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Stimulation of the Primary Motor Cortex Enhances Creativity and Technical Fluency of Piano Improvisations

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ABSTRACT

Musical improvisation is an ecologically valid and contextually appropriate medium to investigate the neuroscience of creativity. Previous research has identified several brain regions that are involved in musical creativity: the dorsolateral prefrontal cortex (DLPFC), the ventral medial prefrontal cortex (vMPFC), the pre-supplementary motor area (pre-SMA), and the ventral and dorsal premotor cortex (vPMC and dPMC, respectively). These brain regions underpin high-level processing and motor functions. The present study asked whether the primary motor cortex (M1 region) plays a role in creativity and technical fluency. The M1 region underpins the acquisition and consolidation of novel motor skills and hand movement. Here, we used transcranial direct current stimulation (tDCS) to investigate the overarching research question. tDCS is a non-invasive mode of brain stimulation that is delivered via two saline-soaked electrodes diametric in charge: the anodal electrode *stimulates* neural activation; the cathodal electrodes *inhibits* neural activation. A bi-hemispheric, online tDCS montage was used. Eight proficient pianists were recruited and separated into two tDCS groups: Anodal-Left M1/Cathodal-Right M1 (n = 4) and Cathodal-Left M1/Anodal-Right M1 (n = 4). tDCS was administered whilst participants performed musical improvisations. The level of creativity and technical fluency was judged independently by an expert musician adjudicator. We hypothesised that the Anodal-Left M1/Cathodal-Right M1 (excitatory) tDCS group will demonstrate an enhancement of creativity and technical fluency compared to the Cathodal-Left M1/Anodal-Right M1 (inhibitory) tDCS group. The preliminary results show that during musical improvisation, creativity (p = .07) and technical fluency (p = .05) increased when excitatory tDCS was applied to the left M1 region of proficient pianists. Furthermore, there was no apparent decrease in creativity and technical fluency for the inhibitory tDCS group. In light of these preliminary findings, we conclude that there is some evidence that the M1 region contributes to musical creativity. Future work with a larger sample size will shed further light on this contribution.

I. INTRODUCTION

Investigating the neural underpinnings of creative cognition is important to understand how novel ideas and behaviour manifest. The two key constituents of creativity include: *originality* and *congruency* (Boccia, Piccardi, Palermo, Nori & Palmiero, 2015). Originality involves the generation of novel responses to a stimulus; congruency relates to the appropriateness of the responses given in a specific context (Dietrich, 2004). Musical improvisation is a quintessential creative behaviour that can be investigated using neuroscientific methods to identify specific brain regions that contribute to creativity (McPherson & Limb, 2013). A prominent method used to investigate musical creativity is functional magnetic resonance imaging (fMRI) (e.g., Limb & Braun, 2008). fMRI measures the blood-oxygenated level dependent (BOLD) signal that indicates the activation and deactivation patterns of brain regions in response to a stimulus (Sawyer, 2011). We now review the core brain regions involved in musical improvisation – a form of musical performance that requires, by definition, creativity (Bengtsson, Csıkszentmihalyi & Ullén, 2007).

A. Brain Regions Involved in Musical Improvisation and Creativity

Previous literature has shown that several brain regions are involved in creative music improvisations: the dorsolateral prefrontal cortex (DLPFC), which is part of the Executive Control Network (ECN) and regulates attention, working memory and monitoring (Limb & Braun, 2008; Bengtsson, Csıkszentmihalyi & Ullén, 2007); and the ventral medial prefrontal cortex (vMPFC), which is part of the Default Mode Network (DMN) and regulates mental simulation and mind wandering (Bashwiner, Wertz, Flores & Jung, 2016). Importantly, these brain regions are diametrically opposed; the activation of one (e.g., ECN) results in the deactivation of the other (e.g., DMN) (Limb & Braun, 2008; Bengtsson, Csıkszentmihalyi & Ullén, 2007; de Manzano & Ullén, 2012a).

