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The Neuroscience of Creativity (Structure and Emotion)

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Discovering the Cadenza

Why Cadenza?

The cadenza represents musical freedom, creativity, improvisation. A structure is provided but does not place rigid boundaries on the artist. In literature studying creativity it is defined as the generation of novel, useful ideas [1]. Musical improvisation is a form of creativity in a musical context. It requires the real-time generation and evaluation of melody and rhythm. It is one of our most complex cognitive tasks. Studying this task neuroscientifically is no less complicated. How is it we measure the result of musical improvisation, musical creation, the making of something new? What happens in our brain during? After? How does musical creativity change the brain?

History of the study of creativity

Methodology to investigate spontaneous musicality has rapidly developed from psychological ponderances to functional magnetic resonance imaging. Jeff Pressing was the first to meaningfully articulate an “explicit cognitive formulation” to facilitate understanding and investigation of musical improvisation (note – musical creativity and improvisation will be used interchangeably for the remainder of this review). He required that “any model of improvisation must explain three things: how people improvise; how people learn improvisational skill; and the origin of novel behavior” [2]. In short, improvisation is an acquired skill (it must be learned). Does musical improvisation have to be a professionally trained jazz pianist soloing over a ii, V, I chord change? That may be what Pressing had in mind, but improvisation, for the purpose of this review, includes any generation of novel music. Current research supports the idea that we are innately creative, improvisational creatures [3]. For as any "non-artists" that have tried their hand at painting knows; creativity does not require exceptional performance. Even amateur improvisation is improvisation.

What goes on in your brain when you're making music?

With the real-time imaging techniques we have at our disposal, investigation of creativity has never been more accessible. Resulting from this accessibility is a plethora of data produced from varying techniques and experimental designs. Previous literature takes approaches ranging from EEG (a macro-scale technique measuring electrical changes on the scalp) to pharmacological targeting (altering neurotransmitter/neuromodulatory systems) to fMRI (measuring metabolic activity within the brain) to investigate the process of creativity [4, 5, 6]. Using fMRI, Boccia et al. found pathways and regions correlated with different modes of creativity (musical, verbal, and visuo-spatial) using a collection of imaging studies [7]. Taking seven fMRI studies, with 100+ participants total, they reported regions consistently activated across experiments. Studies selected had one condition of musical improvisation (i.e., experimental group) and one condition in which participants reproduced a conventional, pre-written piece of music (i.e., control group). Additionally, the authors note that "studies on artistic creativity enrolled professional artists, such as pianists, or subjects with artistic training". They found eleven regions, spanning across all four cortical lobes, that were active during improvisation. Their findings demonstrate how creative processes are not localized to a single brain area. Together, these regions form a neural network (also called a cognitive network). Neural networks are discrete populations of neurons spatially dispersed, but temporally synchronized; a neural network is composed of neuronal ensembles responsible for our higher cognitive functions (such as creativity) [8].

Creative Networks

In the literature of creativity, most often discussed is the default network (or DN). The DN is linked to internal thought, mind-wandering, and a loss of self-awareness. Tasks externally driven lead to lower activation of the DN [10]. Therefore, it is believed that the DN manufactures self-generated thought independent of outside stimuli (i.e., sensory stimuli from the environment). Internal mental activity does not equate to passivity though, as was once proposed [9]. Rather, activation of the DN is predicated on the “need to actively self-generate mental contents in order to arrive at the desired goal” [6].

Studies investigating the neural correlates of creativity demonstrate activation of key nodes in the DN. Shofty et al. employed direct brain stimulation to investigate a link between creative thought and the DN [9]. In a domain-general participant group (participants were not professional musicians), the alternative use task (or AUT) was used to measure creativity. The AUT asks participants to provide alternative uses to everyday objects, assessing creative thinking [11]. Consenting participants undergoing open brain surgery for tumor removal were stimulated at a region within the DN or a region outside the DN, while completing an AUT. They found that stimulation of the DN node increased the originality score of the participants, while stimulation outside the DN did not alter creative thinking. This unique approach to investigating creativity provided the first evidence of the DN contributing to creative thinking.

