Measuring creativity in an improvised jazz context:

A preliminary tDCS study

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Declaration of Originality

The works within this thesis are original and have not been submitted for publication, written by another person, nor submitted for a higher degree to any other University or institution. The empirical research contained within this thesis was approved by the Human Research Ethics Committee (Medical Sciences) at Macquarie University (reference number: 5201600392).

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Abstract

Musical improvisation involves the generation of original and contextually appropriate musical sequences. This investigation focused on whether brain stimulation applied to the motor cortex influences creativity and technical fluency in musical improvisations. Previous research on creativity has examined two important brain networks: the dorsolateral prefrontal cortex (DLPFC), which underpins attention and monitoring, and the medial prefrontal cortex (MPFC), which regulates mind wandering and mental simulation. Other research on music has examined the significance of the premotor cortices, which include the ventral and dorsal pre-motor cortex (vPMD & dPMD, respectively) and the pre-supplementary motor area (pre-SMA) that aid in the generation of musical sequences and high level of motor planning and execution. To date, the primary motor cortex (M1) has not been explored in musical creativity.

The M1 mediates movement of the hand, and is also involved in the consolidation and acquisition of motor skills. This investigation examined the role of the M1 regions in creativity, motor performance and technical fluency in a jazz improvisation context. The relationship between creativity and technical fluency was also assessed. The role of the M1 regions was evaluated with transcranial direct current stimulation (tDCS), which is a non-invasive, safe and painless form of brain stimulation that modulates the neural activity over the desired area. Minute electrical currents are delivered through two saline-soaked electrodes: the positive (anodal) electrode stimulates neural activity, whilst the negative (cathodal) electrodes inhibits neural activity.

Bi-hemispheric, online tDCS was applied to the M1 region of proficient musicians. Two tDCS groups were used, Anodal-Left M1/Cathodal-Right M1 (n = 4) and Cathodal-Left M1/Anodal-Right M1 (n = 4) whilst they completed a sight reading and improvisation task. The level of creativity and technical fluency of the performances were assessed by an expert adjudicator (n = 1). It was hypothesised that applying excitatory tDCS over the M1 region of proficient musicians will enhance both creativity and technical fluency compared to inhibitory tDCS. The results from the preliminary study illustrates a trend that excitatory tDCS over the M1 region enhances creativity *(p =.07)*. Furthermore, excitatory tDCS also significantly enhanced technical fluency *(p =.05)* when compared to inhibitory tDCS. These preliminary results provide some evidence that the M1 region is a brain

area that aids in the enhancement of creativity, technical fluency, and motor performance in an improvised jazz context with proficient musicians.

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1. Introduction

Creativity is a mode of cognition that requires *novelty* and *applicability* within the context in which it is utilised (McPherson & Limb, 2013; Boccia, Piccardi, Palermo, Nori & Palmiero, 2015). The novelty component of creativity encapsulates a divergence from convention; the applicability component demonstrates a congruency to the specific context in which it is invoked (Dietrich, 2004; Schwab, Benedek, Papousek, Weiss & Fink, 2014). Music is an ideal domain for the study of creativity, because creativity is a central aspect of many musical activities (Beaty, 2015). Specifically, musical performance is a form of creative artistic human behaviour that can be investigated at the behavioural and neuroscientific level (McPherson & Limb, 2013; Groussard, Viader, Landeau, Desgranges, Eustache & Platel, 2014; Vaquero, Hartmann, Ripollés, Rojo, Sierpowska, François, Càmara, van Vugt, Mohammadi, Samii, Münte, Rodríguez-Fornells & Altenmüller, 2016). Musical improvisation is a form of musical performance that requires a high level of training and requires the two key facets of creativity: *novelty* and *applicability* (Bengtsson, Csıkszentmihalyi & Ullén, 2007). Musical improvisation has been utilised as an investigative paradigm in neuroscience to examine creativity in general, and in particular, the neural correlates that mediate the cognition of creativity (Bengtsson, Csıkszentmihalyi & Ullen, 2007; Beaty, 2015; Berkowitz, & Ansari, 2008; de Manzano & Ullén, 2012; Limb & Braun, 2008). The main purpose of the present study is to examine and understand the neural operations that facilitate creative musical improvisations. A significant theoretical foundation on musical improvisation is provided by Pressing's (1988) music improvisation model. Pressing's (1988) music improvisation model details the process of attaining expertise in musical improvisations, and provides an important foundation for the present study.

1.1 Pressing's (1988) Music Improvisation Model

Pressing's (1988) improvisation model is built on the premise that an improviser must develop an array of previously learnt motor sequences that can be utilised in improvisational performances (Pinho, de Manzano, Fransson, Eriksson & Ullén, 2014; Beaty, 2015). This component of Pressing's (1988) model is referred to as the knowledge base (Beaty, 2015). However, Pressing's (1988) model also implicates a degree of conscious monitoring at the time of the performance, which consists of continuous evaluation and decision-making processes (Beaty, 2015). This component is identified as referents (Beaty, 2015).

The vital components of Pressing's (1988) model are: (1) an improviser utilises an automated sequence of motor sequences pre-learnt through a calculated and explicit practicing regime; and (2) as a result, the reassignment of cognitive control is placed onto the decision-making and evaluative processes involved in musical improvisation (Beaty, 2015). These components of Pressing's (1988) music improvisation model can be experimentally investigated to better understand the mechanisms that mediate creativity (Bengtsson, Csıkszentmihalyi & Ullén, 2007). For example, musical improvisations, with respect to creativity, have been investigated in previous research using functional magnetic resonance imaging (fMRI) as a tool to understand the cognitive neuroscience of creative behaviours (Limb & Braun, 2008; Bengtsson, Csıkszentmihalyi & Ullén, 2007; Pinho, Ullén, Castelo-Branco, Fransson & de Manzano, 2016). These studies will now be reviewed.

1.2 The brain networks associated with musical improvisation and creativity

1.2.1 The dorsolateral prefrontal cortex

The neural mechanisms that mediate musical creativity in an improvisational context have been investigated using fMRI to identify the specific brain regions and networks that facilitate the development of creativity (Berkowitz, & Ansari, 2008; de Manzano & Ullén, 2012; Limb & Braun, 2008; Bengtsson, Csıkszentmihalyi & Ullén, 2007; Pinho et al., 2014). fMRI is a neuroimaging technique that provides a detailed representation of the brain regions activated during a task. The examination of brain region activation is measured by the blood-oxygenated level dependent (BOLD) signal (Sawyer, 2011; Jorge, van der Zwaag, Figueiredo, 2014; Fink & Benedek, 2014; Hall, Robson, Morris & Brookes, 2014). A distinct brain region that has been identified in creativity is the dorsolateral prefrontal cortex (DLPFC) (Limb & Braun, 2008; Bengtsson, Csıkszentmihalyi & Ullén, 2007; Pinho et al., 2016). The DLPFC is part of the Executive Control Network (ECN) which operationalises attention, working memory, monitoring and organisation (Bengtsson, Csıkszentmihalyi & Ullén, 2007; Limb & Braun, 2008). The activation of this brain region in musical improvisation suggests that creativity requires a degree of cognitive control and mediates creative behaviours (Bengtsson, Csıkszentmihalyi & Ullén, 2007). On a theoretical level, an important function of the DLPFC, *monitoring*, is a key element in Pressing's (1988) music improvisation model. Specifically, Pressing (1988) argues that the performer must monitor their performance and consciously attend to elements of the improvisation (Beaty, 2015).

The fMRI study conducted by Bengtsson, Csıkszentmihalyi & Ullén (2007) sought to address creativity using musical improvisations and Pressing's (1988) music improvisation model to better understand the general question of the neural mechanisms of free selection in creative behaviours. The participants were instructed to perform musical improvisations on melodic templates that were devised for the experiment (Bengtsson, Csıkszentmihalyi & Ullén, 2007). There were three conditions in the paradigm: Improvise, Reproduce, and Free Improvisation (FreeImp) (Bengtsson, Csıkszentmihalyi & Ullén, 2007). In the 'Improvise' condition, the participants were instructed to base their musical improvisations on the melodic templates presented; the 'Reproduce' condition involved the participants recalling, to the best of their abilities, the improvisations in the 'Improvise' condition (Bengtsson, Csıkszentmihalyi & Ullén, 2007). Finally, a sub-set of the participants from the sample (5 out of 11) were administered the 'FreeImp' condition, which involved a musical improvisation based on the melodic templates *without* being instructed to remember the improvisation (Bengtsson, Csıkszentmihalyi & Ullén, 2007).

The main finding from the study was the activation of the DLPFC during the 'Improvise' and 'FreeImp' conditions (Bengtsson, Csıkszentmihalyi & Ullén, 2007). This finding is indicative of musical improvisations being mediated by conscious control (Bengtsson, Csıkszentmihalyi & Ullén, 2007). Furthermore, there was a higher level of activation of the DLPFC during the 'FreeImp' condition compared to the 'Improvise' condition, which the authors delineate could have been accounted for by the increased level of complexity, with respect to the musical elements utilised in the 'FreeImp' condition. This finding, with respect to the theoretical foundations in Pressing's (1988) music improvisation model, demonstrates a congruency between the music improvisational model and neuroscience; specifically, the DLPFC, which underpins the operations associated with cognitive control: attention and monitoring (Bengtsson, Csıkszentmihalyi & Ullén, 2007; Limb & Braun, 2008). These two operations of cognitive control are well represented in Pressing's (1988) music improvisational model (Beaty, 2015).

