

The neuroscience of musical creativity

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ABSTRACT

Creativity may be defined as the individual or collective ability to generate novel and useful ideas, considering the temporal and cultural context in which these ideas arise and crystallise into works. This brain function is of great evolutionary importance and, in the case of music, plays a major cultural role, since music is a language involving particular brain processes, and has been present across all civilisations and historical periods. Heredity and the environment, including learning and practice, play a role in musical creativity, which involves different neural networks. We should highlight the central role of the dialogue/struggle between the default mode network (introspection) and the executive control network (decision-making), moderated by the salience/relevance network (insula). This ability also involves the motor system, the reward system, mirror neurons (empathy), and the limbic system, which provides the basis for musical creativity (emotional states). Musical creativity does not require a particularly high intelligence quotient. Through different neurophysiological and neuroimaging techniques, both structural and functional, the involvement of these neural networks and the central role of the right hemisphere and the prefrontal lobe are becoming increasingly clear. Musical creativity is a complex phenomenon and, at present, only a small proportion of the underlying brain mechanisms is known.

KEYWORDS

Neuromusicology, neuroscience and creativity, musical creativity, competitive neural networks

Introduction

Creativity is the capacity to generate original or novel ideas, which may materialise in the form of theories, mathematical formulas, artistic works, inventions, or modification of existing objects, and which crystallise into new contributions or achievements, always considering the sociocultural context in which they emerge. The conceptual, aesthetic, or material outcomes of creativity frequently provide solutions to current problems or anticipate future challenges. In short, creativity is the ability to generate new and useful products.¹

Creativity facilitates adaptation to the environment and may occasionally play a pivotal role in evolution. Such is the case for some of the most relevant creative achievements and discoveries: the wheel, writing, the printing press, heliocentrism, the law of gravity, the steam engine, electricity, the theory of evolution, the theory of relativity, the internal combustion engine, infectious agents, vaccines, penicillin, the genetic code, the telegraph, the telephone, radio, television, the Internet, and artificial intelligence. We must also acknowledge the impact of certain religious, philosophical, and cosmological ideas,

as well as the unique contributions of different forms of art (literature, music, painting, architecture, theatre, opera, film).

A creative person, the press (environment) surrounding the creator, the creative process, and the product constitute the four pillars (the four Ps) of creativity (Figure 1).²

Creativity as an inventive capacity has been studied by a wide range of disciplines, including psychology, art history, the history of science, philosophy, sociology, aesthetics, pedagogy, and political science. Today, given the widespread understanding that creative ability is not a “divine gift” but the result of a special brain capacity, neuroscience is increasingly focused on the study of the cognitive processes involved in the broad fields of creation, innovation, and invention.³ The three great classical music composers Johann Sebastian Bach (1685-1750), Wolfgang Amadeus Mozart (1756-1791), and Ludwig van Beethoven (1770-1827) were, and still are, regarded by many as geniuses with divine inspiration.

This study reviews neuroscientific knowledge of the brain processes that are thought to be involved in musical creativity.

Development

Neuroscience and creativity

To study creative function, neuroscience has focused on designing questionnaires, measurement scales, paradigms, and relatively simple and reproducible tasks that are compatible with neurophysiological and neuroimaging techniques, in order to identify changes in brain function. The Consensual Assessment Technique (CAT) is a creativity measurement tool validated in different cultures,⁴ with special versions for the assessment of musical creativity, even in children.⁵

Magnetic resonance imaging (MRI) has become the most frequently used neuroimaging technique, as it enables, depending on the purpose of the study, the measurement of the surface or volume of different brain regions of interest (morphometric MRI) or the detection of activation in different brain areas during task performance. This is based on the fact that oxygen extraction from the blood reaching the brain is proportional to neural activation, and results in a measurable and quantifiable signal (functional MRI and BOLD [blood-oxygenation-level-dependent] imaging). Evaluating temporal synchronisation in the

patterns of activation of different brain regions through statistical analysis of the data enables estimation of the degree of connectivity between them.⁶ Positron emission tomography using 18F-fluorodeoxyglucose (18F-FDG-PET) has also been used in different studies, since it is able to identify brain regions with higher glucose metabolism, which are involved in the execution of the task under study. Electroencephalography, magnetoencephalography, and evoked potential studies are the most frequently used neurophysiological techniques; transcortical magnetic stimulation is also increasingly used.