However, recent studies have also shown that these two brain regions operate concurrently in musical improvisations (Pinho, Ullén, Castelo-Branco, Fransson & de Manzano, 2016). Further research has investigated high-level motor areas and their role in musical creativity, including the pre-supplementary motor area (pre-SMA) and the premotor cortex (PMC). The PMC can be further separated into the ventral premotor cortex and dorsal premotor cortex (vPMC & dPMC, respectively) (Berkowitz & Ansari, 2008; de Manzano & Ullén, 2012a). These premotor areas are interconnected and involved in cognition (Bashwiner et al. 2016). Specifically,

the pre-SMA is involved in timing aspects of performance; the PMC is involved in performance of original motor tasks (Berkowitz & Ansari, 2008; de Manzano & Ullén, 2012a). The focus of the present study is on the primary motor cortex (M1 region) and its possible role in mediating creativity and also technical fluency in the context of improvised jazz performance.

B. The Primary Motor Cortex

The M1 region is involved in the consolidation and acquisition of new motor skills (Sosnik, Flash, Sterkin, Hauptmann & Karni, 2014; Karok & Witney, 2013). Furthermore, the M1 underpins movement properties of the hand that include: dexterity, finger individuation, velocity, and direction (Sosnik et al. 2014). The M1 region covers both hemispheres of the brain (Vines, Nair & Schlaug, 2008). The connection between the two hemispheres is inhibitory in nature, and this is known as the inter-hemispheric inhibition connection (IHIC) (Vines, Nair & Schlaug, 2008). In other words, when the M1 region of a specific hemisphere is activated (e.g., the left M1), the right M1 is inhibited through the IHIC system to further concentrate activation to the left M1 region (Vines, Nair & Schlaug, 2008). Moreover, the left M1 mediates control of the right hand, whereas the right M1 mediates control of the left hand (Vines, Nair & Schlaug, 2008). Studies have confirmed that the M1 region operates asymmetrically. For instance, Vines, Nair and Schlaug (2008) found in right handers that stimulating the left (dominant) M1 region with transcranial direct stimulation (tDCS) had effects for both hands; whereas, stimulating the right (non-dominant) M1 region had effects for the contralateral (opposite) hand. For the purpose of experimental control in the present study, pianists were instructed to only use their right hand when performing jazz improvisations.

C. Technical Fluency in Musical Improvisations

In a musical context, technical fluency refers to the technical ability of the performer to express musical ideas with their musical instrument. Together with creativity, technical fluency of musical improvisations in the present study are measured. It is, however, yet to be determined if these components are related. Thus, another aim of the study is to assess whether technical fluency and creativity are related in an improvised jazz context.

D. Transcranial Direct Current Stimulation

In this study, tDCS was applied to modulate the activation of the M1 region of proficient musicians. tDCS is a neuro-modulatory brain stimulation technique that alters the activation patterns of neurons over a desired area (Karok & Witney, 2013; Vines, Nair & Schlaug, 2008). tDCS is comprised of two saline-soaked electrodes that deliver two different charges: the anode (positive) electrode stimulates neural activity; whereas the cathode (negative) electrode inhibits neural activity (Nitsche, Schauenburg, Lang, Liebetanz, Exner, Paulus & Tergau, 2003). There are disparate tDCS methodologies that have been used in previous studies (e.g., Furuya, Klaus, Nitsche, Paulus & Altenmuller, 2014). There are two forms of tDCS that are used for experimentation: Online vs. offline tDCS. Online tDCS involves the *simultaneous* application of tDCS and measurement of task performance; whereas, offline tDCS involves a *separation* of stimulation and task performance (Karok & Witney, 2013).

Furthermore, there are two tDCS configurations (placement) of electrodes: unihemispheric and bihemispheric. Unihemispheric tDCS involves one electrode (either the anodal or cathodal) over a specific area and hemisphere of the brain (e.g., the left DLPFC) and the remaining electrode is placed on the contralateral (opposite) hemisphere's mastoid (behind the ear) and serves as a reference and concentrates stimulation (Karok & Witney, 2013). Bihemispheric tDCS is comprised of both electrodes placed on both hemispheres of the brain (e.g., left and right M1 region) stimulating one hemisphere and inhibiting the other (Waters-Metenier, Husain, Wiestler & Diedrichsen, 2014). A study conducted by Karok & Witney (2013) investigated the optimal tDCS configuration and found bihemispheric, online tDCS is a superior method compared to unihemispheric tDCS (Karok & Witney, 2013). Therefore, the present study incorporated a bihemispheric, online tDCS montage.