1.2.2 The default mode network

The Default Mode Network (DMN) has also been implicated within the literature on musical creativity (Limb & Braun, 2008; Bashwiner, Wertz, Flores & Jung, 2016). The DMN is a brain network that is activated in mind wandering and mental simulation (Bashwiner et al. 2016) and includes the ventral and dorsal medial prefrontal cortex (vMPFC & dMPFC, respectively) (Limb & Braun, 2008; Bashwiner et al., 2016). The study conducted by Limb and Braun (2008) sought to address the degree to which cognitive

control mediates creativity in musical improvisations. The researchers observed activation of the MPFC (a region of the DMN) with the deactivation of the DLPFC (a region of the ECN), suggesting an important role for the DMN in musical improvisations (Limb & Braun, 2008).

The study involved four conditions: Scale Control, Scale Improvisation, Jazz Control, and Jazz Improvisation. The Scale Control condition involved the participants performing a diatonic musical scale, ascending and descending with their right hand to control for musical complexity (Limb & Braun, 2008). The Scale Improvisation condition involved the participants performing the same scale, however, the order of notes could be varied with the rhythm still controlled (Limb & Braun, 2008). The Jazz Control condition involved the participants performing a memorised melody from music that was devised for the experiment (Limb & Braun, 2008). The Jazz Improvisation condition involved the participants performing a musical improvisation based on the music presented in the Jazz Control condition (Limb & Braun, 2008). Limb and Braun (2008) posit that the deactivation and activation patterns of the DLPFC and MPFC, respectively are required for musical improvisation and were found in both improvisation conditions (Scale Improvisation and Jazz Improvisation). They further argue that mediating factors, such as conscious attention and monitoring, which is mediated by the DLPFC, might inhibit creative thinking involved in musical improvisations (Limb & Braun, 2008). To further exemplify the mediation of creative musical improvisations, Pinho et al.'s (2014) fMRI study found an overall decline in activity over the DLPFC with a simultaneous increase in connectivity with the premotor regions, the premotor cortex and the pre-supplementary motor area (Pinho et al., 2014).

The findings from previous and recent fMRI studies focusing on the ECN and DMN brain networks demonstrate that in the context of creativity, one network operates in the absence of the other. For example, the ECN (Bengtsson, Csıkszentmihalyi & Ullén, 2007; de Manzano & Ullén, 2012a), the DMN (Bashwiner et al., 2016; Limb & Braun, 2008; Pinho et al., 2014), although in some cases both operate concurrently (Pinho et al., 2016; Beaty, Benedek, Silvia & Schacter, 2016). The findings presented in these neuroscientific studies regarding the ECN and DMN are compatible with Pressing's (1988) music improvisation model. The activation and deactivation of these brain networks can explain much about how creativity is operationalised in the brain. Nonetheless, in addition to the ECN and DMN, other research has examined the significance of the premotor cortices and the pre-supplementary motor area, and its possible role in musical creativity within an improvisational context (Berkowitz, & Ansari, 2008; de Manzano & Ullén, 2012a).

1.2.3 The premotor cortex and the pre-supplementary motor area

The premotor areas of the brain have also been investigated in musical improvisational contexts using fMRI. The premotor cortex (PMD) that can be separated into their dorsal and ventral counterparts (dPMD and vPMD, respectively) and the pre-supplementary motor area (pre-SMA) (Berkowitz, & Ansari, 2008; de Manzano & Ullén, 2012a). The dPMD, vPMD and the pre-SMA are regions that are interconnected and are linked to cognition, high-level motor functions and planning execution (Bashwiner et al., 2016; de Manzano & Ullén, 2012a; Sosnik et al., 2014). The dPMD and vPMD are involved in the selection, performance and maintenance of novel motor tasks, which include musical improvisations (Berkowitz, & Ansari, 2008). The pre-SMA has been previously implicated in the generation of temporal dimensions of performance (de Manzano & Ullén, 2012a). Berkowitz and Ansari (2008) and de Manzano and Ullén (2012a) have sought to elucidate the roles of the premotor cortices in musical improvisations. These studies have separated the melodic and rhythmic qualities of musical performances and compared the neural activity using fMRI. They demonstrated that the pre-SMA, dPMD and vPMD regions are involved in rhythmic and melodic processing. In light of the aforementioned motor areas, a distinct brain region, the primary motor cortex (M1), mediates movement of the hand (Sosnik, Flash, Sterkin, Hauptmann & Karni, 2014) and motor learning (Karok & Witney, 2013) and has not been investigated in musical creativity. The M1 region is an important area of the brain to investigate the possible implications of creativity in a musical improvisation context because skilled, dexterous use of the hand and fingers is required to attain expertise in musical instruments, such as the piano (Sosnik et al., 2014). The M1 region will be the area of focus in the present study.

1.3 The primary motor cortex and motor performance

The structure of the M1 region includes an inhibitory network between the left and right hemispheres of the human brain (Vines, Nair & Schlaug, 2008). This is known as the inter-hemispheric inhibition connection (Vines, Nair & Schlaug, 2008). The inter-hemispheric inhibition connection system operates on the basis that if one hemisphere is excited during the activation of specific hand movements, the corresponding M1 region in the opposing hemisphere naturally inhibits to allow this process (Vines, Nair & Schlaug, 2008). Previous studies have demonstrated an asymmetry of the M1 region (van den Berg, Swinnen & Wenderoth,2011). For instance, individuals that use their non-dominant (e.g., left hand) in a task, activate their left (ipsilateral) M1 region more than the right (contralateral) M1 region (van den Berg, Swinnen & Wenderoth, 2011).

The M1 region is involved in the stabilisation of previously learnt motor sequences of the hand, which is known as consolidation (Karok & Witney, 2013; Censor & Cohen, 2011; Koyama, Tanakad, Tanabee & Sadato, 2015; Kim & Shin, 2014; Hardwick, Rottschy, Miall & Eickhoff, 2013). Consolidation of motor sequences is predominantly acquired in the early stages of motor learning (Jelic, Milanovic & Filipovic, 2015). In addition, the M1 region also subserves distinct properties of hand movement, including: velocity, orientation, finger dexterity and direction (Sosnik et al., 2014). In the current study, the M1 region is being explored by using proficient pianists to investigate creativity and motor performance. For the purposes of this study, motor performance will be referred to as sight reading accuracy, which encompasses timing and pitch note accuracy. The M1 region operates in an opposing fashion: The right M1 region is associated with movements of the left hand. Whereas, the left M1 region is associated with movements of the right hand (Vines, Nair & Schlaug, 2008). The primary characteristic of the M1 region is the consolidation and maintenance of previously learnt sequences of motor activity (Karok & Witney, 2013). The attainment of skilled motor performance is accomplished by the following process: synergy and sequence (Penhune & Steele, 2012; Waters-Metenier, Husain, Wrestler & Diedrichsen, 2014). Synergy is a component of motor performance that requires the formulation of original activation of specific muscles in the hand to generate movement (Waters-Metenier et al., 2014). Sequence is the process by which the formulated muscular activations accomplished in the 'synergy' stage is organised and executed (Waters-Metenier et al., 2014).

Various repetitive transcranial magnetic stimulation (rTMS) studies have demonstrated that applying low-frequency repetitive TMS over the M1 region inhibits the process of acquiring and consolidating motor skill and performance (Penhune & Steele, 2012; Hotermans, Peigneux, de Noordhout, Moonen & Maquet, 2008). Low-frequency rTMS is another medium of brain stimulation that produces inhibitory effects and can be utilised to investigate the M1 region (Censor & Cohen, 2011; Koyama, Tanakad, Tanabee, & Sadato, 2015). Specifically, low-frequency (1Hz) rTMS inhibits the functioning of the M1 region allowing inferences to be made on its mechanics and operations (Hotermans et al., 2008; Censor & Cohen, 2011). The aforementioned rTMS studies have demonstrated the significance of the M1 region in the acquisition of skilled motor performance. The M1 has also been investigated with transcranial direct current stimulation (tDCS). For example, the study conducted by Waters-Metenier et al. (2014) sought to address the generation of novel synergies and the possible implications of the M1 by training the non-dominant (left) hand from neurotypical participants. Waters-Metenier et al. (2014) developed a task that required participants to press a keyboard in a chord-like fashion.