Another network involved in creative cognition is the executive network (EN; also called the executive-control network, or just control network). The EN is active when attention is diverted externally [12]. EN has no discrete role in generating creativity on its own. The executive network's role in creativity is predicated on its interaction with the DN.

EN X DN Crosstalk

This interaction - between the DN and EN - mediates attention between endogenous (internal cognition) and exogenous (externally driven) stimuli [13]. The DN and EN work in tandem to produce and filter creative cognition, respectively [6]. Besides creative cognition, collaboration between the DN and EN is observed in several other cognitive processes [14].

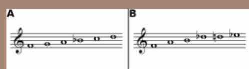
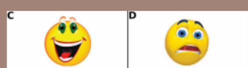
Domain-general creative cognition can be measured using divergent thinking paradigms. One study found the creative quality of responses to correlate to increased connection between nodes in the default and executive network [15]. This finding is consistent with recent literature, supporting the notion that DN and EN interplay facilitates creative thought.

It has been established that creative thought involves two steps: idea generation (usually associated with the DN) and idea evaluation (usually associated with the EN) [16]. Artistic performance (or domain-specific cognition) follows the same activation patterns as domain-general cognition but with more nuance. Pinho et al. takes this work a step further by manipulating the goal of the creative task [17]. Professional pianists were instructed to improvise with either a certain emotional content (happy/sad) or with a certain key (F# minor). Key nodes of the executive and default network activated differentially depending on the creative task. An upregulation of default network regions is associated with increased internal mental activity. On the other hand, an upregulation of executive network activity (the regions comprising this network) is associated with the consideration of external stimuli by the participant. They found that the activation of the DLPFC (a key node of the executive-control network) was decreased in the emotional condition. From our understanding of the EN, we can assume that musical improvisation guided by emotions is less restricted by the top-down control (i.e., consideration of external stimuli) of the EN. The complexity of the process of creativity makes its neural correlates complex by nature. This research illustrates that creative cognition involves different neural networks, to different degrees, under different creative circumstances. Taking these results together, and as we further our understanding of higher order cognitive processes, we begin to understand more about ourselves and what parts of our brain give rise to creativity.

Music changes lives

Musical creativity involves interactions between functionally distinct groups of neurons in different locations. It is complex. Technical analysis of creativity is fascinating, but why do research on musical creativity? When the research is looked at, what do we see? I see a world where music becomes a therapeutic intervention. Because beyond the anatomy and imaging techniques, music can change lives. Improving academic performance, inspiring workplace and societal engagement, encouraging patients during rehabilitation from brain injury, providing an emotional outlet for neurotypical and neurodivergent youth alike are all avenues of musical intervention [18,19,20]. The list of potential therapeutic applications of music goes on. Doing technical, quantitative research on processes such as musical creativity legitimizes them as alternative therapeutic options in the future - potentially giving options to patients who might otherwise not have any options at all.

Results (adapted from Pinho et al., 2016)

Goal of Creative Task	**Activity** (as compared to opposite condition)	**Functional Connectivity** (to the right DLPFC)
Pitch-set Conditions  	• bilateral DLPFC (right & left) • PMD (motor area) • bilateral parietal lobes	• rDLPFC ◦ premotor network ▪ bilateral PMD ▪ motor cortices ▪ rCerebellum • lDLPFC ◦ no significant findings
Emotional Conditions  	• lDMPFC • bilateral insulae • occipital lobe	• rDLPFC ◦ several DN regions ▪ MPFC • lDLPFC ◦ resembles rDLPFC connection pattern

Slide from capstone presentation illustrating the differential activation between the executive and default networks during different creative tasks.