Creative capacity is associated with certain personality traits: extraversion, agreeableness, conscientiousness, neuroticism, and, above all, openness to experience/intellect. These are considered the key five traits of creativity, although the binomial openness/intellect is regarded as the most influential. Openness to experience is a common trait among artists, whereas intellect is more frequent among scientists.⁷

The generation of novel, useful ideas involves divergent thinking (providing multiple possible solutions to a problem) and convergent thinking (selecting the most appropriate solution). In some cases, certain psychological disorders may enhance or hinder creative capacity: although it is not always the case, anxiety and depression may inhibit some creative processes, while bipolar disorder, alcohol abuse, and schizophrenia may have the opposite effect.⁸ Some types of dementia have been observed to increase or even trigger creativity⁹; cases have been reported of frontotemporal dementia associated with enhanced creativity across multiple fields, such as painting and literature or music.¹⁰

The creative individual establishes associations between their perception of the outside world and their inside world; this comparison generates new ideas, which are used to formulate, and ultimately to propose, novel solutions. Classic models of creativity¹¹ postulate five stages in the creative process: preparation, incubation, intimation, illumination, and verification. Some authors simplify the process into four stages: incubation, illumination, evaluation, and verification (Figure 1).⁸

The creative process is complex and multifaceted, with clear differences between conceptual, aesthetic, and material innovations. In aesthetic/visual creativity, auditory processing plays a major role in music, whereas visual processing is central to painting, sculpture, and

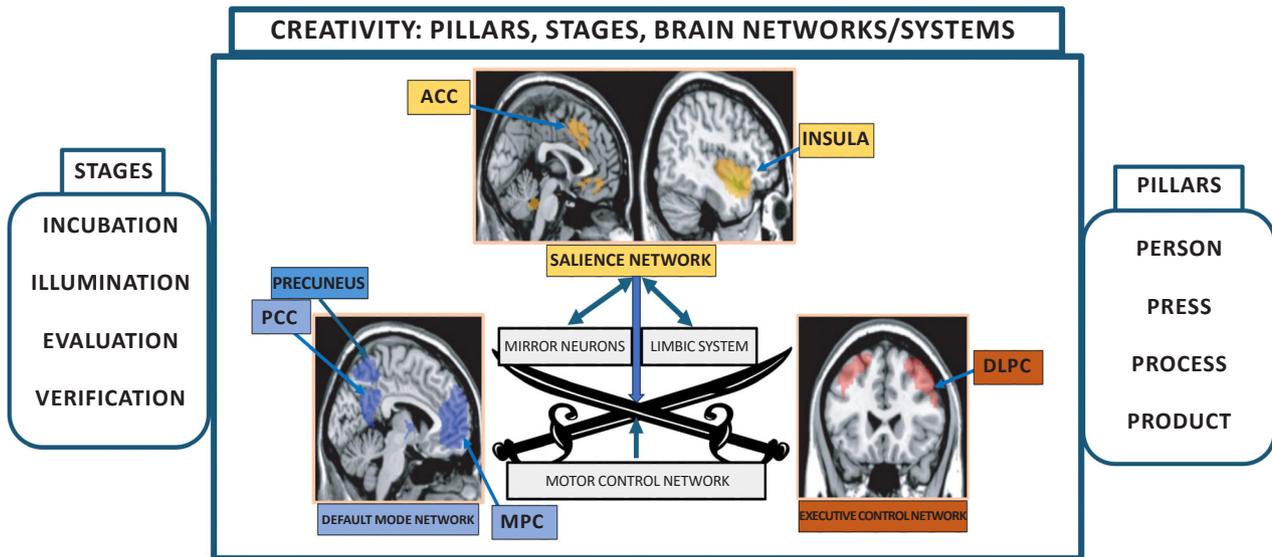


Figure 1. Stages and pillars of creativity, and brain networks and systems involved in creativity. ACC: anterior cingulate cortex; DLPC: dorsolateral prefrontal cortex; MPC: medial prefrontal cortex; PCC: posterior cingulate cortex.

architecture. All creative processes involve introspection and imagination. In the generation of novel ideas, and particularly conceptual ideas, intelligence promotes creativity, although disinhibition processes, sometimes triggered by different psychological and neurological disorders, may also promote artistic creativity. Intuition and dreams have traditionally been considered to play a relevant role in certain creative activities. A high intelligence quotient does not necessarily equate to creative ability; artistic creativity is more frequently associated with openness to experience, whereas scientific creativity tends to be associated with intellect.

