Musical Creativity and the Brain

By Mónica López-González, Ph.D., and Charles J. Limb, M.D.

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Editor's note: On the spot, as great jazz performers expertly improvise solo passages, they make immediate decisions about which musical phrases to invent and to play. Researchers, like authors Mónica López-González and Dana Foundation grantee Charles J. Limb, are now using brain imaging to study the neural underpinnings of spontaneous artistic creativity, from jazz riffs to freestyle rap. So far, they have found that brain areas deactivated during improvisation are also at rest during dreaming and meditation, while activated areas include those controlling language and sensorimotor skills. Even with relatively few completed studies, researchers have concluded that musical creativity clearly cannot be tied to just one brain area or process.

Article available online at http://dana.org/news/cerebrum/detail.aspx?id=35670

While working with young jazz soloists, Miles Davis once said, "Play what you hear, not what you know."[1] Practice, experience, and sheer talent taught Davis that a personally and socially satisfying gig occurs when the ideas entering the musician's imagination are developed through solo improvisations instead of ignored in favor of practiced patterns.[1] Simply put, no one wants to pay for and hear a contrived performance. Both the fascination we have with the art of in-the-moment creation and the value we place on it continue to flourish. Contemporary artists as varied as pianist Keith Jarrett, vocalist Bobby McFerrin, and rapper Eminem make their living off of improvising and regularly pack concert venues.

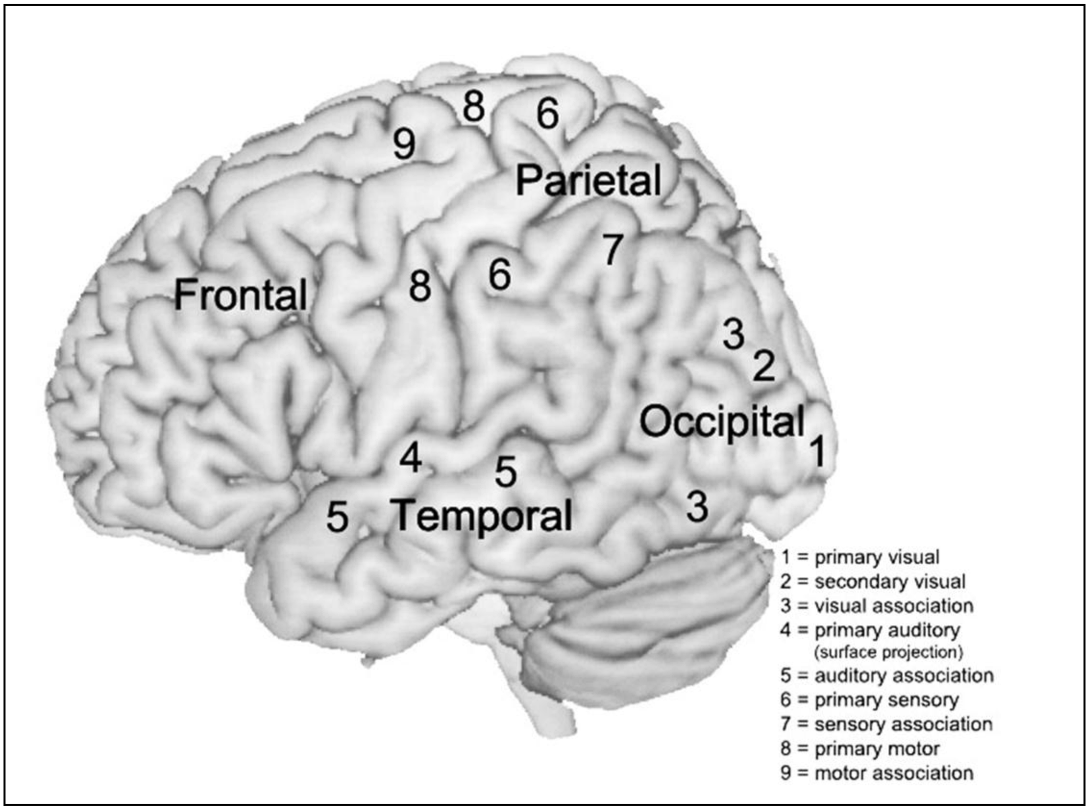
Which brings us to the main questions underlying both theoretical and empirical work on creativity: What is it, and how do we accomplish it? The literature on creativity and its related topics—intuition, expert knowledge, problem-solving, achievement, and case studies of exceptional accomplishments—is vast, with perspectives coming from fields as diverse as philosophy, psychology, cognitive science, musicology, and art history.[2-15] But research on creativity, particularly from the psychological perspective, can be considered a young science, having progressed only after prominent American psychologist J.P. Guilford made a plea for its empirical study during his 1950 presidential address to the American Psychological Association.[3] Despite the later advent of brain-imaging techniques in the 1990s, the neuroscience of creativity began to harbor interest and to pick up pace only very recently.

