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The Neuroscience of Jazz Improvisation: The Intrinsic Neural Mechanisms, Neuroplasticity and Training, and Interpersonal Real-Time Coordination

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Abstract. To explore creative cognition in depth, the perspective that Jazz improvisation brings about turns out to be unique and interesting. Jazz improvisation implies real-time generation, instant evaluation, and immediate execution of novel musical creativity. In this review, the most updated neuroscientific research findings in three core sub-fields, intrinsic neural mechanisms, experience-driven neural plasticity, and interpersonal collaboration, are intensively discussed. Improvisations always involve complex brain networking rather than single reaction in an isolated region, where correlations of dynamic interactions among default modes, executive control, attention, sensory-motor, and reward systems occur at the same time. Interactions among these networks and schemes support the generation of spontaneous creativity, predictive motor planning, and sustained immersive experiences. It has also been discovered that long-term jazz training could lead to the enhancement of structural and functional neural plasticity, which strengthens the white matter pathways, like the arcuate fasciculus, and enhances connections between the prefrontal cortex and the premotor area, enabling professionals to convert internal intentions into smooth musical output. Brain synchronization scanning studies show that ensemble improvisation heavily relies on brain synchronization and error monitoring of predictions as well as emotional resonance, which implies that creativity could be an outcome derived from social processes. Despite of various ways of study have been applied in this area and a lack of long-term data, more and more evidence shows that improvisation is the result of adaptive neural cooperation formed through practice and interaction. This review puts forward a comprehensive framework for the understanding of neural mechanism of jazz improvisation and proposes that multi-model and ecologically valid methods should be applied in further research.

Keywords: Jazz improvisation, Creative cognition, Default mode network, Neural plasticity, Auditory-motor integration

1. Introduction

By creativity, we normally refer to the generation of novel ideas and works that are appropriate in the context. Such ideas or works could probably develop from interaction among individuals and

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domains as well as environments [1]. Musical improvisation is among the most challenging creative tasks, as it implies real-time production of original material under temporal constraints. Among various musical genres, jazz improvisation represents a highly valuable example for neuroscience research, as it contradictorily combines both free-style and structured characteristics based on the strictest rules, for example, harmonic progressions and rhythmic conventions [2].

Non-invasive neuroimaging technology, like functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), has equipped researchers with visible and measurable tools to examine neural dynamics during improvisation in ecologically valid conditions. Early studies mapped out activities in isolated regions that account for executive control, motor planning, auditory processing, and rewarding separately [2, 3]. However, recent works claim that improvisation actually emerges from interactions among more complex networks, especially in the default mode, executive control, salience, and sensorimotor systems [4, 5].

Despite of the breakthrough in the research, two major questions remain unsolved. Firstly, prior reviews often take neural regions as isolation rather than components of coordinated functional networks. Secondly, while solo improvisation has been extensively examined, the emerging hyper scanning technique exploring duo and group improvisation remains at theoretical stage and not well integrated [6].

This review is developed in the following three major domains:

(1) innate neural mechanisms, including the generation of novel musical material, motor execution, and sustained improvisation;

(2) neuroplasticity driven by past experiences, with the examination of how practice and training shapes functional and structural brain networks;

(3) environmental and situational factors, highlighting the role of real-time feedback, duo and group interactions, and prediction-error monitoring in shaping performances.

By integrating discoveries into the above domains, this review puts forward a comprehensive framework for understanding the neural mechanism of jazz improvisation, from the foundational neural substrates to adaptive processes that unfold during training and social interaction.

2. Essential neural mechanisms behind improvisation

Neuroimaging evidence all points to one conclusion: improvisational creation is developed through distributed neural circuits rather than in isolated regions [3]. These circuits dynamically support the generation of creativity and the execution of sensorimotor functions as well as the maintenance of internal motivation.

2.1. Generation of ideas: prefrontal reconfiguration and default mode network engagement

The core cognitive challenge of improvisation lies in generating novelty while preserving coherence. This process is related to the reorganization inside the prefrontal cortex (PFC). A recent fMRI study by Limb and Braun demonstrated the decreased activities in the dorsolateral prefrontal cortex (DLPFC) during melodic improvisation. As the DLPFC mediates conscious self-monitoring and executive inhibition, its downregulation is interpreted as reduced self-censorship. As a result, it triggered the generation of free association [2].