A defining feature of *Homo sapiens sapiens* is an enlarged frontal lobe: this brain region is considered to play a central role in cognition, language, and behaviour¹²; the same is true for creativity. The brain is currently understood as an integrated system that functions through neural networks connecting multiple brain regions, including not

only the prefrontal, temporal, and parietal lobes, but also the limbic system, basal ganglia, and cerebellum.

Two neural networks play a particularly prominent role in the creative process: the default mode network and the executive control network. The former is associated with episodic memory, imagination, simulation, and divergent thinking, guiding the first stages in the generation of creative ideas.¹³ The latter, in contrast, evaluates, filters, modifies, and guides the proposals generated/imagined by the default mode network towards a definite or specific objective (convergent thinking). During the creative process, the two networks interact in an antagonistic dialogue, which can also involve cooperation at certain stages (Figure 1). We should also mention the involvement of the salience network in its principal hub, the insula, which acts as a switch/modulator of the alternating activation of the default mode and executive function networks.

All creative processes involve numerous brain functions, including attention, curiosity, executive function, explicit and implicit memory, and global cognitive flexibility, without overlooking intuition, which is enhanced by the intrinsic satisfaction of being presented with something novel and rewarding. In creativity, it has been hypothesised that intuition is enhanced by the competitive interplay between implicit and explicit memory, with mild attenuation of the prefrontal lobe; this is known as the Andras effect.¹⁴

Music and musicality

According to the classic definition, music is the art of arranging sound and silence in time. Sounds and silence are omnipresent in nature, but in music, they convey a sense of purpose: music is a language that is able to evoke, express, and even intensify emotions. In discussing language, emotions, intention, and art, we are referring to a brain function with a collective dimension of communication and affective bonding.¹⁵ Music maintains an important relationship and connection with other forms of art (literature, theatre, cinema), and this interaction enhances its communicative impact.

Musicality is the ability of an individual or community to perceive, reproduce, or create musical works. Pitch, timbre, intensity, rhythm, melodic contour, and harmony are the main elements of musical language.¹⁶ Singing, playing an instrument, conducting an ensemble, composing, arranging and orchestrating, choreographing and/or dancing, acting as a recording engineer or disc jockey, and even listening to music are all activities that involve musicality.

For some authors,¹⁷ the phylogenetic origins of music and language may have emerged from a common “musi-language” used by our ancestors to facilitate auditory communication and which would have evolved into two differentiated systems involving distinct brain processes. There is no specific “musical” region in the brain. Neuroimaging studies have shown that the various elements of musical language are processed in different brain regions. Music has a syntactic structure in which sequences of different pitches and their timing (rhythm) play a prominent role.¹⁸ Speech and music share central characteristics, namely the generation and auditory reception of sounds. However, they involve different brain processes, serve different purposes, and each has its own

syntax, that is the set of complex rules by which elements are combined into sequences.¹⁹ The Greek philosopher Aristotle (384-322 BC) argued that language is an essential feature of human nature. Some centuries later, Jesus Christ was considered the Word made flesh (*et verbum caro factum est*); logically, the Word became flesh (a human) in order to speak. The Baldwin effect refers to the way in which a culturally invented trait is transformed into an instinctive, heritable trait through natural selection: neural plasticity induced by learning is transmitted to subsequent generations.²⁰ Music is present in all human cultures, and musicality is considered to be a process shaped by biological evolution.²¹

Music and imagination

Imagination (mental imagery), whether visual, auditory, or a combination of both, is an intrinsic characteristic of the brains of composers, and can enhance musical creativity. Examples include the undulating arpeggios of the *Trout quintet* by Franz P. Schubert (1797-1828), which evoke the jumps of a trout in the water, or the sounds of different animals in *The carnival of the animals*, composed by Camille Saint-Saëns (1835-1921).²² In many compositions, the reading and mental representation of a literary text (whether poetic, dramatic, or narrative) contributed decisively to the composer’s mental imagery. A paradigmatic example is Friedrich von Schiller’s (1759-1805) *Ode to joy*, forever linked to the final movement of Beethoven’s *Ninth symphony*. *Adiós ríos, adiós fontes* (Goodbye rivers, goodbye springs), by the Galician poet Rosalía de Castro (1837-1885), a poem on the enduring tragedy of emigration from her homeland, inspired the composition and many heartfelt performances by the Galician-Leonese musician Amancio Prada (born 1949).