E. Aims, Design & Hypothesis

The aims of the study were to: (1) investigate the M1 region as a possible brain region that contributes to musical creativity and technical fluency; and (2) assess the possible relationship between technical fluency and creativity in the context of a musical improvisation. There were two tDCS conditions: Anodal-Left M1/Cathodal-Right M1 (n = 4) and Cathodal-Left M1/Anodal-Right M1 (n = 4). We predicted that the application of Anodal-Left M1/Cathodal-Right M1 tDCS would improve creativity and technical fluency relative to the application of Cathodal-Left M1/Anodal-Right M1 tDCS.

II. METHOD

A. Participants

Eight proficient jazz pianists (4 female; mean age = 20.25, SD = 2.25) and one independent expert musician adjudicator participated in the study. Six of the eight participants were right-handed; one participant was left-handed and one was mixed-handed. All participants gave informed consent to participate in the study. A TMS screener was administered prior to tDCS application to ensure that participants did not have any neurological disorders, metal implants, or any other brain-related conditions that may cause risk or harm. All participants satisfied the TMS screener. Participants were reimbursed $50 or course credit for their participation. This study was approved by the Macquarie University Human Research Ethics Committee (HREC Medical Sciences) Reference number: 5201600392.

B. Stimuli

Ten original musical pieces were written specifically for this study to ensure novelty. All pieces incorporated an electronic drum kit, electronic piano, grand piano and live electric bass guitar. The electronic drum kit, electronic piano, and grand piano were programmed using *Notion* music generation software; the live electric bass was recorded using *GarageBand* and was performed by the first author. Each musical piece contained a total of ten bars. As shown in Figure 1, the first bar involved a four-beat count-in using the high-hat of the drum kit to indicate that the piece is about to begin. The next four bars, indicated with the rehearsal mark 'A', involved all instruments and a novel melody which was presented on the treble clef only. Participants played along to the melody while sight-reading a musical score. The next section, indicated with the rehearsal mark 'B', consisted of five measures representing the section when participants performed their improvisations. All the pieces were written to conform to the jazz genre in terms of harmonic and rhythmic qualities. Six of the ten pieces were written in varying major key signatures; the remaining four pieces were written in varying minor key signatures. All ten pieces were programmed at 90 beats per minute.

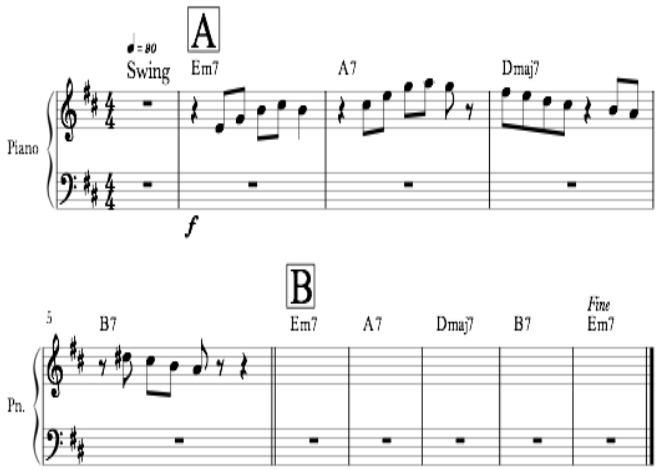

Figure 1. A sample of the stimuli used in the experiment. The stimuli was divided into two sections: Section 'A' required sight-reading a novel melody to ensure ecological validity and a context on which to base their improvisations. Section 'B' was the improvisation section that was designated for improvisations. Participants played with their right-hand only.

C. Equipment

A bihemispheric, online tDCS montage was used in the study. tDCS consisted of two saline-soaked electrodes (anode and cathode). The electrodes were placed on C3 and C4 sites that correspond to stimulation of the M1 region. These sites are derived from the 10-20 electroencephalogram system that specifically targets the M1 region. tDCS was programmed to deliver 1.4mA constantly during the session. The participants were subjected to tDCS stimulation lasting between fifteen and twenty-one minutes (including ramp-up and ramp-down). This duration of tDCS is considered safe (Bikson, Datta and Elwassif, 2009). The ramp-up period lasted 30 seconds when the session began; the ramp-down period lasted 30 seconds at the session. All participants were stimulated for two and a half minutes (including the ramp-up period) before the task commenced to ensure a controlled and adequate degree of stimulation was administered before the performance began.

tDCS was administered using the Neuro-Electrics Instrument Controller (NIC) on a 15-inch MacBook Pro. The NIC software controlled the configuration of tDCS and allowed the impedances of the electrodes to be monitored. An 11-inch MacBook Air was connected via a ThunderBolt cable to a 27-inch iMac to present the musical stimuli to the participants. The 11-inch MacBook Air was used by the experimenter to organise and record the performances. All performances were conducted on a Musical Instrument Digital Interface (MIDI) keyboard.

