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The neural basis of musical improvisation: the contribution of electroencephalography studies

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Abstract

This paper is aimed at presenting and discussing the main electroencephalography (EEG) studies analyzing brain activity during musical improvisation. A brief overview of the history of musical improvisation and its link to creativity highlights improvisation as a dynamic, spontaneous musical expression. The review of EEG studies revealed connections between cognitive control, flow states, and emotion in musical improvisation. The dual-process model of creativity is discussed, emphasizing the balance between spontaneous and controlled cognitive processes, depending on the individual's experience level. The potential of transcranial direct current stimulation (tDCS) to enhance improvisational skills, particularly in less experienced musicians, is explored as well. Findings have implications beyond musical training, extending to mental health and creative development. By stimulating brain areas involved in musical creativity, tDCS could open new possibilities for musicians to generate original ideas and boost creative fluency.

Keywords: musical improvisation; creativity; EEG; neuromodulation; tDCS

1. Introduction

Musical improvisation (Berkowitz, 2010) falls within the domain of musical creativity (Antonietti & Colombo, 2014) and has specific characteristics such as a certain amount of spontaneity, a coherent pattern, rules from a long musical tradition, and an underlying structure in order to be understandable to the originator and the listener (Czerny, 1836). This paper aims to consider the brain activity of subjects engaged in musical improvisation, specifically delving into electroencephalography (EEG) studies to investigate the mechanisms underlying the generation of new combination of sounds. This corpus of knowledge can provide the basis to propose neurofeedback devices (Sasaki et al., 2019) or to implement neurostimulation, such as transcranial Direct Current Stimulation (tDCS), in order to increase creativity in music and enable those with less expertise in this area to expand their abilities.

This review is based on experimental research reviewed from Scopus database, using keywords "music" and "creativity" cross-referenced with "brain", "neur*", "improvisation", "state", "relaxation", "meditati*", and "arousal" limited to 2010-2023, considering neuroscience and psychology studies written in English. As shown in the PRISMA flow diagram (Figure 1), many articles were initially identified, but studies about the state of mind were excluded due to limited numbers. Only experimental EEG-based studies were selected. Reviews and meta-analyses were excluded. Additionally, neurostimulation studies were founded and then included for future perspectives. Less than 50 studies were reviewed, primarily experimental.

The article reviews the history of improvisation and its link to creativity, examines neural (Lopata et al., 2017; Rosen et al., 2020; Sasaki et al., 2019) and emotional (Dikaya & Skirtach, 2015; Ramirez-Melendez & Reija, 2023) correlates, and explores tDCS for improving improvisation in different fields (Rosen et al., 2016).

1.1 Musical creativity

Musical creativity, as defined by Bashwiner (2018, p. 495), is "the generation (and modification) of novel note and duration sequences". It is unique for three reasons: it integrates motor and auditory patterns, occurs mostly at the unconscious level, in the "implicit system" (Dietricht & Haider, 2015), and is evaluated on the basis of pleasure rather than objective measures.

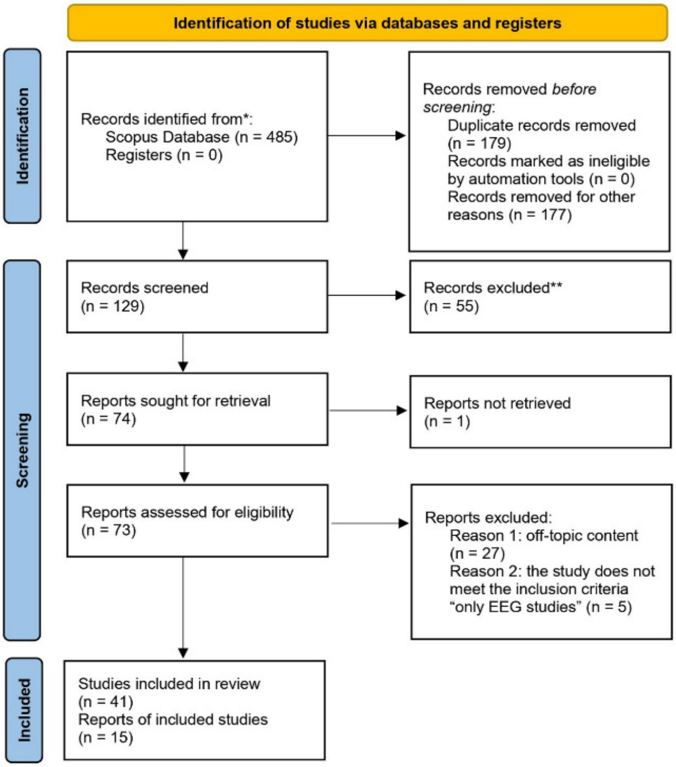

Figure 1. PRISMA flow diagram. The PRISMA flow diagram provides a detailed visual representation of the study selection process conducted for this systematic review. The diagram clearly outlines the number of studies at each stage of the review process, providing transparency in study selection. Source: Page et al. (2021)