This was developed to measure the novel generation of muscular activity (synergy). The results from the study demonstrate that participants who received bi-hemispheric tDCS showed a greater improvement in motor performance, however, the evaluation of synergy learning, as Waters-Metenier et al. (2014) concede, was difficult to present based solely on the differences in pretest and post-test results. Waters-Metenier et al. (2014) highlight a future direction in subsequent studies to further investigate synergy motor learning. The study conducted by Waters-Metenier et al. (2014) sought to investigate the role of the M1 region in the generation of novel motor sequences using tDCS. The tasks devised in the study involved two different forms of key pressing: configuration and sequence (Waters-Metenier et al., 2014). The former task involved the pressing of keys in a chord-like fashion; the latter task involved the pressing of keys in an individualised fashion (Waters-Metenier et al., 2014). The current study is focused on musical improvisation, which involves the generation of novel motor sequences (Bengtsson, Csıkszentmihalyi & Ullén, 2007). Consequently, a musical task is implemented to build upon the foundations of the Waters-Metenier et al. (2014) study by investigating technical fluency and creativity by modulating the neural activity of the M1 region using tDCS.

tDCS has also been utilised to examine the motor performance of musicians in a finger sequencing task by stimulating the M1 region (Furuya, Klaus, Nitsche, Paulus & Altenmuller, 2014). The findings in the Furuya et al., (2014) study demonstrated a decrease in performance from the musicians compared to the neurotypical group in a finger dexterity task. However, differences in methodology could have accounted for the results; for example, the experimental procedure used in the study separated the tDCS stimulation and task. This is an example of an offline tDCS configuration, which has been demonstrated to be inferior to online tDCS (Kim & Shin, 2014). In other words, the results obtained from Furuya et al. (2014) could be explained by the tDCS configuration used. In the current study, we are investigating the role of the M1 region in creativity, technical fluency and, sight reading accuracy, that involves: timing and pitch note accuracy (Kim & Shin, 2014). The basis for the present study is built upon Furuya et al's. (2014) and Waters-Metenier et al's. (2014) investigations, however, several enhancements have been made in our experimental paradigm and methodology. Specifically, the use of bi-hemispheric, *online* tDCS over the M1 region and a musical task with higher ecological validity. Our investigation focuses on creativity and technical fluency and specifically, the implications of the M1 for modulating creativity in musical improvisation. No previous study has investigated the M1 region in a musical improvisational context using tDCS to examine creativity and technical fluency.

1.4 Technical fluency and creativity in musical performances

Research has confirmed that the M1 region is involved in the acquisition and consolidation of the dexterous use of the hand (Sosnik et al., 2014; Karok & Witney, 2013). This research provides a rationale for also investigating the effect of tDCS on technical fluency and motor performance in a musical context. Motor performance in a musical context can be separated into two components. These components include accuracy and timing (Kim & Shin, 2015). In the current study, a measure of motor performance will be referred to as sight reading accuracy. Accuracy refers to the number of correct notes that are played; timing refers to the placement of the notes on a temporal scale (the beat on which it was intended to be placed). Technical fluency, in a musical context, can be described as the level of skill utilised in a performance, but excludes other dimensions, such as creativity, emotional sensitivity and interpretation. If the M1 region plays a role in technical fluency, then applying tDCS over the M1 region during an improvisational context should significantly affect the fluency of performances. It is unclear, however, whether this manipulation will also influence musical creativity, and whether technical fluency and creativity vary independently of one another. Thus, one aim of the current study is to examine the possible relationship between creativity, technical fluency and sight reading accuracy in an improvised jazz context.

1.5 Transcranial direct current stimulation

tDCS is a neurostimulation technique that is capable of modulating the neural activity over the region in which it is placed (Karok & Witney, 2013; Vines, Nair & Schlaug, 2008). tDCS is delivered through saline-soaked electrodes that are diametric in charge (Vines, Nair & Schlaug, 2008). The positive (anode) electrode stimulates neural activity and the negative (cathode) electrode inhibits neural activity (Vines, Nair & Schlaug, 2008; Nitsche, Schauenburg, Lang, Liebetanz, Exner, Paulus & Tergau, 2003). Online, bi-hemispheric tDCS is a more prominent configuration to uni-hemispheric tDCS to elicit results of motor performance (Karok & Witney, 2013; Vines, Cerruti & Schlaug, 2008; Waters-Metenier et al., 2014). Bi-hemispheric tDCS is a configuration that places the two electrodes over two sites on both hemispheres (Waters-Metenier et al., 2014). Uni-hemispheric tDCS involves the placement of the anodal or cathodal electrode on the desired area and the other electrode as a reference (Karok & Witney, 2013). In the present study, a bi-hemispheric tDCS configuration will be utilised. Online tDCS encapsulates the symbiotic application of tDCS whilst performing a task and is regarded as superior to offline tDCS (Karok & Witney, 2013; Vines, Cerruti & Schlaug, 2008). Offline tDCS is composed of a separation of the stimulation stage

and the performance of the task (Kim & Shin, 2014). The current study will implement an online bi-hemispheric tDCS configuration to determine its effects on musical improvisation and performance.

In light of the architecture of the M1, bi-hemispheric tDCS increases the mechanics of the inter-hemispheric inhibition process (Vines, Nair & Schlaug, 2008). For instance, the tDCS study conducted by Vines, Nair & Schlaug (2008), sought to determine the mechanics of the M1 with the concurrent utilisation of tDCS. Their study has demonstrated that placing the electrode on the dominant (left) M1 region affected both hands in performance; however, placing the electrode on the right (non-dominant) hemisphere only affected the left (non-dominant) hand (Vines, Nair & Schlaug, 2008). Recently, tDCS has been utilised to investigate creativity by stimulating the DLPFC with the alternative uses task, which is affiliated with the concept of divergent thinking originally formulated by Guildford (1950) (Colombo, Bartesaghi, Simonelli & Antonietti, 2015; Beaty, Benedek, Wilkins, Jauk, Fink, Silvia, Hodges, Koschutnig, Neubauer, 2014; Boccia et al., 2015). The study conducted by Colombo et al. (2015) involved the use of tDCS over the DLPFC to measure creativity in a behavioural task. Results obtained from Colombo et al. (2015) demonstrated that anodal tDCS over the DLPFC did improve creativity in a behavioural task only after a 'divergent' prime.

1.6 Expert adjudication of musical performances

Previous neuroimaging studies that have examined creativity and motor performance in a musical improvisational context have not employed expert adjudication to judge the creative and technical facets of performance (see Limb & Braun, 2008; Bengtsson, Csıkszentmihalyi & Ullén, 2007; Berkowitz, & Ansari, 2008; de Manzano & Ullén, 2012; Pinho et al., 2014; 2016). Not using expert adjudication to assess the level of creativity in the aforementioned studies demonstrates a significant limitation in the literature in understanding the neural mechanisms that underpin creativity. The purpose of utilising expert adjudication in the current study is to separate generic musical sequences from musical sequences that are creative. Therefore, the current study is addressing this significant limitation by utilising expert adjudication to address the following points: (1) to mitigate experimenter bias in assessing creativity; and (2) a greater degree of validity and reliability in the adjudication of what constitutes creativity in the context of musical improvisations. The only study in a musical context that has incorporated expert adjudication was the study conducted by Beaty, Smeekens, Silvia, Hodges & Kane (2013).

This study focused on: (1) musical improvisation using an original piece of music; (2) divergent thinking, a behavioural task that measures the level of creative thinking, and (3) an intelligence test. The aim of the study was to investigate the possible relationship between musical improvisation, creative thinking, practice and general intelligence. In Pressing's (1988) music improvisational model, the attainment of improvisational expertise is dependent on a repertoire of musical sequences that is utilised in performance (Beaty, 2015). Therefore, in the context of this study on creativity, it is important to discern between a truly novel musical performance based on creative ideation and a previously practiced musical sequence that is generic. The use of expert adjudication in the experimental paradigm serves to examine and evaluate creativity and technical fluency on a finer level.

1.7 Aims, Design & Hypothesis

The aims of the current study can be separated into conceptual and methodological aims. The conceptual aims are: (1) to examine the M1 region as a possible site that contributes to creativity within a musical improvisational context; (2) better understand creativity and technical fluency and to determine if these components of performance are interrelated or not, as judged by an expert adjudicator; and (3) assess the level of sight reading accuracy by measuring accuracy and timing. The methodological aims are: (1) to add to the body of literature regarding the use of tDCS in analysing the sight reading accuracy of proficient musicians; and (2) to evaluate the efficacy of tDCS as a experimental tool to investigate the neural underpinnings of creativity. The independent variable that is being manipulated is the tDCS configuration and its effect on the dependent variables, which are creativity, technical fluency and sight reading accuracy in a music improvisation context.

Specifically, online bi-hemispheric tDCS will be applied on proficient pianists' M1 region whilst they perform musical improvisations. All participants acted as their own control and were pseudo-randomly allocated into one of two tDCS stimulation groups: Anodal-Left/Cathodal-Right (excitatory tDCS); Cathodal-Left/Anodal-Right (inhibitory tDCS). Ten original musical stimuli were generated for the purposes of this study and to ensure novelty. The participants were instructed to base their improvisations on the melodic motif that was presented in the musical stimuli and must be congruent to the harmony in the piece. Each stimulus is separated into two sections, with each section reflecting two distinct skills, both of which are evaluated.