Any empirical work on the topic, however, requires a clear operational definition. The general consensus is that as a prominent characteristic of human intelligence, creativity is a fundamental activity of human information processing.[12] A primary difference between our brains and those of other animals is our capacity to engage in cognitive abilities such as reasoning, representation, association, working memory, and self-reflection. During any creative act, from language production to marketing techniques selling the latest iPhone, ideas or past experiences are combined in novel and significant ways via the interaction of such cognitive capacities. The *creative cognition approach* is the current model dominating the neuroscientific study of creative thinking. According to this approach, creativity is far from a magical event of unexpected random inspiration. Instead, it is a mental occurrence that results from the application of ordinary cognitive processes.[16]

Humans appear to have a propensity for making complex new things that are not explicitly necessary for biological survival or reproduction. In comparison to other arts, such as design, photography, and sculpture, however, the universal abilities of musical creation and processing are generally accepted as some of the oldest and most fundamental of human socio-cognitive development. In fact, researchers have argued for music's role in evolutionary biology.[17-19] Scholar Ellen Dissanayake has further claimed from an ethnological stance that the creation and appreciation of art more generally are advanced adaptive behaviors that are key to social survival.[20-22]

Creativity and Prefrontal Cortex Function

A summary of brain structure and function reveals the importance of the prefrontal cortex (PFC) to creative thinking. The brain is functionally divided into the frontal lobe and three posterior cortices known as the occipital, the parietal, and the temporal (OPT). Neurons in the OPT cortices are devoted to perception and long-term memory. Primary sensory cortices of all sense modalities, such as visual, motor, somatosensory, and auditory, are located in the OPT cortices, respectively. Each sensory cortex has an association cortex that further gathers and incorporates sensory information from its respective primary cortex.



Courtesy of Mónica López-González and Charles J. Limb

Unlike the other cortices, the frontal lobe neither receives direct sensory input nor stores long-term memory. The frontal lobe is the seat of executive function and is essential to our ability to plan, to make decisions, to form judgments, to assess risk, and to formulate insight. The PFC, which occupies half the frontal lobe, integrates already highly processed information to enable even higher cognitive functions such as self-construct,[23] complex social function,[24] planning,[25] and intentional action,[26] among others. Research has further shown that working memory,[27] temporal integration,[28] and sustained and directed attention[29] are key cognitive functions that provide the underlying framework to compute even higher cognitive functions because they act as buffers, simultaneously maintaining in-the-moment information in consciousness and ordering it in space-time as associations proceed.[30]

As neuroscientist Antonio Damasio suggests, a working memory buffer is critical for creative thinking because it allows for the retention of relevant knowledge while problem-solving;[31] without it, the back-and-forth reworking of associations and consequent novel solution identification would be impossible feats, as is the case in monkeys and humans with PFC lesions.[32] The PFC is further divisible into two functionally distinct parts: the ventromedial (VMPFC), which is connected to the amygdala and the cingulate cortex in the limbic system and is implicated in emotional evaluation,[24] and the dorsolateral (DLPFC), which receives input from the occipital, parietal, and temporal regions and sends direct output to the motor cortices. Here too, Damasio notes the importance of these functional distinctions and suggests that the PFC's ability to evaluate appropriateness is critical to the problem-solver as she determines how creative her solution really is.[31]

Types of Creative Processes and Their Underlying Brain Mechanisms

If we are to understand the underlying mechanisms of creative production, what is important is not so much the context for which the result was produced, but rather the hypothesis that creative thinking can lead to different types of inventions and disparate processes. In line with psychologist Ronald Finke's findings that mental images can be generated intentionally or spontaneously during the problem-solving process,[11] one of the more interesting proposals circulating is neurocognitive scientist Arne Dietrich's claim that either of these problem-solving modes can occur within an emotional or cognitive context. Moreover, creative behavior is ultimately the result of a combination of the four psychological processes described below.[14]