Improvisation is a form of musical creativity which combines melodies, rhythms, dynamics, and colours spontaneously to generate an "instant composition" (Dobbins, 1980), reflecting the creators' experience and impacting both them and the audience emotionally (Dikaya & Skirtach, 2015). Musical improvisation well exemplifies "ecological creativity" (Boden, 1994), where something new is born.

Unlike musical composition, which requires cognitive effort, improvisation is spontaneous and happens quickly and in real-time. Max Richter explained that composers "manufacture a space where this story can happen", stressing the cognitive load involved in composition (Stone-Davis, 2015). In contrast, improvisation is immediate.

1.2 Musical improvisation

Musical improvisation has long been part of Western classical music. Composers such as Bach, Mozart, Beethoven, Liszt, and Chopin often improvised their works before writing them down (Dolan et al., 2013). In the 19th century, however, "faithfulness to the composer's score" dominated live performances (Dolan et al., 2018). With the jazz turn, musicians often improvised without sheet music, giving their product a highly personal sense. Keith Jarret's 1975 Köln piano concert is a famous example of "channelling a stream of intuitive thoughts" in real time (Lopata et al., 2017). Improvisation is also key in rock music, as seen with Led Zeppelin and Deep Purple, where guitar or keyboard solos are modified from the studio-recorded version, and in rap's freestyle, where artists improvise rhyming lyrics (Liu et al., 2012). Over time, improvisation has spread across genres, showcasing its ability to constantly reinvent itself and support learning, divergent thinking and self-actualization (Landau & Limb, 2017).

2. Musical improvisation and state of flow

EEG methodology can provide data with high temporal resolution, making it useful for in-depth exploration of creative processes (Stevens & Zabelina, 2019). While methods like functional Magnetic Resonance Imaging (fMRI) are common in creativity research, EEG has higher ecological validity due to fewer physical constraints, minor invasion, and lack of noise, so it is more suitable for sensitive populations, such as children or claustrophobic people.

A topic investigated through EEG is the state of flow during musical improvisation (Chirico et al., 2015). Csikszentmihalyi (1975, 1996) defined the multidimensional phenomenon of "flow" as a state of intense focus, control, and action awareness during an activity perceived as highly self-rewarding, characterized by clear goals and feedback, altered time perception, loss of self-consciousness, and a balance between challenge and skill. This immersive experience can also be experienced during musical improvisation.

Dolan et al. (2018), by analyzing brain activity with EEG, investigated the differences between improvised and scored performances of a piece by Franz Schubert in both musicians, in particular a professional polyphonic trio (consisting in voice, flute and piano), and listeners in order to observe whether a certain "state of mind" experienced by the musicians is elicited in the listeners. The authors considered the connection between flow and musical improvisation exploring whether it aligns with Carhart-Harris's (2014) Entropic Brain Hypothesis (EBH), which distinguishes between high entropy "primary states" (e.g., REM sleep, psychedelics) and low-entropy "secondary states" typical of everyday life. They wondered whether improvisation can be understood as a "primary state". High Lempel-Ziv (LZ) signal complexity, an EEG measure for entropy, was observed during improvisation. In post-performance evaluations musicians reported greater mental and physical freedom and surprise at their improvisations, reflecting a "non-conscious-analytic" use of musical knowledge, with more pleasure and less effort.

The fact that musical improvisation involves elements dating back to the flow was supported not only by musical analysis – which revealed, for example, longer phrasing, greater violations than the score, with increased risk-taking – but also by listeners' evaluations, who, even blindfolded, regarded improvisations as more emotionally engaging.