First, section ‘A’ comprised the sight-reading phase, with specific focus on pitch note and timing accuracy. Second, section ‘B’ comprised the improvisation phase, with specific focus on creativity and technical fluency. The hypothesis for the study are the following: (1) Participants in the Anodal-Left/ Cathodal-Right condition, which is the optimum tDCS configuration targeting the dominant hand will show a greater increase in technical fluency, sight reading accuracy and creativity compared to the Cathodal-Left/ Anodal-Right condition (Vines et al., 2008).

2. Method

2.1 Participants

Sixteen participants (15 musicians and 1 expert adjudicator) were recruited for this study through the Psychology participant pool (SONA system), along with advertisements posted at Macquarie University, The University of New South Wales, the James Morrison Academy of Music, and the Conservatorium Of Music. One expert adjudicator was recruited from the Arts faculty from Macquarie University to assess the technical fluency and creativity levels of the performances derived from the proficient musicians. Seven proficient musicians were excluded from the study and analysis due to a failure in the TMS screener or for not performing the task in accordance to the instructions provided. The TMS screener is a questionnaire to screen participants that may experience adverse reactions to brain stimulation techniques, such as tDCS. Therefore, eight proficient musicians’ (4 female) data were utilised in the analysis for the study (mean age = 20.25 S.D = 2.25).

All proficient pianists except two were right-handed (one participant was left-handed and the other was ambidextrous). All participants gave informed consent and questionnaires were administered to gather information about the participants’ musical background, see Figure 1 for the information gathered about the proficient musicians’ musical background and experience. See Figure 2 for the musical experience of the expert adjudicator. The participants were reimbursed $50 or course credit for their participation in the study. This study has been approved by the Macquarie University Human Research Ethics Committee (HREC Medical Sciences).

2.2 Stimuli

The musical stimuli comprised a pre-recorded programmed drum kit, grand piano, electronic piano and a live electric bass recording using Notion and GarageBand music generation software. Ten novel musical pieces were generated specifically for this study; each piece consisted of ten bars played at 90 beats

per minute. The pieces were written in varying major and minor key signatures. Six of the pieces were written in a major key signature and the remaining four stimuli were written in a minor key signature. See Appendix I for all notated scores of the stimuli utilised in the experiment.

Participants	Hours practicing piano per week	Formal piano education	Hours listening to music per week	Started playing piano (age)
Participant 1	10	13	12	3.5
Participant 2	9	13	4	9
Participant 3	5	4	50	5
Participant 4	10	7	5	5
Participant 5	3	10	8	6
Participant 6	5	10	15	5
Participant 7	18	6	7	4
Participant 8	2	13	14	5
Mean	7.75	9.50	14.38	5.31
Standard Deviation	5.18	3.51	14.96	1.67

Figure 1: Mean number of hours that the participants practice the piano per week, the mean number of years of formal music education, the mean number of hours listening to music per week, and the mean age at which they started playing the piano.

Expert adjudicator	Education level	Years of formal music education	Principle instrument	Approx. number of hours of practice per week	Adjudication experience
1	Doctorate	20 +	Double and electric bass	7	Yes

Figure 2: Musical experience of the expert adjudicator that was recruit to assess the musical performances.

Each piece consisted of a total of ten bars, the first bar consisted of a four beat count-in with the drum kit to prepare the participants for the performance. Bars two to nine consisted of the music dedicated to the participants' performance and the tenth bar indicated the completion of the performance with the word 'Fine' presented above. Bars two to five were labelled using an 'A' marker to indicate the first section of the piece. This section of each stimulus consisted of the drum kit, electric bass guitar, electronic piano, and grand piano playing a novel melody within the jazz genre utilising quintessential jazz chord progressions. The rhythmic and harmonic qualities of the pieces are congruent with the jazz genre.

The focus of bars two to five of the music was to provide a foundation for the performer to subsequently base their improvisations in bars six to ten. Bars two to five of the performances were analysed for sight reading accuracy (pitch note and timing accuracy). Bars six to ten of each stimulus was dedicated to the improvisation component of the performance for creativity and technical fluency (judged by the expert adjudicator). This section was labeled 'B' and was separated by two faint bar lines to aid in distinguishing between the 'A' and 'B' sections of each piece. The only instruction that was given to the participants was to build their improvisations from the melody and to afford the same treatment as if they were performing with live accompaniment. Figure 3 displays an example of a musical score that was presented to the participants. The audio and musical scores generated from the performances was collected and analysed to ascertain an understanding of creativity and technical fluency. The participants' performances were recorded on a musical instrument digital interface compatible keyboard.

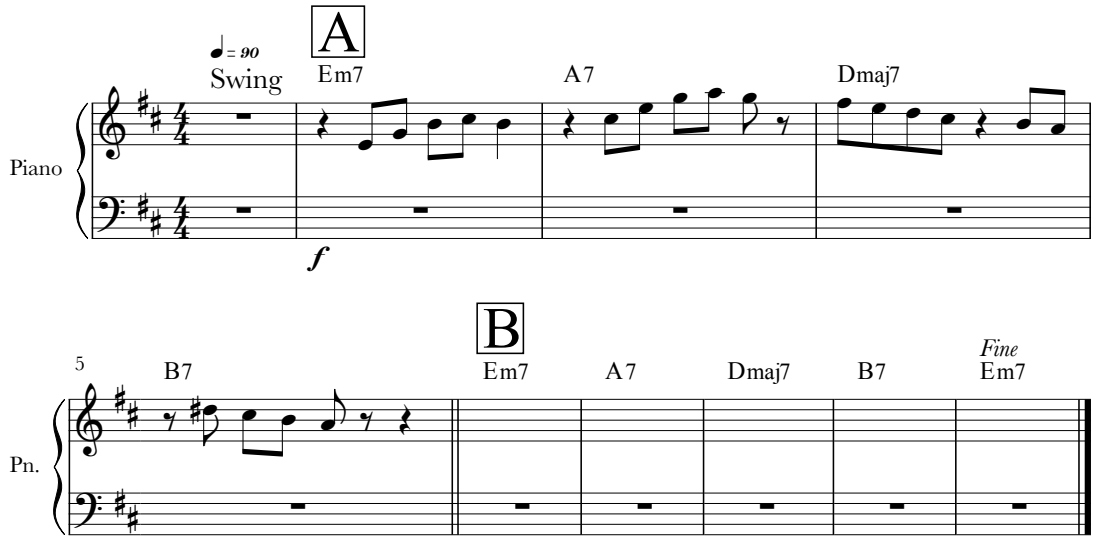


Figure 3. Sample of the musical score that was presented to the participants during the experiment. This sample was written in the key of D major in an 8th swing feel at a tempo of 90 b.p.m. The 'A' section is the 'sight-reading' component, whereby the participants were instructed to play the displayed melody as accurately as possible. The 'B' section is the improvisation component, which encompassed an improvisation based on the melody in the previous section and the harmonic structure of the music. The participants were instructed to play with their right only during the experiment.

2.3 Equipment

tDCS was set to 1.4mA and was delivered through two saline-soaked electrodes (Anodal & Cathodal) measuring 25cm2, which delivered a current density of 0.056/cm2. The electrodes were securely attached onto a cap, which was placed on the participants' heads. The electrodes were placed on areas C3 & C4, which corresponds to the M1 region on the 10-20 electroencephalogram (EEG) system, this configuration is congruent to a bi-hemispheric tDCS application (Furuya et al., 2014; Karok & Witney, 2013). Compared to offline uni-hemispheric tDCS, online bi-hemispheric tDCS is a configuration that has been previously demonstrated to elicit the most prominent effects in a motor task (Karok & Witney, 2013). Online tDCS is a mode of tDCS that encapsulates the simultaneous application of tDCS whilst performing a task (Karok & Witney, 2013), as opposed to offline tDCS, which involves a separate stimulating session prior to the task (Kim & Shin, 2014). This study implemented an online, bi-hemispheric configuration of tDCS.

All measures were taken to situate the cap with the Cz electrode site on the EEG system being present directly on top of the scalp whilst being in line with the tragus of the ear to ensure the stimulation of the M1 region. The participants were stimulated between fifteen and twenty-one minutes, including a 30 second ramp up and 30 second ramp down period. This duration of tDCS is considered safe (Bikson, Datta & Elwassif, 2009). Before commencing with the task, the participants were stimulated for two and a half minutes (including ramp up). This was to ensure that the participant was comfortable and accustomed to the sensations of tDCS. Furthermore, this protocol was implemented to ensure that a degree of stimulation was already established before commencing the task. The tDCS software, Neuro-Electrics Instrument Controller, was run using a laptop (MacBook Pro 15inch) to configure the tDCS parameters and to monitor the impedances of the electrodes. An 11inch MacBook Air was also used to record the musical performances with GarageBand music recording software. This computer was also utilised by the experimenter to organise and present the musical stimuli to the participants by connecting via a thunderbolt cable to a iMac 27inch computer. The musical stimuli (musical score & audio) were generated using an iPad 2 with Notion music generation software. The drum kit, electronic keyboard and grand piano were written using the Notion music generation software. The bass guitar was recorded live on Garageband and played by the author.