Synaesthesia

Synaesthesia is an extraordinary perceptual phenomenon in which certain stimuli (inducers), such as numbers, days of the week, sounds, or colours, trigger a wide range of concurrent perceptions, such as sounds, tactile sensations, flavours, and colours or visual representations. This phenomenon is believed to facilitate artistic creation.^{23,24} Renowned musicians and composers with synaesthesia include the Hungarian Franz Liszt (1811-1886), the Frenchman Olivier Messiaen (1908-1992), the Russian Alexander Scriabin (1872-1915), and

the Finn Jean Sibelius (1865-1957). The Russian painter Wassily Kandinsky (1866-1944), the French poet Arthur Rimbaud (1854-1891), and the Russian writer Vladimir Nabokov (1899-1977) also belonged to this group of artists with confirmed synaesthesia.

Auditory-visual synaesthesia is the most common type: in the brain, auditory perception involves the temporal lobe, which also contributes to visual recognition via direct connections with the occipital lobe, responsible for processing shapes and colours; the parietal lobe is involved in spatial representation. Rather than specific regions, synaesthesia relies on neural networks connecting sensory, motor, and prefrontal regions.²⁵ Individuals with multiple types of synaesthesia have been found to be more creative, and to use divergent thinking.²⁶

Musicality and heredity

Musicality and musical creativity are known to exhibit familial aggregation: more than half of professional musicians are the children of musicians. A paradigmatic example is the family of J.S. Bach, which includes more than 30 musicians (instrumentalists and composers) spanning six generations.²⁷ In Spain, we should mention the García family, a well-known lineage of singers, composers, and music teachers, beginning with the Sevillian Manuel García (1775-1832), and continuing with his children Manuel Patricio, María Malibrán, and the universally renowned Pauline Viardot, contributing numerous artists over four generations. Genetic studies conducted in monozygotic and dizygotic twins have demonstrated the significant contribution of heredity (70%-80%) on pitch recognition²⁸; however, the influence of the environment, and particularly practice, is also highly relevant.²⁹

A recent review of genetic studies identified over 20 genes linked to musical aptitude,³⁰ mainly:

1) *GATA2*, involved in cochlear development. This gene regulates *SNCA*, which encodes alpha-synuclein, a protein involved in Parkinson's disease, Lewy body dementia, and multiple system atrophy. *SNCA* is located on chromosome 4q22, a region closely related to dopaminergic function, and is highly relevant for musical aptitude, as *SNCA* expression increases when listening to or performing music.

2) *PCDH7* encodes protocadherin-7, expressed in cochlear hair cells (responsible for pitch perception) and the amygdala (involved in emotional processing).

3) *FOXP1* and *FOXP2* are linked to speech development and musical ability. The dopaminergic system is involved not only in motor control but also in reward mechanisms; in birds, it is central to song production.

4) Haplotypes RS1 and RS3 (12q14.2) of the *AVPR1A* gene, involved in the synthesis of arginine vasopressin receptor 1A, present a strong association with creative ability.

Heritability coefficients for musical aptitude are estimated at 0.84 for general creativity, 0.40 for composition, 0.46 for arranging/orchestration, and 0.62 for improvisation.²⁷

Absolute pitch and congenital amusia

Absolute pitch is defined as the capacity to identify the pitch of a sound without any external reference. This rare ability is present in one in every 1500-10 000 individuals (frequency varies between ethnic groups and is higher in Asian populations). Absolute pitch is not considered essential to become a professional musician, and some authors suggest that it may be acquired. Individuals with absolute pitch frequently begin musical training at younger ages; they display temporal lobe asymmetry and an enlarged planum temporale (located posterior to the auditory cortex) on morphometric MRI. Absolute pitch presents a certain degree of familial aggregation, although no clear association has been observed with any specific gene or locus (heterogeneous inheritance); the concordance rate is around 75% in monozygotic twins and 45% in dizygotic twins. Absolute pitch is more prevalent in patients with Williams syndrome, a condition caused by a hemizygous microdeletion (involving 26-28 genes, including the elastin gene) on chromosome 7 (7q11.23). The syndrome is characterised by special abilities in music (often emerging at a young age), face recognition, and spoken language. In contrast, these patients exhibit difficulty with visuospatial tasks, mathematics, and abstract reasoning, and they usually have overall learning disability and a lower intelligence quotient.³¹