EEG data also showed high LZ complexity during musical improvisation, specifically in the right hemisphere, a response which was also detected in listeners, supporting the idea that musicians' flow states can be transferred to audiences, without this being due to performance observation, the musicians' movements, and the level of expertise. In conclusion, the link between improvisation and flow was confirmed, where creativity, emotional connection, and shared experiences emerge in real-time.

3. Improvisation is not just spontaneity

Although improvisation is a practice where musicians spontaneously express creativity to generate new melodies, it also requires cognitive control to decide what to play and link together ideas in novel combinations (Landau & Limb, 2017). The medial frontal cortex, responsible for motor task planning, enables sequential organization of ideas, such as harmonic structure and timing pitches and dynamics (Norgaard, 2014). Sasaki et al. (2019) studied EEG activity in fourteen subjects playing guitar, a polyphonic instrument, with little experience in improvisational practice. In the "Scale" condition, subjects played a major scale with predetermined chords, while in the "Improv" condition they improvised using the same chord. Higher alpha and beta activity was found in the medial frontal (MFC) and prefrontal cortex (MPFC) during improvisation, linked to internal control and attention respectively. MPFC activation is linked to internally generated thoughts, self-expression (Landau & Limb, 2017), and creative processes (Beaty et al., 2014). Additional alpha 1 (8.5-10 Hz) and alpha 2 (10.5-12 Hz) activity was found in regions associated with perceptual motor control (premotor cortex, PMC), sensory feedback regulation (inferior parietal lobe, IPL), and acoustic monitoring (right and left superior temporal gyrus, STG).

Contrary to previous studies (Pinho et al., 2014; McPherson et al., 2016), the authors observed increased dorsolateral prefrontal cortex (DLPFC) activity in the beta band (21.5-30 Hz) during musical improvisation, which is associated with outward-directed attention (Hendelman, 2016). This difference is attributed to participants' level of experience, as novices require more motor coordination, relying on executive control, which explains increased DLPFC activity in participants with approximately two years of experience, unlike experienced musicians who depend on automatic, flow-related processes. Studies also suggest that the strictness of improvisational task rules can influence DLPFC activation: greater restrictions result in higher activation (Pinho et al., 2016), while tasks involving emotional representation result in lower activation. McPherson et al. (2016) noted lower DLPFC activity when improvising with positive emotions.

Relative to the balance between control and spontaneity in improvisation, Rosen et al. (2020) proposed a dual-process creativity model. Creativity involves type 1 associative processes – which are fast, automatic, and unconscious – and type 2 executive control processes, which are slower, controlled, conscious, and require cognitive effort. According to the authors, the equilibrium between these processes is mediated by the subject's experience. In their study using high-density EEG, brain activity was recorded from 32 jazz guitarists with varying experience as they improvised on the basis of professional jazz chord sequences. Spectral power analyses (SPM) assessed the effects of performance quality, rated by experts, and improvisation experience, measured by the number of live jazz concerts. SPM results showed left hemispheric beta and gamma activity in posterior regions (CP3, P5, PO7, FC1) for high-quality improvisations, while low-quality performances were linked to temporo-parietal (TP8) and right frontopolar (FP1, FP2) activity. When adjusting for experience, the best improvisations showed right hemispheric activity in the frontal lobes. In the high vs. low-quality contrast significant clusters were observed in the right frontal region, with gamma activity around C3 (41 Hz) extending to F3 (43 Hz). The low-quality contrast revealed clusters around TP8 and the frontopolar electrode FP2 (beta: 28 Hz, gamma: 33 Hz) and alpha activity near FC2 (10 Hz). Furthermore, experienced improvisers showed gamma activity in left fronto-central and posterior regions (near FCz, 32-45 Hz), while less experienced players had beta and gamma activity in frontal and prefrontal regions, particularly around AF3 (14-20 Hz) and FC6 (22-47 Hz).

The findings indicate a balance between associative (type 1) and executive (type 2) processes, regulated by frontal activity. However, this changes with experience: beginners rely more on type 2 processing, as seen in heightened frontal and prefrontal activation, linked to cognitive control. In contrast, professionals, while maintaining some control, rely more on type 1 processing, with reduced frontal activity and greater engagement of posterior regions. Both groups use type 2 processing, but experienced musicians automate key creative aspects, allowing type 1 processes to dominate and enabling more flexible chord combinations and "harmonic violations" (Bianco et al., 2017).