2.4 Experimental paradigm

The participants in the study were pseudo-randomised into the two stimulation groups with the melodic sequences counterbalanced in order to maintain an equal number of participants per condition and to

mitigate any presentation bias. The two stimulation groups were: Anodal-Left M1/Cathodal-Right M1 (excitatory tDCS) and Cathodal-Left M1/Anodal-Right M1 (inhibitory tDCS). The experimental paradigm consisted of two blocks: control and stimulation. All participants played five melodies without tDCS in the first block and five melodies in the second block with one of two types of tDCS. The groups in the experiment consisted of the following: Group 1A were administered the first melodic sequence in the first block, which was completed without tDCS. The second block of trials consisted of the second melodic sequence with the Anodal-Left M1/Cathodal-Right M1 tDCS configuration. Group 1B were administered the same tDCS configuration with the melodic sequences counterbalanced (melodic sequence 2 and 1 in blocks one and two, respectively). Group 2A were administered the Cathodal-Left/Anodal-Right tDCS configuration with the melodic sequences corresponding to the blocks (melodic sequence 1 in block one & melodic sequence 2 in block two, respectively). Group 2B received the same tDCS configuration as Group 2A with the melodic sequences counterbalanced (melodic sequence 2 in block 1 & melodic sequence 1 in block 2, respectively). Refer to Figure 4 for an illustration of the experimental paradigm.

The experiment lasted for approximately 90 minutes. The ten musical stimuli were randomly assorted into the two melodic sequence blocks (melodic sequence 1 & melodic sequence 2) that correspond to the two blocks of the experimental procedure. The ten musical stimuli that were specifically generated for the study were randomly separated into two sequences that corresponded to the two blocks in the procedure. The order of the stimuli for each participant was also randomly distributed within the two blocks. See Figure 5 for an illustration of the groups, tDCS configurations and melodic sequences.

Group	Block one (B1)	Block two (B2)	Melodic sequence (1 & 2)
1A	No treatment	Anodal-Left/Cathodal-Right	Melodic sequence 1 - Melodic sequence 2
1B	No treatment	Anodal-Left/Cathodal-Right	Melodic sequence 2 - Melodic sequence 1
2A	No treatment	Cathodal-Left/Anodal-Right	Melodic sequence 1 - Melodic sequence 2
2B	No treatment	Cathodal-Left/Anodal-Right	Melodic sequence 2 - Melodic sequence 1

Figure 4: The experimental design. All participants were assigned to each condition in a pseudo-random manner with the stipulation that an equal number of participants were allocated into each group. Thus, all musical stimuli were used in an equivalent number of times in the study. The melodic sequences were initially randomised into two melodic sequences and were counterbalanced into each sub-group. Furthermore, the trials within each melodic sequence were further randomised for each participant.

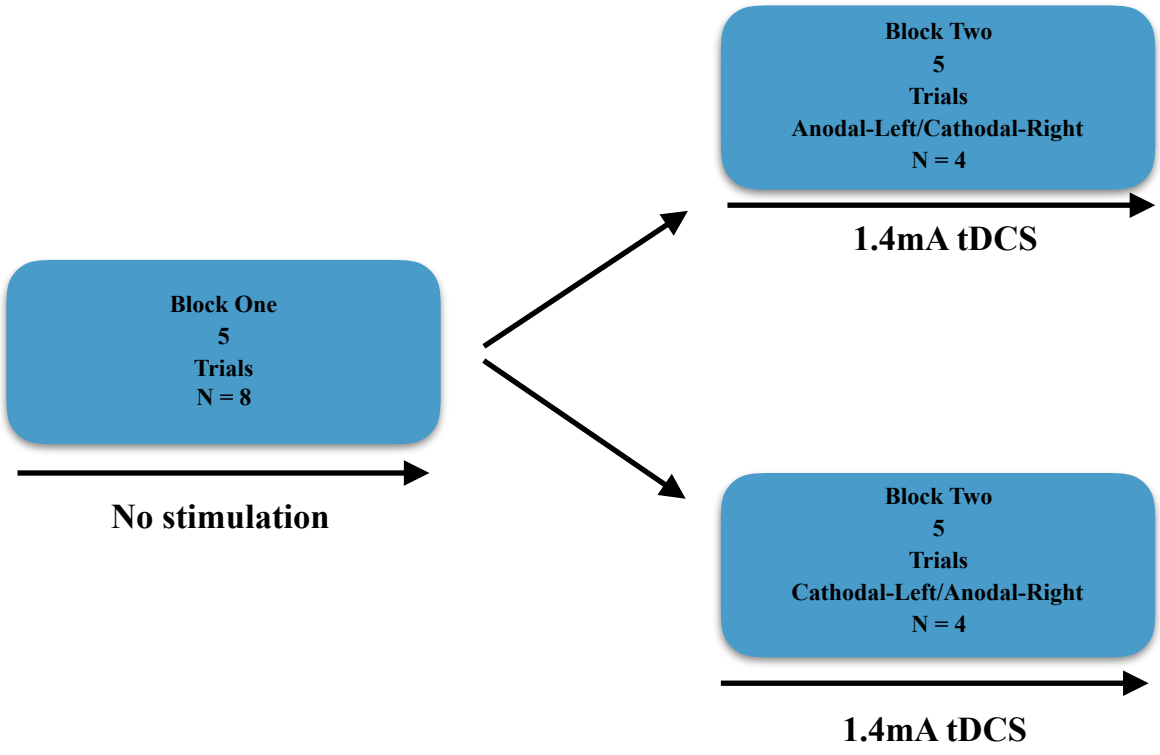


Figure 5: A single experimental procedure. The first block of trials consisted of five musical improvisations without stimulation. In the second block of trials, 1.4mA bi-hemispheric tDCS was applied whilst the participants completed the remaining five musical trials. The participants were stimulated between 15-21 minutes, including a 30 second ramp up & a 30 second down period.

2.5 Procedure

The participants entered the auditory laboratory and were provided with the TMS screener to determine if tDCS was safe to administer. The participants who satisfied the TMS screener were then presented with the consent form containing information about the study and tDCS. Once the participants provided informed consent, they were administered one part of a questionnaire to determine their handedness and musical background (the remaining section of the questionnaire pertained to the sensations of tDCS experience and whether the experiment conditions allowed the participants to perform to the best of their abilities and express their creativity; therefore, this second part of the questionnaire was administered after the completion of the experiment). After this, the participants were briefed about the procedure of the experiment. Participants were seated comfortably in front of the MIDI keyboard and directly in front of the participant, the computer monitor (iMac 27inch) presented the musical stimuli.

The iMac 27inch computer was connected to a laptop (MacBook Air 11inch) that acted as a second monitor to organise and drag the specific musical stimuli for presentation to the participant. For an illustration of the experimental configuration, see Figure 6 and 7. Two practice trials were initially presented so participants could familiarise themselves with the experimental procedure. The practice trials exactly replicated the procedure in the actual trials, however, different musical stimuli were utilised in the practice trials. The practice and actual trials consisted of two stages: familiarisation and performance.

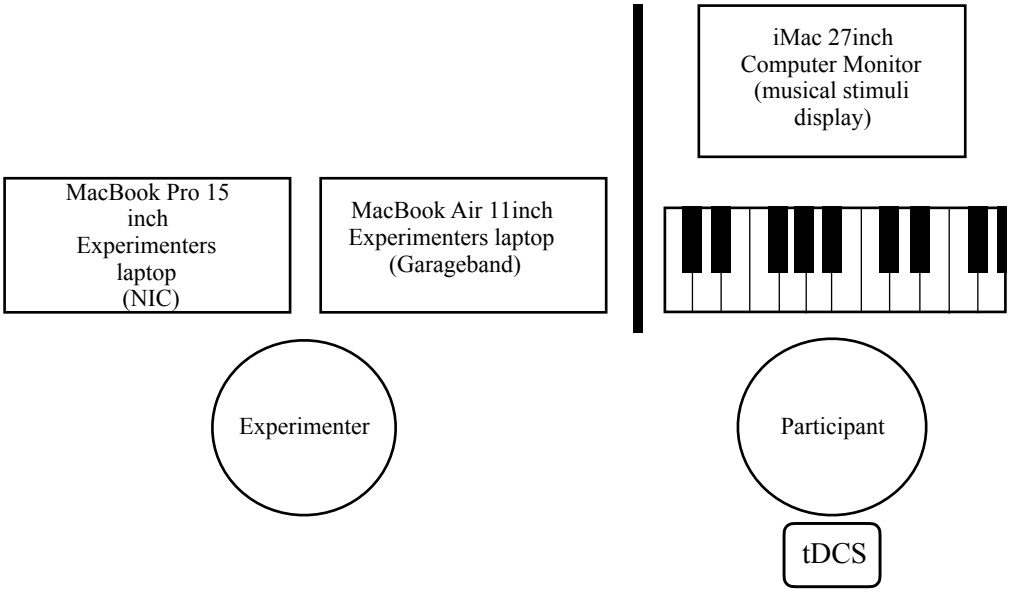


Figure 6: Configuration of the participant being seated in the auditory laboratory in front of the computer monitor with the musical score being presented. 1.4mA tDCS was delivered through two diametrically opposing charged electrodes placed on the scalp of the participant. The subject was be instructed to play with their right hand. The laptop with GarageBand was recording and scoring the performances from the participants and the laptop running the NIC software was connected to the tDCS device via bluetooth and was used to monitor impedances and set the tDCS parameters for the experiment.