REFERENCES

1. The Standard Definition of Creativity, (available at https://www.tandfonline.com/doi/epdf/10.1080/10400419.2012.650092?needAccess=true&role=button).
2. Pressing, J., 1988. Improvisation: methods and models. In: Sloboda, J.A. (Ed.), Generative Processes in Music: The Psychology of Performance, Improvisation, and Composition. Clarendon Press, Oxford, pp. 129–178.
3. Hambrick, D. Z. *et al.* Deliberate practice: Is that all it takes to become an expert? *Intelligence* **45**, 34–45 (2014).
4. Jia, W. & Zeng, Y. EEG signals respond differently to idea generation, idea evolution and evaluation in a loosely controlled creativity experiment. *Sci Rep* **11**, 2119 (2021).
5. Beversdorf, D. Q., Carpenter, A. L., Miller, R. F., Cios, J. S. & Hillier, A. Effect of propranolol on verbal problem solving in autism spectrum disorder. *Neurocase* **14**, 378–383 (2008).
6. Andrews-Hanna, J. R., Smallwood, J. & Spreng, R. N. The default network and self-generated thought: component processes, dynamic control, and clinical relevance. *Ann N Y Acad Sci* **1316**, 29–52 (2014).1.
7. Boccia, M., Piccardi, L., Palermo, L., Nori, R. & Palmiero, M. Where do bright ideas occur in our brain? Meta-analytic evidence from neuroimaging studies of domain-specific creativity. *Front Psychol* **6**, 1195 (2015).
8. Yeo, B. T. T. *et al.* The organization of the human cerebral cortex estimated by intrinsic functional connectivity. *J Neurophysiol* **106**, 1125–1165 (2011).

9. Shofty, B. *et al.* The default network is causally linked to creative thinking. *Mol Psychiatry* **27**, 1848–1854 (2022).1.

10. The human brain is intrinsically organized into dynamic, anticorrelated functional networks | PNAS. https://www.pnas.org/doi/10.1073/pnas.0504136102.

11. Guilford, J. P., Christensen, P. R., Merrifield, P. R., & Wilson, R. C. (1978). Alternate uses: Manual of instructions and interpretations. Orange, CA: Sheridan Psychological Services.1.

12. Seeley, W. W. *et al.* Dissociable Intrinsic Connectivity Networks for Salience Processing and Executive Control. *J. Neurosci.* **27**, 2349–2356 (2007).

13. Bressler, S. L. & Menon, V. Large-scale brain networks in cognition: emerging methods and principles. *Trends in Cognitive Sciences* **14**, 277–290 (2010).

14. Experience sampling during fMRI reveals default network and executive system contributions to mind wandering | PNAS. https://www.pnas.org/doi/10.1073/pnas.0900234106.1.

15. Mayseless, N., Eran, A. & Shamay-Tsoory, S. G. Generating original ideas: The neural underpinning of originality. *Neuroimage* **116**, 232–239 (2015).

16. Finke, R. A., Ward, T. B. & Smith, S. M. *Creative cognition: Theory, research, and applications*. vi, 239 (The MIT Press, 1992).

17. Pinho, A. L., Ullén, F., Castelo-Branco, M., Fransson, P. & de Manzano, Ö. Addressing a Paradox: Dual Strategies for Creative Performance in Introspective and Extrospective Networks. *Cerebral Cortex* **26**, 3052–3063 (2016).

18. Guhn, M., Emerson, S. D. & Gouzouasis, P. A population-level analysis of associations between school music participation and academic achievement. *Journal of Educational Psychology* **112**, 308–328 (2020).
19. Thaut, M. H. *et al.* Neurologic Music Therapy Improves Executive Function and Emotional Adjustment in Traumatic Brain Injury Rehabilitation. *Annals of the New York Academy of Sciences* **1169**, 406–416 (2009).1.
20. Rickson, D. J. Instructional and Improvisational Models of Music Therapy with Adolescents Who Have Attention Deficit Hyperactivity Disorder (ADHD): A Comparison of the Effects on Motor Impulsivity. *Journal of Music Therapy* **43**, 39–62 (2006).