Lopata (2017) examined alpha brain activity (8-13/14 Hz) and found significant frontal activity during musical tasks with varying creativity levels, comparing musicians with and without formal improvisation training. This study aimed to observe changes in frontal activity between spontaneous and deliberate creativity tasks. The study assessed alpha band activity, linked to type 1 intuitive states (Fink & Benedek, 2014), in three tasks with distinct creativity levels: passive listening, memory playback, and free improvisation. The non-trained group (non-FITI) exhibited less hemisphere activity across all tasks, while greater alpha activity in the right hemisphere was noted during listening and moderate activity in the other tasks. Conversely, the trained group (FITI) showed modest left hemisphere during passive listening, increasing gradually in memory playback and improvisation, with significant right hemisphere activity, particularly in free improvisation. Correlational analyses revealed differences between groups. The non-FITI group showed no significant correlations between left and right frontal alpha activity and age and musical or improvisational experience. However, negative correlations emerged between improvisation and musical experience and between improvisation and experience in improvisation. In contrast, the FITI group exhibited correlations between frontal alpha activity in both hemispheres and all tasks, with positive correlations between left frontal activity and age and musical and improvisational experience, while no significant right hemisphere correlations were observed. Thus, spontaneous type 1 activity was present in subjects with improvisation training.

A second aim of this study was to examine if frontal alpha activity correlated with higher creative performance, evaluated using the Musical Improvisation Performance Questionnaire (MIPQ). Results showed a correlation between right frontal alpha activity and MIPQ scores in the trained group, suggesting that this activity supports spontaneous processing and improves performance, consistent with Sasaki et al. (2019). In conclusion, musical improvisation appears to balance cognitive control and spontaneity, influenced by experience and reflected in frontal lobe activity.

4. Emotional correlates in musical improvisation

Music, like any artistic activity, allows the expression of a wide range of emotions. McPherson et al. (2016) highlighted the close link between emotions and musical creativity through an fMRI study that showed emotional intent modulates prefrontal areas (e.g., MPFC and DLPFC) involved in musical creativity during improvisation. While studies exist on emotions in musical performance (Ghodousi et al., 2022; Pousson et al., 2021), there is a lack of research on emotions experienced during musical tasks with varying creativity levels. Ramirez-Melendez and Reija (2023) address this gap.

The study aimed to investigate emotional correlates in ten professional musicians playing polyphonic drums during three tasks: rhythmic exercise, pattern-based improvisation, and rhythmic improvisation. EEG was recorded from AF3, F3, AF4, and F4 electrodes on the prefrontal lobe, crucial for emotional regulation, at baseline and during the tasks. Arousal was calculated as the inverse of the alpha brainwaves (8-12 Hz) across the four prefrontal areas [(arousal = 1/ (αF3 + αF4 + αAF3 + αAF4)], while valence was assessed via the alpha difference between F3 and F4 (valence = αF4-αF3). Arousal levels showed no significant differences between baseline and tasks. No distinct frontal lobe alpha activity was observed during improvisation, aligning with the literature's lack of consensus on frontal alpha spectral power increase during creative tasks. However, valence levels were higher during both improvisation tasks compared to baseline and higher in free improvisation than in pattern-based improvisation. The authors linked this increase to greater right prefrontal alpha power relative to the left. These findings suggest that generating original ideas is closely associated with positive emotions, particularly in freer creative processes.

Dikaya and Skirtach (2015) examined the relationship between emotions and improvisation focusing on neurophysiological correlates through spectral power and coherence. They compared improvisation with melody perception, mental reproduction, and mental improvisation, while also assessing differences based on chord modes (major for positive, minor for negative emotions) and musicians' expertise. Results showed significant spectral power and coherence differences between resting state and musical tasks, with delta band (0.5-4 Hz) increases in the left frontal cortex and left temporal cortex during improvisation, particularly in auditory associative regions, linked to rhythm perception and complex music processing. Additionally, beta 1 band increases were observed along the "creative axis" and coherence analysis showed strong long-distance and interhemispheric cortical connections in beta 1 (13-24 Hz) and beta 2 (24-35 Hz) bands. Distinct neurophysiological correlates showed different brain activations based on musical modality. Significant effects in the theta band (4-8 Hz) were found in anterior and posterior regions. Major chords induced positive emotions, with increased spectral power in the left anterior theta and beta1 bands, and low-frequency, short-distance coherence in the left hemisphere. In contrast, minor chords elicited negative emotions, showing increased low-frequency power in the right frontal and temporal regions, along with low-frequency, short-distance connections, and high-frequency, long-distance connections in the right hemisphere. The results showed frontal activity in both hemispheres during improvisation, with left-hemisphere dominance and short-distance connections for positive emotions and right-hemisphere dominance with both short- and long-distance connections for negative emotions. This challenges theories linking creativity primarily to right-hemisphere activity (e.g., Jung et al., 2013). The observed high-frequency connectivity, unlike studies that did not support increased neural connectivity (e.g., Fink & Benedek, 2014), may reflect more challenging improvisations. In professional musicians, high-frequency interhemispheric connections were noted, likely indicating internal resource activation during creative idea generation and originality assessment.