D. Experimental Paradigm

The participants were pseudo-randomised into the two tDCS stimulation groups: Anodal-Left M1/Cathodal-Right M1 (n = 4) and Cathodal-Left M1/Anodal-Right M1 (n = 4). The ten novel musical stimuli were initially randomised into two melodic sequences to organise the presentation of the stimuli; each melodic sequence consisted of five of the ten musical stimuli and corresponded to the two blocks of the experiment. For each participant, the trials within the respective melodic sequence were randomised to mitigate any presentation bias due to order effects. The experimental paradigm consisted of two blocks: block one served as the control in which no tDCS was administered; block two consisted of one of the two types of tDCS stimulation. See Table 1 and Figure 2 for a detailed description of the experimental paradigm and design. The duration of the experiment lasted for approximately 90 minutes.

Table 1. Experimental conditions used in the study.

Group	Block one	Block two	Melodic sequence
1A	**No treatment**	**Anodal-Left M1/Cathodal-Right M1**	**Melodic sequence 1 – Melodic sequence 2**
1B	**No treatment**	**Anodal-Left M1/Cathodal-Right M1**	**Melodic sequence 2 – Melodic sequence 1**
2A	**No treatment**	**Cathodal-Left M1/Anodal-Right M1**	**Melodic sequence 1 – Melodic sequence 2**
2B	**No treatment**	**Cathodal-Left M1/Anodal-Right M1**	**Melodic sequence 2 – Melodic sequence 1**

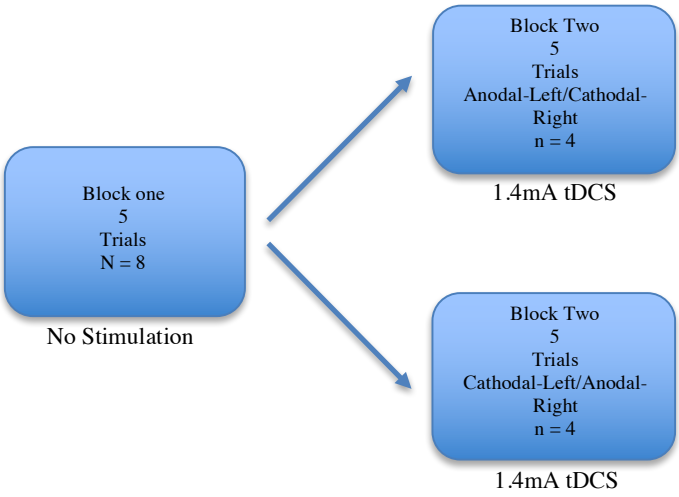

Figure 2. The experimental procedure. The first block consisted of five trials with no stimulation. The second block consisted of five trials with tDCS stimulation set at 1.4mA.

E. Procedure

Upon entering the laboratory, participants were presented with the TMS screener to determine if the application of tDCS was safe to administer. Participants then provided informed consent and completed a demographic questionnaire. To familiarize the participants with the experiment, two practice trials were administered. Both the practice trials and experiment trials consisted of two stages: familiarisation and performance.

The familiarisation stage consisted of two playings of each stimulus. In the first playing, the participant was instructed to listen and follow the melody presented in section 'A' *without* playing the piano. The entire duration of the stimuli was presented. In the second playing, the participants were instructed to play the melody presented in section 'A' with their right hand only. Section 'B' in the second playing was not played. In the familiarisation stage, the piano accompaniment playing the melody in the section was played through the speakers. The purpose of the familiarisation stage was to ensure that the participants were familiar with the procedure of the trial. A sub-set of participants required more playing's to be familiar with the piece before the performance.

In the performance stage, two opportunities to play the entire trial was afforded. The participants were instructed to play the melody presented in section 'A' and then improvise in section 'B'. Importantly, the piano accompaniment was removed during their improvisation. Participants were informed of this instruction prior to the commencement of the performance stage. The audio from all the trials were randomised across participants, conditions, and blocks, and collected onto a USB and sent to the independent expert musician adjudicator for evaluation.