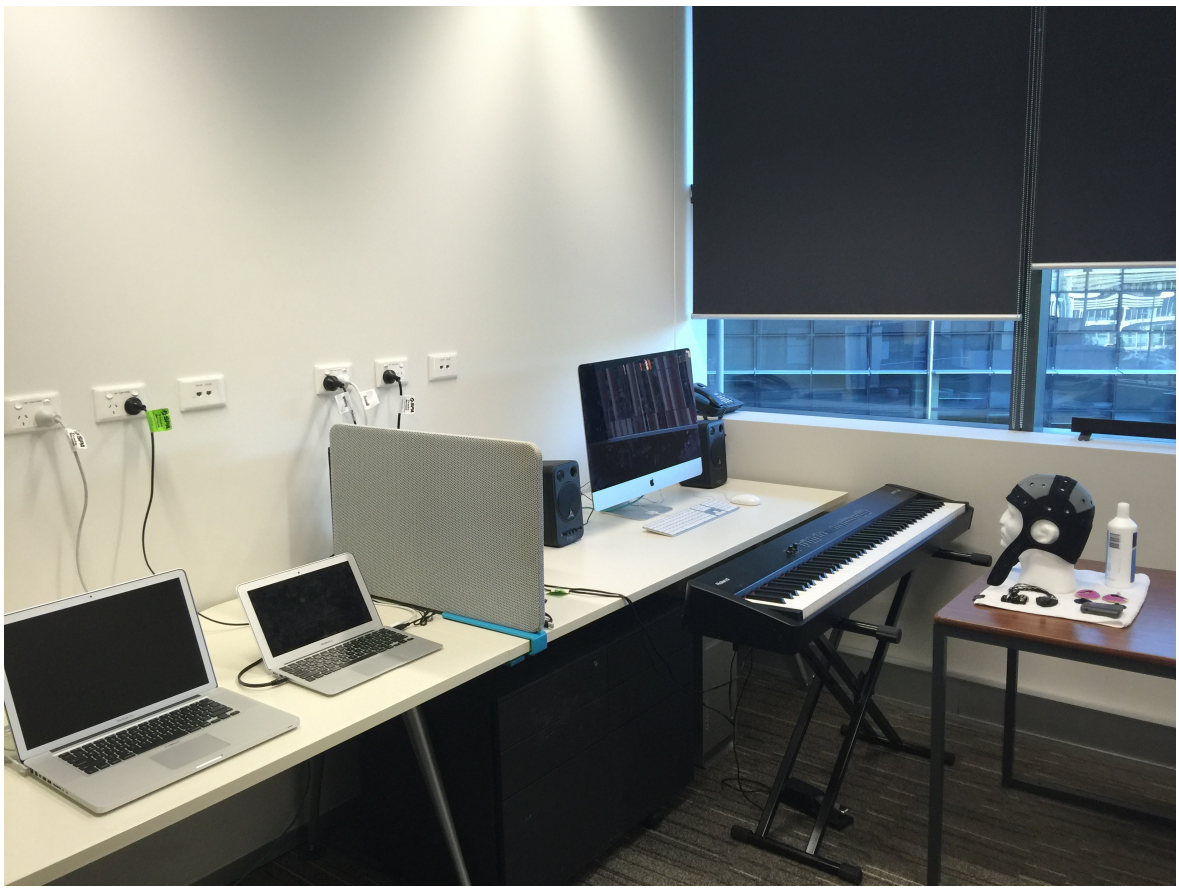


Figure 7: Photograph of the auditory laboratory in which the study was conducted and presents the arrangement of the laboratory for experimentation.

In the performance stage, the participants were afforded two opportunities to play the displayed melody with their right hand (section A) and then improvise (section B). After the completion of the two practice trials, the actual trials began. The participants were asked if they had any questions concerning the procedure. After the completion of the experiment, the participants completed the remaining part of the questionnaire pertaining to the level of possible discomfort elicited by the tDCS on a numerical scale with supplementary comments. The questionnaire also addressed whether the task afforded the participants the ability to perform to the best of their abilities and express their creativity.

In the familiarisation stage of each trial, two presentations of the stimuli were presented to the participant and the piano melody in section 'A' was present in each presentation. In the first presentation, the participant was instructed to listen to the stimuli and follow the musical score *without* playing the piano. In the second presentation, the participant was instructed to play the displayed melody on the monitor with the audio accompaniment with their right hand only. This stage was designed to ensure that the participant was

familiar with the stimuli before commencing with the performance stage. However, some participants required more attempts at the familiarisation stage of the experiment before they reported themselves 'familiar' with the melody. In the performance stage, the audio stimuli *without* the piano accompaniment was played to the participants; the participants were informed of this change prior to the commencement of the trials. The participants were also informed of the stimulation condition in which they were placed in and were asked if their data could be used for analysis in the study. All participants agreed for their data to be used in this study. The participants' data was collated onto a USB with de-identified names to ensure the expert judge was completely blind to the condition, order of trials and expertise of the participants.

2.6 Expert adjudication of technical fluency and creativity

The expert judge was provided with all the audio and musical stimuli that was used in the study and presented to the participants to adjudicate the level of creativity and technical fluency in the improvisation section only. The expert adjudicator was provided with written instructions defining creativity and technical fluency in the context of jazz performance, see Appendix H. They were asked to score the creative and technical fluency facets of the performances and were blind to the condition the participants were placed in. The order of musical stimuli that was presented to each respective participant was randomised to the judge to ensure the mitigation of any judgement bias (for a review, see Thompson, 2014, Chapter 9). The creative and technical facets of the performances were judged on two Likert scales. These judgements were supplemented with details of specific examples and room for the judge to provide qualitative data to complement the quantitative data from the Likert scales. The judge was presented with two scales ranging from one to ten, see Appendix H. The first scale was used to indicate the level of creativity demonstrated in the performance and the other scale was used to indicate the level of technical fluency demonstrated in the performance.

2.7 Statistical analysis

Creativity and technical fluency of the improvisation section of the musical performances were measured using Likert scales by the expert judge. The total order of the stimuli were randomised across participants and conditions to mitigate any possible bias in adjudication. In all of the participants' performances, the mean scores provided by the expert judge for the first and second blocks were calculated for each participant. The mean score from the second block was subtracted from the mean score from the first block to produce a difference score. The difference score was used to measure whether creativity and technical fluency increased in block two (tDCS stimulation) compared to block one (control) for both

groups. The difference score was analysed by independent sample t-tests. To assess the relationship between creativity and technical fluency, all scores from the expert adjudicator (n = 80) derived from all the participants' performances was used to compute a correlation. Further analyses were conducted by computing a correlation for creativity and technical fluency scores from the expert adjudicator for each tDCS stimulation group Anodal-Left M1/Cathodal-Right M1 (excitatory tDCS) (n = 40) and Cathodal-Left M1/ Anodal-Right M1 (inhibitory tDCS) (n = 40). A regression was conducted using the technical fluency score to predict the creativity score for both tDCS stimulation groups.

An independent samples t-test was computed to analyse the mean differences of the melodic features in the musical improvisations for both tDCS stimulation groups, that include: the total number of notes played, pitch range of notes played, and a count of the total number of different notes played. Furthermore, a multiple regression was also conducted to investigate the potential influence of the aforementioned melodic predicators on the participants' performances for creativity and technical fluency in the improvisation section. Sight reading accuracy was measured by pitch note accuracy and timing in the sight reading section. Sight reading accuracy was analysed by comparing to the timing and pitch notes in the stimuli presented to the participants in both blocks. The mean scores for pitch note accuracy for the first block (no stimulation) and the second block (stimulation) was calculated for each participant. A negative number indicates that the participant played the note *lower* than the note presented; the positive number indicates that the participant played the note *higher* than the note presented in the stimuli. A negative number was converted into the equivalent positive number to determine the average deviation from the note presented in the stimuli regardless of the direction of errors (unsigned pitch errors). An independent sample t-test was utilised to analyse the mean pitch note accuracy between the two blocks across all participants.

The timing accuracy was calculated by determining the on-set timing of each note in the sight reading component from the stimuli and the on-set timing of each note played by each participant. The timing from the participants was subtracted from the timing presented, which generated a negative or positive number measured in milliseconds that determine the timing accuracy (or asynchrony) of the participants' sight reading performance. A negative number indicates that the participant played the note *early* compared to the note presented in the stimuli; a positive number indicates that the participant played the note *late* compared to the note presented in the stimuli. The negative numbers from each stimuli in the first block was converted into a positive number to demonstrate, irrespective of lateness or earliness of the placement of the note, the

degree of timing of the participant. An independent sample t-test was utilised to analyse the mean timing accuracy between the first block (no stimulation) and the second block (stimulation) for each participant.