On the contrary, an increase in activation was observed in the medial prefrontal cortex (mPFC) and the nodes of the default mode network (DMN), particularly in the posterior cingulate cortex (PCC) [3, 4]. The DMN is associated with spontaneous thinking, mental simulation, and the retrieval

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of autobiographical memories. Therefore, improvisation invokes internally generated content rather than responses triggered by external cues.

This oppositional pattern supports the "dual-process" account of creative cognition, wherein the executive control network (ECN) temporarily releases constraint while DMN-associated associative processing turns dominant [7]. In other observations, professional improvisers demonstrate enhanced functional connectivity between prefrontal and premotor regions, suggesting that experience improves the balance between spontaneity and control [4]. These research findings collectively reveal the characteristics of the neural mechanisms underlying creative cognition (Table 1).

Table 1. Major brain networks and relevant regions in improvisation

Network	Primary Functions in Improvisation	Key Brain Regions
Default Mode Network (DMN)	Internal generation, self-guided imagery, idea formation	mPFC, PCC, angular gyrus
Executive Control Network (ECN)	Monitoring, decision evaluation, inhibition of dominant responses	dlPFC, ACC
Salience Network (SN)	Detection of novelty, switching between self/other demands	ACC, anterior insula
Sensorimotor Network	Timing, motor execution, auditory-motor mapping	M1, SMA, cerebellum, basal ganglia
Social/Empathy Network	Prediction of others' intentions, affective coordination	dmPFC, TPJ, IFG, insula
Cerebellar Network	Temporal prediction, error correction, fine-tuning	Cerebellar hemispheres, dentate nucleus

2.2. Motor execution: auditory-motor integration and predictive processing

Internally generated musical ideas require seamless translation into motor output. This transformation involves a tightly coupled auditory-motor loop encompassing the premotor cortex, supplementary motor area (SMA), primary motor cortex, and superior temporal gyrus (STG) [8].

Observations show that improvisation heavily relies on predictive coding: the brain continuously generates anticipatory models of expected sound based on motor intent, comparing predicted outcomes against real auditory feedback [9]. This real-time correction process happens at a millisecond rate.

Meanwhile, the sophistication of expertise helps in development of measurable neuroplastic adaptations. Functional connectivity studies indicate stronger coupling between auditory and motor cortices in improvising musicians compared to non-improvising musicians [3]. Diffusion tensor imaging shows increased integrity of white matter tracts, especially the arcuate fasciculus, supporting accelerated auditory-motor transformations [1].

2.3. Sustaining improvisation: reward, automation, and immersion

The high cognitive load of jazz improvisation leads to an essential question: how can musicians generate novel phrases uninterrupted for minutes, while maintaining artistic coherence and emotional engagement? Research demonstrates that this remarkable sustainability relies on a self-reinforcing neural cycle, driven by intrinsic reward, enabled by automated execution, and enhanced by immersive states. These three components work in concert to support the dynamic continuity of improvisation [10].

Intrinsic Reward. A powerful intrinsic motivation is the primary prerequisite for sustaining improvisation. Neuroimaging evidence shows that smart violations and resolutions of auditory expectations in music robustly activate core reward regions, like the nucleus accumbens (NAcc) and ventral tegmental area (VTA), accompanied by the extra release of dopamine [9]. In the context of improvisation, the musician becomes the creator of novelty. Their brain continuously monitors output, and when self-generated phrases are both novel and musically logical, this intrinsic reward mechanism is triggered [1]. Dopamine release not only produces a transient feeling of joy, more importantly, reinforces the ongoing creative behavior, incentivizing the musician to continually explore subsequent phrases. This fuels the fundamental motivation for sustaining improvisation [9].

Motor Automation: Research reduces cognitive load through proceduralizing of sensorimotor patterns [1]. In the process of improvisation, an unconscious direct mapping is formed among finger movements, harmonic choices, and auditory expectations. This automated processing significantly saves cognitive resources, freeing up working memory and attention from basic execution details. Then the released resources are completely allocated to higher-order creative processes like melodic development, emotional expression, and structural organization, providing the necessary cognitive foundation for prolonged, uninterrupted improvisational output [10].