Deliberate cognitive: This process involves inventiveness that comes from sustained work in a discipline. Take, for example, Eadweard Muybridge, the British photographer who experimented for years with multiple cameras and precision timing. Eventually, he created a string of negatives proving that all of a horse's hooves are indeed airborne at a certain point during a trot. The PFC induces this type of creativity by allowing for focused attention and connections to information stored and perceived in other parts of the brain. Muybridge revolutionized the field of animal locomotion by systematically using his knowledge of camera mechanics in novel ways and serendipitously uncovering the physics behind motion pictures.

Deliberate emotional: Remember when you were given a *Where's Waldo?* book and told to look for the guy with glasses, a red-and-white-striped shirt, and a matching hat? After a seemingly endless search, "Aha!"—you found him and smiled with satisfaction. Deliberate emotional creativity refers to the experience of such an "aha" moment, typically associated with a positive emotion. As with deliberate cognitive creativity, the VMPFC's attentional network is involved. However, instead of connecting directly to perceptual and long-term memory areas, attentional resources are directed to emotional structures in the limbic system. Studies have recently shown that the "aha" moment is precisely correlated with significant activity in the amygdala,[33] a structure known for its role in emotional learning.[34] So next time you look for Waldo, you'll remember how pleasant it felt to find him in the past, and that will keep you motivated to continue searching.

Spontaneous cognitive: Otherwise known as the "eureka" moment, this type of creativity typically occurs suddenly when one has left the problem-solving context and directed attention to a completely different task. Here, the dopamine-rich basal ganglia of the brain, involved in the execution of automatic behaviors,[35] operate outside conscious awareness. Searching in vain for novel solutions forces you into a mental gridlock. Until the problem is temporarily removed from conscious awareness, new perspectives cannot be gained.[11] As you perform an unrelated activity, the PFC connects information in novel ways via unconscious mental processing.

Spontaneous emotional: Usually referred to as an epiphany, this type of creativity occurs when neural activity in the amygdala is spontaneously represented in working memory. Given the biological significance of emotional events, these types of moments tend to be intense. While no apparent knowledge is necessary, specific skills may be required for these insights to come to fruition.

What Do We Know About Spontaneous Musical Creativity in the Mind/Brain?

Brain-imaging studies in music cognition have focused primarily on the neurobiology of music processing and the perception of emotion.[36] Until recently, researchers neglected the psychological and neuroscientific study of the process of musical composition in both longitudinal case studies of musical scoring and studies of instantaneous, real-time creation. In 2007, researchers began to explore spontaneous improvised musical material as it is generated, perceived, and communicated among musicians.

From the jazz artist's perspective, improvisation refers to the dynamic moment at which the artist employs immediate decision-making as new ideas are conceived of and then integrated into the ever-evolving musical output.[1] In regards to cognitive processes, improvisation can thus be defined as the spontaneous generation, selection, and execution of novel auditory-motor sequences. Since musicians must generate a potentially infinite number of contextually meaningful musical phrases by combining a finite set of notes and rhythms, researchers consider musical improvisation an optimal way to study the neural underpinnings of spontaneous creative artistic invention. While the study of real-time musical improvisation has been made easier with the use of custom-built, nonferromagnetic piano keyboards, noise-canceling microphones, electrostatic headphones, and contemporary functional magnetic resonance imaging (fMRI) techniques, experimenting with such a hallmark of artistic creation is no easy task. The conductors of music experiments must find just the right balance of experimental control and ecological validity.

So far, researchers at three laboratories have specifically examined highly constrained simple melodic improvisations by classically trained pianists.[37-39] Their investigations have found that the generation of musical structures implicates the sensorimotor and classic perisylvian language cortices (Wernicke's and Broca's semantic and syntactic processing areas), and the PFC, in particular the DLPFC.