A correlation was computed on the technical fluency score and timing accuracy for both tDCS stimulation groups. The difference score for the two blocks in the experiment for technical fluency and timing accuracy for each tDCS stimulation group, Anodal-Left M1/Cathodal-Right M1 and Cathodal-Left M1/Anodal-Right M1 was computed to determine if there is a relationship between these two aspects. Another correlation was conducted for the difference creativity score and difference timing accuracy for both tDCS stimulation groups. Lastly, a regression was computed on the technical fluency score using timing accuracy as a predictor to determine if timing accuracy predicts the technical fluency scores.

3. Results

3.1 Creativity in musical improvisation

Eight participants' data were used in the final analysis. See Table 1 for the demographics, musical experience, and scores for creativity and technical fluency in the first block. The experimental paradigm consisted of two independent variables, which corresponds to the two tDCS stimulation groups (Anodal-Left M1/Cathodal-Right M1 and Cathodal-Left M1/Anodal-Right M1) hereby labelled as excitatory tDCS and inhibitory tDCS, respectively. Excitatory tDCS encompassed the excitatory electrode placed on the left M1 region with the inhibitory electrode placed on the right M1 region. Inhibitory tDCS encompassed the inhibitory electrode over the left M1 region with the excitatory electrode over the right M1 region. The three dependent variables in the study are creativity, technical fluency and sight reading accuracy. The creativity scores increased between the two tDCS stimulation groups, excitatory tDCS *(M* = 1.20*, S.D* = 0.82*)* and inhibitory tDCS stimulation group *(M* = .15*, S.D* = .50*)* and was approaching statistical significance; *t(*6*)* = 2.19*, p* = .07; this result did represent a large effect size, *d* = 1.55 (Field, 2013). A Cohen's d effect size range include: 0.2 (small), 0.5 (medium), 0.8 (large) (Field, 2013). This result demonstrates that there is a trend that excitatory tDCS over the left M1 increases the level of creativity in a musical improvisational context compared to inhibitory tDCS over the left M1. See Table 2 for the mean and standard deviation scores for creativity for all participants in the excitatory tDCS stimulation condition. See Table 3 for the mean and standard deviation scores for creativity for all participants in the inhibitory tDCS stimulation condition. Figure 8 illustrates the mean scores between the two tDCS stimulation groups and the difference score for creativity.

Table 1. Demographics, musical experience, and mean scores for creativity and technical fluency from the expert adjudicator for both tDCS stimulation groups.

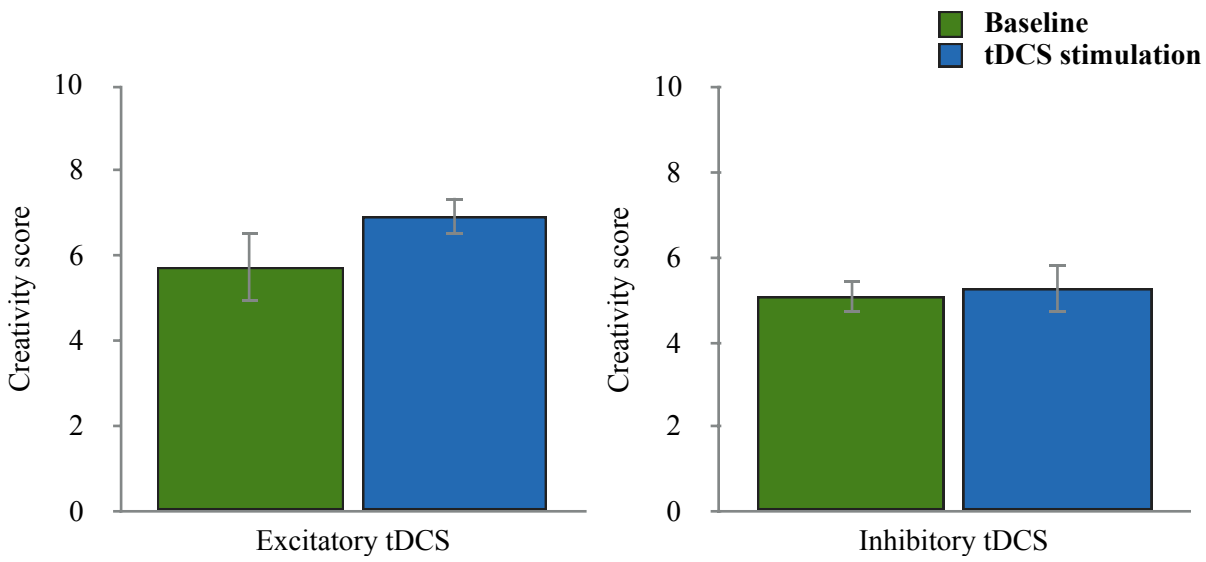
Participants	tDCS group	Age	Handedness	Hours practicing piano per week	Formal piano education	Hours listening to music per week	Started playing piano (age)	Creativity (Block one)	Technical fluency (Block one)
1	Excitatory tDCS	18	Right	10	13	12	3.5	5.2	5.2
2	Excitatory tDCS	23	Right	9	13	4	9	8	7.6
3	Excitatory tDCS	19	Right	3	10	8	6	5.6	6.6
4	Excitatory tDCS	18	Right	5	10	15	5	4.2	5.6
5	Inhibitory tDCS	19	Left	5	4	50	5	4.2	5.2
6	Inhibitory tDCS	24	Ambidextrous	10	7	5	5	5	6.2
7	Inhibitory tDCS	20	Right	18	6	7	4	6	7.2
8	Inhibitory tDCS	21	Right	2	13	14	5	5.2	6.4

Table 2. Mean scores for creativity from the expert adjudicator for the excitatory tDCS stimulation group. The mean scores from the first block consisted of the first five stimuli presented. The mean scores from the second block consisted of the remaining five stimuli presented. These scores were calculated for each participant and a difference score between the two blocks was generated.

Participants	tDCS group	Creativity (Block one)	Creativity (Block two)	Creativity difference score
1	Excitatory tDCS	5.2	6.4	1.2
2	Excitatory tDCS	8	8.2	0.2
3	Excitatory tDCS	5.6	6.8	1.2
4	Excitatory tDCS	4.2	6.4	2.2
	Mean	5.75	6.95	1.20
	S.D	1.61	0.85	0.82

Table 3. Mean scores for creativity from the expert adjudicator for the inhibitory tDCS stimulation group. The mean scores from the first block consisted of the first five stimuli presented. The mean scores from the second block consisted of the remaining five stimuli presented. These scores were calculated for each participant and a difference score between the two blocks was generated.

Participants	tDCS group	Creativity (Block one)	Creativity (Block two)	Creativity difference score
1	Inhibitory tDCS	4.2	4.2	0
2	Inhibitory tDCS	5	5.2	0.2
3	Inhibitory tDCS	6	6.8	0.8
4	Inhibitory tDCS	5.2	4.8	-0.4
	Mean	5.10	5.25	0.15
	S.D	0.74	1.11	0.50



F*igure 8.* Mean creativity scores for the two tDCS stimulation groups from the expert adjudicator in each block. The difference score was generated by subtracting the mean score from the second block from the first block in each condition.

3.2 Technical fluency in musical improvisation

The technical fluency scores increased between the two tDCS stimulation groups excitatory tDCS *(M* = 1.05, *S.D* = .41*)* and the inhibitory tDCS stimulation group *(M* = .20, *S.D* = .57*)* was statistically significant*; t(6)* = 2.42, *p =.05;* this result did represent a large effect size, *d* = 1.72 (Field, 2013). These results demonstrate that excitatory tDCS over the left M1 increased technical fluency compared to inhibitory tDCS over the left M1. Figure 9 illustrates the mean scores between the two tDCS stimulation groups and the

difference score for technical fluency. See Table 4 for the mean and standard deviation scores for technical fluency for all participants in the excitatory tDCS stimulation condition. See Table 5 for the mean and standard deviation scores for technical fluency for all participants in the inhibitory tDCS stimulation condition.

Table 4. Mean scores for technical fluency from the expert adjudicator for the excitatory tDCS stimulation group. The mean scores from the first block consisted of the first five stimuli presented for technical fluency. The mean scores from the second block consisted of the remaining five stimuli presented. These scores were calculated for each participant and a difference score between the two blocks was generated for technical fluency.

Participants	tDCS group	Technical fluency (Block one)	Technical fluency (Block two)	Technical Fluency difference score
1	Excitatory tDCS	5.2	6.6	1.4
2	Excitatory tDCS	7.6	8.2	0.6
3	Excitatory tDCS	6.6	7.4	0.8
4	Excitatory tDCS	5.6	7	1.4
	Mean	6.25	7.30	1.05
	S.D	1.61	0.85	0.82

Table 5. Mean scores for technical fluency from the expert adjudicator for the inhibitory tDCS stimulation group. The mean scores from the first block consisted of the first five stimuli presented for technical fluency. The mean scores from the second block consisted of the remaining five stimuli presented. These scores were calculated for each participant and a difference score between the two blocks was generated for technical fluency.