Immersive Flow: EEG studies show that increased upper alpha band synchronization in the right prefrontal cortex during improvisation is correlated with creative quality [3]. This alpha activity is considered an "inhibitory rhythm," functioning to actively suppress neural processing unrelated to the current improvisation. It acts as a "cognitive shield," effectively blocking distractions lik self-doubt and environmental noise, and locking attention onto the ongoing flow of music generation. This sustained attentional focus directly contributes to a deeply immersive flow state, characterized by a distortion of time perception and a temporary loss of self-awareness [1]. This state is intrinsically rewarding and can further optimize the allocation of cognitive resources, hence significantly enhancing the stability and sustainability of improvisational behavior.

In summary, the sustainability of jazz improvisation is maintained by a precise neural cycle: the intrinsic reward system provides the primary motivation; sensorimotor automation ensures executive fluency by conserving cognitive resources; and prefrontal inhibitory control protects the creative process from interruption by maintaining immersion [1, 3, 9]. These three elements connect and mutually reinforce each other, forming the complete neurobiological foundation for the initiation and maintenance of improvisational behavior.

3. Neuroplasticity and training: how expertise shapes the improvising brain

While intrinsic neural architecture provides the foundation for improvisation, it is long-term musical training that sculpts these systems into highly efficient networks. Expertise in jazz improvisation is associated with both structural and functional neuroplasticity, enabling rapid generation, translation, and evaluation of novel musical material.

3.1. Structural plasticity: white-matter pathways and interhemispheric integration

Studies of professional improvisers reveal increased structural connectivity in white matter tracts crucial for auditory-motor integration. Diffusion tensor imaging (DTI) has demonstrated enhanced fractional anisotropy in the arcuate fasciculus, a pathway linking temporal (auditory) and frontal

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(motor-planning) region [1]. This strengthened tract supports faster bidirectional communication between perception and action, a prerequisite for real-time melodic invention.

Additionally, jazz musicians exhibit increased integrity in the corpus callosum, particularly the anterior midbody, suggesting enhanced interhemispheric transfer between motor cortices [1]. This may facilitate bimanual coordination and bilateral motor control during complex improvisatory passages.

These findings underscore that improvisational expertise is not solely functional—it is embodied in anatomical reconfiguration shaped by years of deliberate practice.

3.2. Functional plasticity: network efficiency and domain-specific connectivity

Functional neuroimaging reveals that expert improvisers recruit brain networks with greater efficiency and specialization. Resting-state fMRI studies show increased coupling between the medial prefrontal cortex and premotor areas, indicating a stronger interface between idea generation (DMN) and execution (sensorimotor network) [3]. This enhanced connectivity supports rapid transformation from conceptual intention to motor output.

Moreover, electroencephalography (EEG) evidence demonstrates reduced latency in auditory-evoked potentials among trained improvisers, reflecting improved predictive coding and auditory expectation [8]. Such efficiency allows experts to anticipate harmonic changes and generate responses ahead of real time—essential for "playing into the future," a hallmark of jazz phrasing.

Crucially, training appears to recalibrate the balance between cognitive control and spontaneity. Compared to novices, experts show greater coactivation between the default mode network and executive control network, suggesting developed metacognitive flexibility [4]. Rather than simply suppressing control, experts strategically deploy it to guide or reshape unfolding ideas.

3.3. Learning improvisation: from rule internalization to generative freedom

The acquisition of improvisational expertise follows a trajectory from rule-based imitation to generative autonomy. Early stages involve explicit learning of harmonic schemas, licks, and rhythmic motifs. Neurocognitively, this corresponds to engagement of dorsolateral prefrontal cortex (DLPFC) for conscious planning and error monitoring [9].

With practice, these rules become automatized, transitioning into procedural memory networks supported by basal ganglia and cerebellum. This shift enables improvisers to manipulate harmonic and rhythmic material creatively while maintaining structural coherence.

Importantly, experts do not abandon rules—they integrate them implicitly. As Berliner observed ethnographically, jazz improvisers "compose in real-time" using an internalized grammar. Neural data supports this: experts demonstrate anticipatory responses to harmonic changes, indicating that rule knowledge becomes predictive rather than reactive [9].

3.4. Pedagogical implications: training the creative brain

Neuroscientific insights challenge the misconception that creativity is an innate gift. Instead, they suggest that improvisational skill emerges through targeted cultivation of neural systems that support flexibility, prediction, and inhibition.

Effective improvisation training may therefore emphasize: Call-and-response exercise which strengthens auditory-motor coupling, Modal and harmonic substitution practice that refines

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predictive modeling, and Free improvisation sessions that promotes DMN–ECN integration and flow tolerance.

