volume 17. pp. 882-290

Kowatari, Y., Lee, S.H., Yamamura, H., Nagamori, Y., Levy, P., Yamane, S., Yamamoto, M. (2009). “Neural Network involved In artistic creativity”, HUMAN BRAIN MAPPING Volume 30. pp. 1678-1690

Lewandowska K**.,** Wachowicz B**.,** Beldzik E., Domagalik A., Fafrowicz M., Mojsa-Kaja J., Oginska H., Marek T. (2012), “A New Neural Framework for Adaptive and Maladaptive Behaviors in Changeable and Demanding Environments”, in: Neuroadaptive Systems: Theory and Applications, Fafrowicz, Marek, Karwowski, Schmorrow (Eds). pp. 43- 67

Limb, C.J., Braun, A.R. (2008). “Neural Substrates of Spontaneous Musical Performance: An fMRI Study of Jazz Improvisation”, PLOS ONE Volume 3 No.2. pp. e1679

Lubart, T. I. (2001). “Models of the creative process: Past, present, and future”, CREATIVITY RESEARCH JOURNAL Volume 13. pp. 295–308

Mednick, S.A. (1962). ”The associative basis of the creative process”. PSYCHOLOGICAL REVIEW Volume 69 No.3. pp. 220-232

Moore, D.W., Bhadelia, R.A., Billings, R.L., Fulwiler, C., Heilman, K.M., Rood, K.M.J., Gansler, D.A., (2009). “Hemispheric connectivity and the visual-spatial divergent thinking component of creativity”. Brain and Cognition Volume 70, pp. 267–272

O’Reilly, T., Dunbar, R., Bentall, R. (2001). “Schizotypy and creativity: an evolutionary connection?”. PERSONALITY AND INDIVIDUAL DIFFERENCES Volume 31 No.7. pp. 1067-1078

Phelps, E. A., LeDoux, J.E. (2005). “Contributions of the amygdala to emotion processing: From animal models to human behaviour”. NEURON Volume 48. pp. 175–187

Pink, D.H. (2008). “A whole new mind”. London: Marshall Cavendish Business

Scott, G., Leritz, L.E., Mumford, M.D. (2004). “The effectiveness of creativity training: a quantitative review”, CREATIVITY RESEARCH JOURNAL Volume 16 No. 4. pp. 361-388

Seeley, W.W., Matthews, B.R., Crawford, R.K., Gorno-Tempini, M.L., Foti, D., Mackenzie, I.R., Miller, B.L. (2008). “Unravelling Bolero: progressive aphasia, transmodal creativity and the right posterior neocortex”, BRAIN Volume 131 No.1. pp. 39-49

Seghier, M.L. (2013). “The angular gyrus multiple functions and multiple subdivisions”, THE NEUROSCIENTIST Volume 19. No.1. pp. 43-61

Shamay-Tsoory, S.G., Adler, N., Aharon-Peretz, J., Perry, D., Mayseless, N. (2011). “The origins of originality: the neural bases of creative thinking and originality”, NEUROPSYCHOLOGIA Volume 49. No.2. pp. 178-185

Shobe, E.R., Ross, N.M., Fleck, J.I. (2009). “Influence of handedness and bilateral eye movements on creativity”, BRAIN AND COGNITION Volume 71 No.3. pp. 204-214

Squire, L.R. (1992). “Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans”, PSYCHOLOGICAL REVIEW Volume 99. pp. 195–231

Squire, L.R., Alvarez, P., (1995). “Retrograde amnesia and memory consolidation: A neurobiological perspective”, CURRENT OPINION IN NEUROBIOLOGY Volume 5. pp. 169–177

Sternberg, R.J., Lubart, T.I. (1996). “Investing in creativity”, AMERICAN PSYCHOLOGIST Volume 7. pp. 677–688

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., Kawashima, R. (2010a). “Regional gray matter volume of dopaminergic system associate with creativity: evidence from voxel-based morphometry”. NEUROIMAGE Volume 51 No.2. pp. 578-585

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., Kawashima, R. (2010b). “White matter structures associated with creativity: evidence from diffusion tensor imaging”. NEUROIMAGE Volume 51 No.1. pp. 11-18

Wallas, G. (1926), “The art of thought”. London: Jonathan Cape