Asking the same neurocognitive question of what distinguishes improvisatory from memorized behavior, researchers Charles Limb and Allen Braun explored improvisation with professional jazz pianists.[40] Instead of improvising over predetermined melodies with a fixed number of notes, participants either freely improvised to the auditory accompaniment of a prerecorded jazz quartet or reproduced memorized jazz sequences. Improvisation, in comparison to the production of overlearned material, was characterized by widespread activation in sensorimotor and language areas. Furthermore, activity observed in the PFC included both deactivation of the DLPFC and lateral orbital (LOFC) regions and focal activation of the medial prefrontal cortex (MPFC). In comparison to the more musically constrained generation studies, this study reveals a state of free-flowing complex musical ideas that may result from the combination of internally generated self-expression (via the MPFC) and attenuation of activity in the DLPFC. This observation is additionally intriguing given that altered states of mind such as dreaming, meditation, and hypnosis have produced such “turning-off” of executive functioning.[41]

We have all most likely experienced moments of intense focused concentration at a task followed by a pleasurable aftereffect. Psychologist Mihaly Csíkszentmiháyli and colleagues proposed and developed the theoretical construct of a flow state, commonly referred to as being in the zone, to describe precisely that optimal experience that occurs during a highly motivated creative (but not necessarily artistic) act.[7, 42] Researchers have made applications and correlations not only to music performance,[43] but also to athletic competition.[44] Research investigating possible links between musical creativity and Csíkszentmiháyli’s concept of flow, however, are sparse in regards to behavioral data, except for a study on long-term group composition,[45] and lacking in neuroimaging data, with the exception of Limb and Braun’s study.[40]

If one characteristic of a generative creative and artistic act is a state of flow, then musical genres other than jazz ought not only to be associated with generalized heightened activity in all sensory modalities, but also to exhibit an equivalent mental state. As with the Limb and Braun study,[40] Mónica López-González and colleagues sought to identify the neural substrates underlying the spontaneous generation of rhyming sequences in hip-hop performance.[46] Freestyle rapping, like jazz, involves the rapid, real-time generation of lyrics to the accompaniment of a rhythmic beat. During López-González’s study, using a similar methodology to that of Limb and Braun, professional freestyle rappers performed to rhythmic accompaniment as they either spontaneously improvised lyrics or recited a pre-memorized novel rap. In line with the other generation studies, improvisation, compared to nongenerative recitation, revealed heightened activity in the superior MPFC, classical language areas, sensorimotor cortices, and the cerebellum. Deactivation was observed in LOFC regions. In sum, the DLPFC and multiple sensory and language areas appear to be associated with the encoding and consequent implementation of novel auditory-motor sequences germane to the act of spontaneous musical improvisation.

Perception of Improvised Material

An alternative to investigating what occurs in the brain during real-time generation of novel material is researching its perception. Are listeners of jazz improvisation capable of evaluating offhand such spontaneously improvised material? Evaluation of improvised material can be important for aesthetics, enjoyment, and economic purposes; entire jazz competitions and festivals depend on this capacity of experienced judges and inexperienced, eager listeners.

The single study that has been done to date made three observations after testing musically trained listeners attempting to differentiate between improvised and rehearsed jazz piano solos.[47] First, judgment ratings revealed that experienced jazz musicians are relatively accurate at classifying performances as improvisations instead of rehearsed imitations. Second, fMRI data revealed correlations between listening to improvisations and increased activity in the amygdala, a structure in the limbic system also implicated in the processing of behavioral uncertainty.[48] Third, fMRI data also revealed that activity in the pre-SMA, superior frontal gyrus, rostral cingulate cortex zone, Broca’s area, and motor-related areas (e.g., the cerebellum, primary motor area, and precentral gyrus) was stronger when people listened to melodies judged as improvised than when they listened to those judged as imitated. These data reveal an apparent cortical overlap between trained musicians listening to novel improvisatory material and those creating it.[37-40, 46]

These observations provide strong evidence that musicians are far from passive listeners. Given personal experience with the art form in question, they engage in action simulation. The extent to which these findings are generalizable to nonmusicians remains to be determined. However, given the amygdala’s sensitivity to cues in musical uncertainty in the performers’ behavior, researchers can hypothesize that even nonmusicians appreciate performance fluctuations such as the timing between keystrokes and the force applied to each keystroke, both prominent auditory features for identifying musical spontaneity.[49] Perhaps witnessing firsthand those unfolding moments of creation makes going to a live jazz performance or searching for that one classical LP recording so rewarding.