F. Expert Adjudication

In order to adjudicate the performances, the independent expert musician adjudicator was presented with the audio files of all trials and the musical stimuli used in the study. The adjudicator was blind to each participant's allocated condition. In the adjudicator's instructions, the definitions of technical fluency and creativity were outlined to create a well-defined focus for adjudication of these constituents of performance. Both technical fluency and creativity were judged using two separate Likert scales ranging from one to ten. A score of one represented a low level of creativity/technical fluency; a score of ten represented a high level of creativity/technical fluency.

III. RESULTS

A. Creativity in Musical Improvisation

An independent samples *t*-test was computed to compare the mean difference in creativity scores between block one (control) and block two (stimulation) for the two tDCS groups: Anodal-Left M1/Cathodal-Right M1 (excitatory tDCS) and Cathodal-Left M1/Anodal-Right M1 (inhibitory tDCS). The analysis revealed that creativity increased for the excitatory tDCS group (M = 1.20, SD = 0.82) compared to the inhibitory tDCS group (M = .15, SD = .50) and this difference approached statistical significance; $t(6) = 2.19$, $p = .07$. A Cohen's d effect size calculation revealed a large effect size, $d = 1.55$. The present results demonstrate that there is a trend that stimulation of the left M1 region in musical improvisation enhances creativity. See Figure 3 for the mean creativity scores for both tDCS groups.

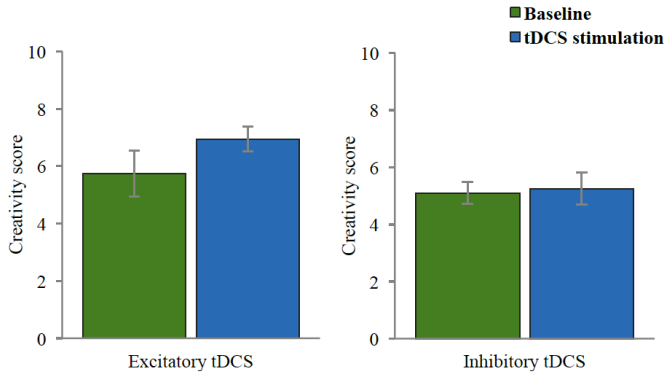

Figure 3. Mean creativity scores for both tDCS groups and the difference between baseline and tDCS stimulation blocks.

B. Technical Fluency in Musical Improvisations

An independent samples *t*-test was computed to compare the mean difference in technical fluency scores between block one (control) and block two (stimulation) for the two tDCS groups: Anodal-Left M1/Cathodal-Right M1

(excitatory tDCS) and Cathodal-Left M1/Anodal-Right M1 (inhibitory tDCS) between block one (control) and block two (stimulation). The analysis revealed that technical fluency increased for the excitatory tDCS group (M = 1.05, SD = 0.41) compared to the inhibitory tDCS group (M = .20, SD = .57). This difference was statistically significant; $t(6) = 2.42$, $p = .05$. A Cohen's d effect size calculation revealed a large effect size, $d = 1.72$. See Figure 4 for the mean technical fluency scores for both tDCS groups. Interestingly, there was no apparent decrease in creativity *and* technical fluency for the inhibitory tDCS group.

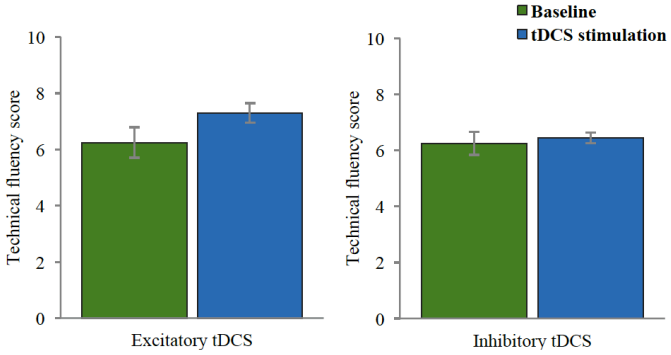

Figure 4. Mean technical fluency scores for both tDCS groups and difference between baseline and tDCS stimulation blocks.

C. Correlation Between Technical Fluency and Creativity

A Pearson's r correlation coefficient was computed to determine if there is a significant relationship between technical fluency and creativity. Firstly, all eighty trials from both stimulation groups across all blocks and participants were used in the analysis. There was a statistically significant positive correlation between technical fluency and creativity, irrespective of tDCS group, $r(78) = .765$, $p < .001$. Further analyses were conducted by separating the trials to the respective stimulation groups (excitatory tDCS = 40 trials; inhibitory = 40 trials). There was a statistically significant positive correlation between technical fluency and creativity scores for the excitatory tDCS group, $r(38) = .820$, $p < .001$ and the inhibitory tDCS group, $r(38) = .732$, $p < .001$.