5. The use of tDCS in musical improvisation

Transcranial direct current stimulation modulates brain activity depending on the parameters used. Studies by Fujiyama et al. (2014) and Furuya et al. (2013) explored its effects on the motor cortex in pianists with different training levels, assessing finger dexterity and fine motor control. Anic et al. (2018) used tDCS to alter left motor cortex activation in jazz pianists during right-hand improvisation. Additionally, tDCS was shown also to influence the evaluation of musical performance (Colombo et al., 2021).

Rosen et al. (2016), following the dual-process model of creativity, examined how tDCS interacts with jazz pianists' experience during improvisation. They targeted electrode F4 near the right DLPFC finding that anodal tDCS improved performance in less experienced pianists by reducing activity in frontoparietal executive regions, which typically hinders novices (Pinho et al., 2014). This enhanced type 2 processes (explicit control) in novices but impaired experienced musicians. Cathodal stimulation, expected to enhance type 1 processes in experts, showed no prefrontal deactivation increase, possibly due to compensatory effects from other brain areas that mask the inhibitory effects. Cathodal stimulation helped novices by reducing prefrontal dominance, promoting a bottom-up approach. This study offers insights into neuroplasticity in musical creativity, with potential applications in other creative fields, and could help novices improve improvisation skills.

6. Limitations

Limitations of these contributions regard the samples, as they considered Western populations. It could be interesting to study also other populations to check if cultural factors are crucial. The reviewed studies also did not involve children, disabled people, or those with mental disorders and this could be a starting point for authors to investigate in the future. It would be intriguing to conduct further EEG studies that take into consideration various instruments, including less conventional ones (e.g., metallophones, bells, or electrophones) in musical improvisation and compare findings with existing literature to assess potential differences.

7. Conclusions

This article reviewed key studies on brain activity during musical improvisation focusing on those using EEG. Cognitive control, state of flow, and emotion were examined. Consistent with a dual-process creativity model, findings highlight a balance between spontaneity (type 1 processes) and control (type 2 processes), modulated by experience. Both processes are always present, but professionals favor spontaneity, while novices rely more on control. Frontal areas, specifically the medial and dorsolateral prefrontal cortex, mediate this balance. Studies also linked improvisation to positive emotions, especially in major keys improvisation. Finally, tDCS has been proposed as a potential tool to enhance improvisation skills in novices.

Indirectly these studies suggest that empowering improvisational skills needs both the acquisition of techniques and strategies which the learner should know so to be enabled to apply them deliberatively during the generation of new pieces of music. This should be the proper approach at the beginning of the apprenticeship process (Colombo & Antonietti, 2017). On the other hand, the parallel message coming from this field of investigation is that relying on emotional cues when the goal is to create music is important as well. This second approach is more appropriate to expert musicians than novices.

Neurofeedback and tDCS devices could potentially develop for music courses, both at an amatorial and professional level, aimed at teaching improvisation and neurofeedback tools that might be used autonomously by people when they are engaged in musical composition. More precisely, such devices could enhance the skills of those with less expertise in such creative practice.

Other future areas of application may be in mental health and well-being psychology, as improvisation can lead to the expression of positive emotions and thus alleviate possible stressful situations or improve the condition of mental disorders such as anxiety and depression. Future studies could move in these directions, considering not only those with some experience in the field of music, but also different audiences. For example, musical improvisation can be used in schools to develop creative thinking. As Ramón and Chacón-López (2021) pointed out, improvisation can provide information about children's comprehension skills and become a valuable assessment tool for teachers.