Approximately 1%-4% of the population have congenital amusia, a disorder characterised by impaired pitch perception (and frequently impaired perception of melody and rhythm) in the absence of history of brain injury or educational deprivation. Amusia is not

associated with alterations in auditory acuity, verbal language processing, or prosody. The potential association with a low intelligence quotient is controversial; for instance, Sigmund Freud (1856-1939) was known to have amusia. Congenital amusia presents marked familial aggregation (46% in first-degree relatives), but is genetically heterogeneous, as is the case with absolute pitch. It has been hypothesised that congenital amusia is caused by a disconnection between right temporal (superior temporal gyrus) and right frontal regions (inferior frontal gyrus).²¹ There is no doubt that congenital amusia has a considerable negative impact on musical creativity.

Improvisation

Training and practice play a prominent role in all types of creativity, both in generating ideas/solutions (divergent thinking) and in selecting the most appropriate solution (convergent thinking). Regarding musical creativity, professional jazz instrumentalists typically have greater improvisation skills than classical instrumentalists, as they frequently receive more improvisation training. This results in enhanced creativity. However, each performance is novel and unique, and artistic concepts and taste vary between individuals and eras.³²

Musical improvisation may be considered a form of instantaneous composition, closely linked to musical creativity. For this reason, numerous studies have employed functional MRI to evaluate brain activity during musical improvisation. One study involving the Venezuelan pianist Gabriela Montero (born 1970), a renowned classical musician with exceptional improvisation skills, revealed that during improvisation, her brain presented decreased connectivity between nodes of the default mode network, as well as increased connectivity between nodes of the visual network (parietal and occipital cortex). This is suggestive of a so-called flow state, characterised by maximal concentration (focus) on a specific task and reduced introspection, which would explain the decreased activation of the default mode network.³³

Musical creativity and brain neuroimaging

A study conducted in 2016 including 239 subjects evaluated musical creativity with a creativity questionnaire and morphometric MRI. Participants with higher levels

of musical creativity (particularly in composition and improvisation) showed greater surface area in the bilateral superior frontal gyrus, bilateral orbitofrontal cortex, left planum temporale, and right middle temporal gyrus, as well as greater subcortical volume in the left amygdala.³⁴ The authors concluded that musical creativity is reflected in brain structure and relies on interaction between the default mode network, limbic system (greater emotional experience), and motor network. Other studies using morphometric MRI have shown that musicians, and particularly those who began practising music at young ages, present greater thickness of the corpus callosum (which connects the two hemispheres) and the arcuate fasciculus (which connects the temporal lobe to the frontal lobe).

The same research group from the University of New Mexico (Albuquerque, United States) used MRI to study 218 individuals, who completed the same creativity questionnaire as in the 2016 study. The researchers found that the default mode network (medial frontal cortex, lateral temporal cortex, precuneus) is highly active in musically creative individuals; the same was true for the dorsolateral prefrontal cortex (executive function); the supplementary motor cortex, premotor cortex, basal ganglia, and cerebellum (motor control); the amygdala (emotion); and the anterior insula (salience).³⁵ A table in this article³⁵ summarises the findings reported by studies analysing musical creativity with neuroimaging or neurophysiological techniques.

Conclusions

Musical creativity is a multifaceted ability influenced by genetic and environmental factors (cultural context and practice). It involves a wide range of neural networks, including the interaction between the default mode network and the executive function network, both modulated by the salience network. Other elements involved in musical creativity are mirror neurons, the motor control network, the limbic system, and the reward system. Musical creativity is a complex phenomenon of which only a small portion of the underlying brain processes is currently understood.

Conflicts of interest

The author has no conflicts of interest to declare. Part of this study was presented at the meeting of the Study Group for the Humanities and the History of Neurology (75th Annual Meeting of the Spanish Society of Neurology, 2023).

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