Communication of Improvised Material

Jazz performance is not typically a solo venture. Provided that it is an interactive live musical discourse among multiple performers, two intriguing questions arise. First, is this musical conversation manifested neurologically, given shared cognitive networks between music and language processing?[50, 51] Second, given the interactive nature of the task, is a state such as Csíkszentmiháyli's flow possible?

In an fMRI study at Johns Hopkins, Gabriel Donnay and colleagues explored a typical jazz improvisation convention known as trading fours, whereby two or more musicians alternate solos of four-measure phrases for arbitrary lengths of time.[52] Results revealed that improvisation during the trading fours task was associated with activation in Wernicke's and Broca's areas, sensorimotor areas, and the lateral PFC and deactivation in the medial frontal PFC. With only a single existing fMRI study exploring the perception of interlocutors during natural language discourse,[53] this study adds to the nascent research hypothesizing that conversation, linguistic or musical, involves a complex network of brain regions that includes the PFC, perisylvian language cortices, and sensorimotor areas. Additionally, given the memory demands for the expected melodic and rhythmic consistency within a trading fours improvisatory task, complete entering into "the zone" may not be an applicable option in such a context. These hypotheses, of course, are but the beginning steps along this line of inquiry.

The Future of the Neuroscience of Artistic Creativity

The empirical study of artistic creativity paves the way for both a better and a more appreciative understanding of the psychological and neural processes underlying a fundamental aspect of human cognition. Although recent scientific work has not yet taken full advantage of its interdisciplinary potential, researchers have implemented a conceptual framework, and cognitive neuropsychologists are slowly beginning to break this optimal human experience into its constituent parts. It is clear even from the minimal studies available within musical creativity that creativity can neither be localized to a single area in the brain nor boxed into a single process phenomenon.

Although researchers are only beginning to uncover the neural substrates of spontaneous invention, no mention has been made about how creative behavior interacts with aesthetic judgment or emotion. Given humans' constant evaluations of the results of creative thinking and the effects it has on our consequent behaviors, it is reasonable to assume that studying the effects of emotion during creation may be another piece to the puzzle of what, how, and why we create. After all, a general social assumption is that emotion guides much of artistic creation. This is yet another empirical question.

Finally, even within the few active years of research on creativity there has been an obvious bias toward studying musical creativity. But music is not the only art form that engages creative thinking and states of flow, provokes emotional responses, has aesthetic value and sociocultural significance, and is widely produced. The most immediate challenge for the field is to bridge into visual and other performing arts in order to formulate a more generalizable theory on artistic creativity.

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Charles J. Limb, M.D., is an associate professor at the Johns Hopkins School of Medicine in the department of otolaryngology-head and neck surgery, where he specializes in neurotology and skull base surgery. He is also a faculty member at the Peabody Conservatory of Music and director of research of the Neuroeducation Initiative at the School of Education. Throughout his career, Dr. Limb has combined his interests in auditory science, clinical treatment of hearing loss, and complex sound perception, especially music. He received his undergraduate degree at Harvard University and his medical training at Yale University School of Medicine, followed by surgical residency and fellowship in Otolaryngology-Head and Neck Surgery at Johns Hopkins

Hospital. He completed a postdoctoral research fellowship at the Center for Hearing Sciences at Johns Hopkins with Dr. David Ryugo, studying the development of the auditory brainstem, and a second postdoctoral fellowship at the National Institutes of Health with Dr. Allen Braun, studying neural mechanisms of music production and perception using functional neuroimaging methods. While at the NIH, Dr. Limb completed a study of jazz improvisation that revealed important new findings regarding patterns of brain activity that underlie spontaneous musical creativity. His current areas of research focus on the study of the neural basis of creativity (in various musical and other art forms) as well as the study of music perception in deaf individuals with cochlear implants. In particular, he is interested in factors that encourage or disrupt creative flow. He is the editor-in-chief of *Trends in Amplification*, the only journal explicitly focused on auditory amplification devices and hearing aids. He is on the editorial board of the journals *Otology* and *Neurotology* as well as *Music and Medicine*. His work has been featured by National Public Radio, TED, *National Geographic*, the *New York Times*, PBS, CNN, *Scientific American*, the British Broadcasting Company, the Smithsonian Institute, the Library of Congress, Canadian Broadcasting Company, Baltimore Symphony Orchestra and the American Museum of Natural History.

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