Longitudinal evidence indicates that even short-term improvisation training induces measurable neural changes, including increased alpha coherence and enhanced auditory discrimination, demonstrating the brain's capacity to learn creative behavior [9].

4. Interpersonal dynamics and real-time coordination

In group musical improvisation, performers must continuously adapt not only to their own motor and auditory outputs but also to those of others. Unlike solo improvisation, which primarily relies on internally generated predictions, ensemble performance requires a dynamic exchange of sensory, motor, and affective cues. This exchange engages large-scale brain networks responsible for joint attention, prediction-error monitoring, and social contingency tracking [3, 7].

Hyperscanning studies—simultaneous neuroimaging of multiple musicians— showed inter-brain synchrony between performers, particularly in frontal and temporoparietal regions. Neural coupling in the dorsomedial prefrontal cortex (dmPFC), temporoparietal junction (TPJ), and inferior frontal gyrus (IFG) correlates with successful joint phrasing and turn-taking [7]. The greater the uncertainty in co-performer output, the stronger the activation in prediction-related pathways, including the cerebellum and anterior cingulate cortex (ACC), suggesting that a balance between expectation and surprise drives adaptive creative reciprocity [3].

Real-time coordination relies on a delicate balance between prediction and prediction error. Overly rigid prediction can lead to mechanical synchrony without creativity, whereas excessive prediction error can produce incoherence. Optimal improvisational exchange emerges when performers remain slightly off-equilibrium—anticipating yet responsive to disruption. This state is often described as "mutual attunement" or "social groove," supported by transient integration within the salience network. During ensemble performance, neural activity shifts from isolated agency to shared agency, wherein aesthetic decisions are distributed across the group [4].

Interpersonal improvisation also recruits affective resonance systems. Activation in the insula and limbic regions suggests that emotional inference plays a role in timing and harmony decisions. Musicians adjust to micro-expressions, breath gestures, or tonal inflections, engaging mirror neuron systems to simulate others' intentions before execution [3, 5]. Thus, ensemble improvisation is not solely auditory; it is predictive, embodied, and socially interpretive.

In summary, group improvisation relies on three interacting mechanisms: neural synchronization between performers, predictive error management for adaptive creativity, and affective resonance for emotional coordination. Together, these mechanisms facilitate real-time, co-creative performance while maintaining both musical coherence and novelty [3, 4, 7].

5. Conclusion

In recent years, advances in neuroimaging and hyper-scanning technologies have significantly deepened our understanding of the neural mechanisms of jazz improvisation. These methods have effectively overcome the limitations of traditional research that focused only on local brain region activities by revealing the dynamic network coordination mechanisms of the brain during the improvisation process. Specifically, the combination of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) has clarified that improvisation relies on the coupling of the default mode network (DMN) and the executive control network (ECN), as well as the coordinated action of the sensorimotor and reward systems, thereby explaining the balance

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mechanism of "freedom and control" in improvisation. Diffusion Tensor Imaging (DTI) further reveals that long-term training can enhance the structural integrity of white matter tracts (such as the arcuate fasciculus), promoting efficient transmission of auditory–motor information. Meanwhile, hyperscanning technology has, for the first time, enabled the simultaneous recording of multiple brains during ensemble performance, discovering that interbrain synchrony in frontal and temporoparietal regions is closely related to the quality of musical interaction, providing a neural basis for understanding social creativity. These achievements not only break through the previous perspective of explaining creativity from only local brain regions but also systematically explain the integration mechanism of cognitive, emotional, and motor circuits in improvisation, providing theoretical basis for music education, creativity training, and even neurorehabilitation.

In the foreseeable future, research paradigms in this field will move toward multimodal integration, such as combining wearable EEG devices with near-infrared spectroscopy to noninvasively and in real time capture brain activity in near-natural ensemble environments, while using machine learning to extract features and model the vast neural dynamic data in order to identify neural markers that support creative collaboration. At the same time, research will not only focus on depicting a more detailed, dynamic, and socially inclusive "neural map of creativity", but also on developing active intervention strategies for neural network regulation based on this knowledge, such as creativity-enhancing strategies based on neural feedback or new neural music therapies for social interaction disorders. However, current research still faces the challenge of balancing method integration, ecological validity, and experimental control, which needs to be gradually addressed through the development of new-generation data acquisition, comprehensive analysis models, and interdisciplinary cooperation.

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