D. Follow-Up Analysis: Melodic Features

In a follow-up analysis, three melodic features were analysed to determine if tDCS had an effect on the above findings. The three melodic features analysed were: number of notes, pitch range, and number of different notes. These features were analysed for performances in the improvisation section only (section 'B' of each stimulus). An independent samples t-test was computed to investigate the difference in each performed melodic feature in each stimulation group:

1) Number of notes.

A difference score was calculated for each tDCS group between block one (control) and block two (stimulation). The number of notes increased in the excitatory tDCS group (M = 3.25 SD = 4.08) relative to the inhibitory tDCS group (M = 1.00 SD = 2.35), but this difference was not statistically significant; $t(6) = .955$, $p > .05$. See Figure 5 for the mean number of notes used for both tDCS groups.

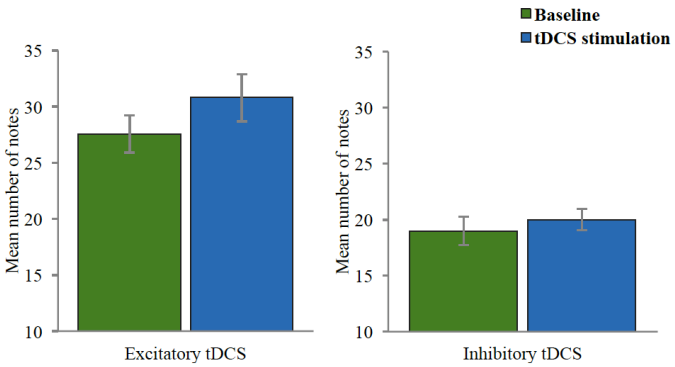

Figure 5. Mean number of notes used for both tDCS groups and difference between baseline and tDCS stimulation blocks.

2) Pitch range.

A difference score was calculated for each tDCS group between block one (control) and block two (stimulation). Although pitch range did increase for the excitatory tDCS group (M = 1.90 SD = 1.50) relative to the inhibitory tDCS group (M = .20 SD = .37), this difference was not statistically significant; $t(3.35) = 2.201$, $p > .05$. See Figure 6 for the mean pitch range used for both tDCS groups.

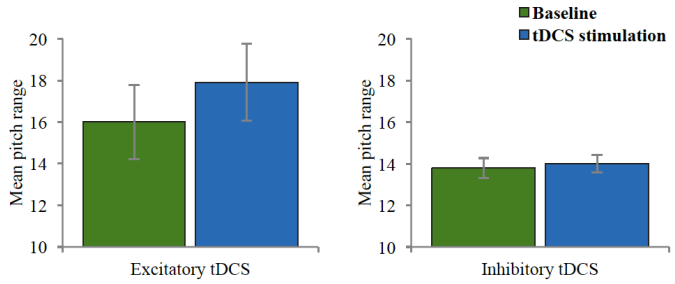

Figure 6. Mean pitch range for both tDCS groups and difference between baseline and tDCS stimulation blocks.

3) Number of different notes.

A difference score was calculated for each tDCS group between block one (control) and block two (stimulation). The number of different notes used was higher for the excitatory tDCS group (M = 1.20 SD = .43) relative to the inhibitory tDCS group (M = .60 SD = .71), but this difference was not statistically significant; $t(6) = 1.441$, $p > .05$. See Figure 7 for the mean number of different notes used for both tDCS groups.

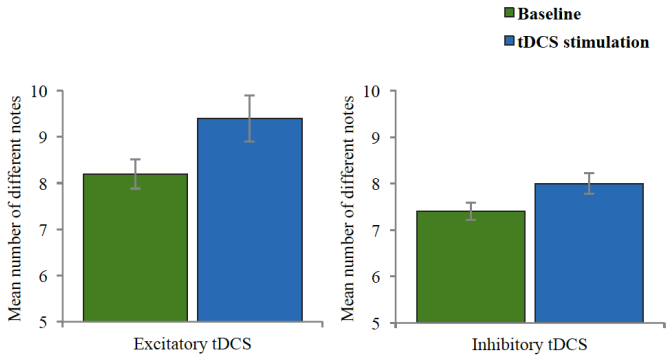

Figure 7. Mean number of different notes used for both tDCS groups and difference between baseline and tDCS stimulation blocks.