Finally, the reviewed studies may have implications also in music therapy practice. Many methods to alleviate the consequences of mental disorders or to lead patients to overcome the limits associated to their pathologies through music ask the clients to improvise, both with musical instruments or with objects or with their voice (Antonietti, 2009). Putting the clients in the relevant mind state can be crucial in order to allow them to exploit their potentialities in musical improvisation.

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Ethical statement

This study is a review of the existing literature and did not involve any experimentation on human or animal subjects. Every information is presented transparently, without omissions or manipulation. This review was conducted in accordance with ethical guidelines for scientific publication. The list of authors correctly reflects the contribution of each member. The authors declare no conflicts of interest.

Author's contributions

All authors contributed to the development and the conceptualization of the article. GG conducted the bibliographic research and wrote the draft version of paper and AA contributed to its revisions.

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SUPPLEMENTARY MATERIALS

Table 1. Summary Table. This Table provides a summary of the main studies included in the review, in order of mention, with details on the authors, year of publication, sample studied, methods used and main results

Author/s	Year of publication	Sample	Method	Main results
Dolan et al.	2018	A professional trio (chamber ensemble) consisting of voice, flute and piano, expert in classical improvisation and an audience of twenty-two adults, with different levels of experience and musical training.	Experimental research	The improvised performance of a piece is physically and mentally freer than its standard version, and it is rated better than the standard one. Musical improvisation involves elements linked to flow experience in both players and listeners.
Sasaki et al.	2019	Fourteen guitarists. Gender: male. Age: 21-41 years (M = 25.12) with little experience playing the guitar. All participants have at least two years of experience in guitar improvisation and one year of experience in songwriting.	Experimental research	Musical improvisation is mediated by processes involved in coordinating planned movement sequences. DLPFC activity differs according to participants' experience: lower activity associated with less executive control and related to the concept of "flow" is observed for experienced musicians, while musicians with less expertise follow the opposite trend.
Rosen et al.	2020	Thirty-two jazz guitarists. Gender: 31 men, 1 woman; Age: 18-55 years (M = 27.9); Musical training: 4-	Experimental research	Both beginners and professional rely on type 2 processing but those with more experience reduce cognitive control and allow type 1 associative processing

		33 years (M = 15.91); Experience: 6-1500 live jazz performances (M = 344.88)		to dominate.
Lopata et al.	2017	Twenty-two jazz and classical musicians. Gender: 13 male, 9 female; Average age: 26.2 years; Average experience in playing: 18.5 years; Average experience in improvisation: 10.2 years	Experimental research	Individuals showed higher frontal alpha band activity, associated with type 1 processing, during musical improvisation than during less creative tasks and this effect is greater for musicians with formal improvisational training. Subjects with prior improvisation training, type 1 spontaneous processing tends to produce higher quality improvised performance, rated better overall by experts in the field.
Ramirez-Melendez & Reija	2023	Ten professional right-handed drummers. Gender: male; Average age: 34 years; Experience: M = 18.7 years; Experience in improvisation: M = 12.9 years; Training in jazz improvisation: M = 5.2 years	Experimental research	In terms of arousal, no significant differences were observed between the baseline condition and the three tasks. In contrast, valence levels were higher in both improvisation tasks, compared to baseline, and in free improvisation compared to pattern-based improvisation. This is indicative of positive emotions and an overall improvement in mood, so the freer the creative process, the greater the positive effect.

Dikaya & Skirtach	2015	136 practicing musicians. Gender: 102 males and 34 females; Age: 19-36 years; Experience: 56 professionals and 80 amateurs. The musicians were pianists, guitarists, and drummers.	Experimental research	In the improvisation condition, an increase in spectral power in the delta band is detected at the level of the left temporal cortex, particularly in the auditory associative regions. Different brain areas were activated depending on the musical modality presented: for major chords in the perceptual task, participants reported experiencing positive emotions, while minor chords are associated with negative emotions.
Osen et al.	2016	Seventeen jazz pianists. Gender: 15 males, 2 females; Age: 19-34 years; Music training: M = 17.17 years old; Jazz training: M = 7.29; Improvisational experience and expertise: M = 108.53 live jazz concerts	Experimental research	The anodal stimulation applied near the right DLPFC, which is related to the subjects' level of experience, allows those with less experience to perform better but hinders the performance of musicians with more experience. As for the cathodal stimulation on the same brain area, there is no further increase in prefrontal deactivation in experienced pianists, while for novices, there is a reduction in prefrontal dominance.