E. Multiple Regression: Melodic Features

A multiple regression was computed to determine if the three melodic features (number of notes, pitch range, and number of different notes) significantly predicted creativity scores. The multiple regression showed no statistical significance for the three predictors on creativity, $F(3,4) = .899$, $p > .05$, adjusted $R^2 = -.045$. Furthermore, a multiple regression was computed to investigate whether results on the three melodic features significantly predicted technical fluency score. The multiple regression demonstrated no statistical significance for the three predictors on technical fluency, $F(3,4) = .463$, $p > .05$, adjusted $R^2 = -.299$.

IV. DISCUSSION

The aims of the study were to (1) assess the M1 region and its influence on creativity and technical fluency in an improvised jazz context using tDCS; and (2) examine whether creativity and technical fluency as interrelated concepts in jazz improvisations. The hypothesis for the study was that participants who receive excitatory tDCS will show an increase in creativity and technical fluency when compared to participants who receive inhibitory tDCS. The results provide preliminary support for both hypotheses.

A. Creativity and Technical Fluency

This preliminary study has shown that when excitatory tDCS was applied to the M1 region, creativity and technical fluency both increased when compared to inhibitory tDCS application. These increases were significant for technical fluency and approached significance for creativity ($p = .07$). Furthermore, there was evidence to suggest that creativity and technical fluency are interrelated concepts in the context of musical improvisations. Specifically, there was a strong positive correlation between creativity and technical fluency, irrespective of tDCS application ($r = .765$). Subsequent analysis revealed a stronger positive correlation for improvisations following excitatory tDCS ($r = .820$, $p < .001$) than for improvisations following inhibitory tDCS ($r = .732$, $p < .001$). In other words, excitatory tDCS elicited higher performance scores on creativity and technical fluency *and* a stronger relationship between ratings of creativity and technical fluency. Although the correlations for both tDCS group elicited statistical significance, a tentative interpretation suggests that excitatory tDCS benefits creativity through an enhancement of technical fluency, whereas inhibitory tDCS does not. Overall, the excitatory tDCS findings suggest that the M1 region does influence technical fluency and creativity in the context of musical improvisations.

B. Melodic Feature Analysis

Specific melodic features in the performances were analysed to determine whether they were also influenced by tDCS. These features include the number of performed notes, pitch range, and number of different notes used in the improvisation section of each trial. Although statistical significance was not reached for the aforementioned features, a positive numerical trend suggested that improvisers in the excitatory tDCS group employed a greater number of performed notes, a larger pitch range, and a greater number of different notes, relative to improvisers in the inhibitory tDCS group.

C. Implications

The primary implication from this study is preliminary evidence that the M1 region contributes to creative cognition in a musical context, perhaps to some extent via an increase in technically fluent performances. In light of the previous literature focusing on creativity in musical improvisations (e.g., Bengtsson, Csıkszentmihalyi & Ullén, 2007; Bashwiner et al. 2016; de Manzano & Ullén, 2012a), this study has provided preliminary evidence that creativity *does* involve low-level motor areas such as the M1 region (Sosnik et al. 2014).

D. Limitations and Future Directions

The small sample size of this study ($N = 8$) has resulted in low statistical power. Thus, a replication of this study using a greater sample size is needed for strong conclusions to be drawn. Furthermore, the implementation of a control group with no tDCS stimulation will provide a control in which to illustrate any change in creativity and technical fluency scores when compared to the two types of tDCS stimulation. Indeed, with the use of a control group, stronger conclusions can be made about the M1 region and its effects on creativity and technical fluency in the context of a musical improvisation. Finally, the recruitment of multiple expert adjudicators in future work will significantly enhance reliability of the results, as inter-rater reliability measures can then be calculated.

V. CONCLUSION

This preliminary tDCS study is the first to utilise bihemispheric online tDCS over the M1 region to determine

its influence on creativity and technical fluency in the context of improvised jazz performance. The preliminary evidence suggests that excitatory tDCS applied over the M1 region of proficient pianists enhances both creativity and technical fluency, relative to inhibitory tDCS. We conclude that creative cognition in a musical context encapsulates technical fluency and involves the M1 region. Future research with a greater sample size will shed further light on these findings.

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