Participants	tDCS group	Technical fluency (Block one)	Technical fluency (Block two)	Technical Fluency difference score
1	Inhibitory tDCS	5.2	6.2	1
2	Inhibitory tDCS	6.2	6.4	0.2
3	Inhibitory tDCS	7.2	7	-0.2
4	Inhibitory tDCS	6.4	6.2	-0.2
	Mean	6.25	6.45	0.20
	S.D	0.74	1.11	0.50

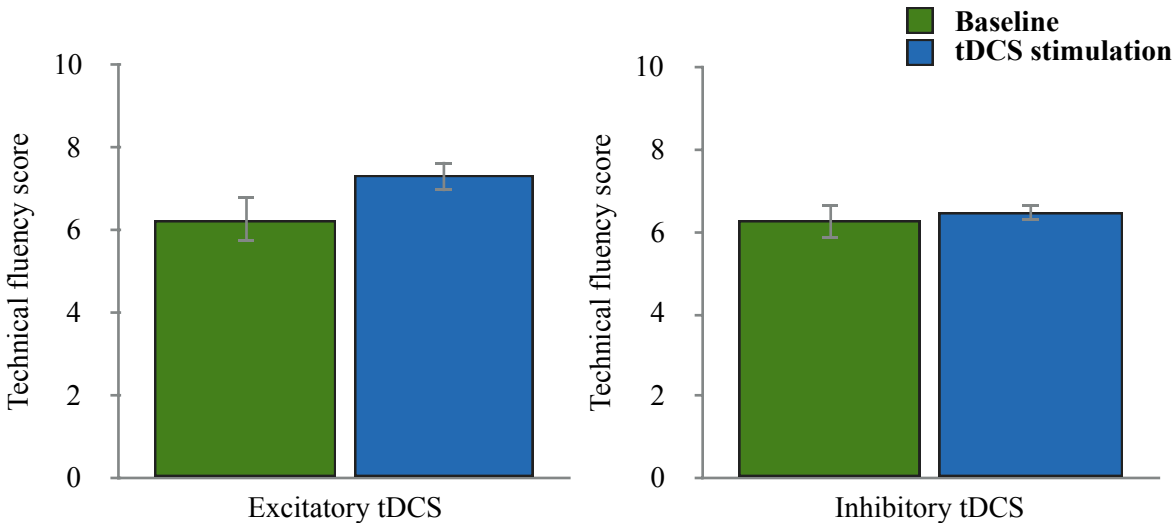


Figure 9. Mean technical fluency scores for the two tDCS stimulation groups from the expert adjudicator in each block. The difference score was generated by subtracting the mean score from the second block from the first block in each condition.

3.3 Correlation between technical fluency and creativity

Results in the following sections are post-hoc exploratory analyses. First, a Pearson's r correlation coefficient was conducted to determine if there is a relationship between the technical fluency and creativity scores given by the judges in the improvisation section. The expert adjudicator scored technical fluency and creativity on a Likert scale and all individual scores were utilised for analysis. All trials were randomised between participants and conditions. Across the 80 improvisations, there was a statistically significant correlation between ratings of creativity and ratings of technical fluency, $r = .765$, $n = 80$, $p = < .001$. Next, creativity and technical fluency scores were separated into the two tDCS stimulation groups for further analysis. The total number of trials for participants in the excitatory tDCS stimulation group ($n = 40$) were used to compute the correlation. There was a statistically significant correlation between creativity and technical fluency for improvisations in the excitatory tDCS stimulation group, $r = .820$, $n = 40$, $p = < .001$, and the inhibitory group, $r = .732$, $n = 40$, $p = < .001$. The Pearson's r value may reflect that when technical fluency was high, creativity was also high, as judged by a single expert adjudicator (Field, 2013). However, the correlation might also reflect the difficulty that an adjudicator has in distinguishing between technical fluency and creativity. Hearing a poorly executed improvisation, for example, the adjudicator may have assigned poor ratings for both technical fluency and creativity, irrespective of the 'creativity' levels in the improvisations.

3.4 Regression: Investigating the influence of technical fluency on creativity

A regression was conducted on the technical fluency score to determine its influence on the creativity score for the excitatory tDCS stimulation group. All trials were utilised for analysis. The regression showed statistical significance between the technical fluency score and the creativity score for the excitatory tDCS stimulation group, $F(1,38) = 77.810$, $p = <.001$, $R^2 = .672$. The R squared score determines that 67.2% of the variability in the dependent variable (creativity) was mediated by technical fluency for the excitatory tDCS stimulation group. A regression was conducted on the technical fluency score to determine its influence on the creativity score for the inhibitory tDCS stimulation group. All trials were utilised for analysis. The regression showed statistical significance between the technical fluency score and the creativity score for the inhibitory tDCS stimulation group, $F(1,38) = 43.968$, $p = <.001$, $R^2 = .536$. The R squared score determines that 53.6% of the variability in the dependent variable (creativity) was mediated by technical fluency for the inhibitory tDCS stimulation group. Although statistical significance was reached for both tDCS groups, the R squared score for the excitatory tDCS stimulation group was higher than the R squared score for the inhibitory tDCS stimulation group, which highlights that technical fluency predicts creativity to a *greater* degree with excitatory tDCS compared to inhibitory tDCS. However, due to the small sample size, caution is needed when interpreting the R squared results, since both groups reached significance.

3.5 Follow-up analyses: Effects of melodic features

Three melodic features were analysed to determine if tDCS had an effect on the features, they were: number of notes used, pitch range, and number of different notes used. The mean scores between the participants in both groups was used for analysis in an independent samples t-test to determine if the difference scores between the two blocks and the two stimulation groups is mediated by tDCS.

3.5.1 Number of notes used

The difference score between the two blocks for both tDCS stimulations groups was calculated and used for analysis. The difference score for the number of notes used between the excitatory tDCS stimulation group *(M = 3.25 S.D = 4.08)* and the inhibitory tDCS stimulation group *(M = 1.00 S.D = 2.35)* was not statistically significant; $t(6) = .955$, $p = >.05$. See Figure 10 for the mean number of notes for both tDCS stimulation groups and between the two blocks.

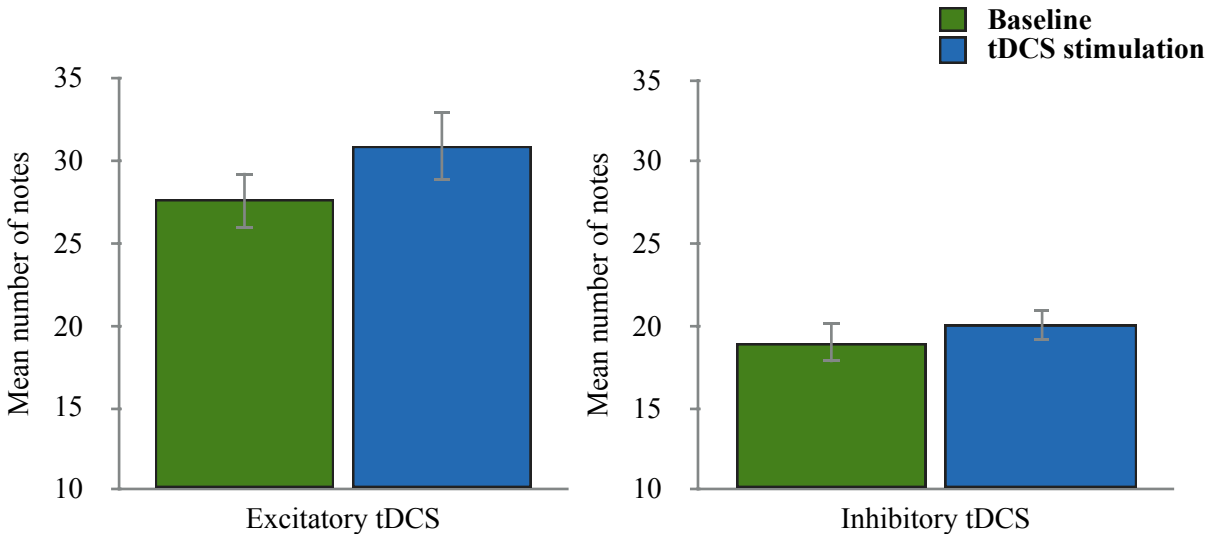


Figure 10. Mean number of notes used in the improvisation section. The left figure illustrates the mean number of notes used in the first and second blocks for the Anodal-Left/Cathodal-Right group. The right figure illustrates the mean number of notes used in the first and second blocks for the Cathodal-Left/Anodal-Right group.

3.5.2 Pitch range

The difference score between the two blocks for both tDCS stimulations groups was calculated and used for analysis. The difference score for the pitch range used between the excitatory tDCS stimulation group *(M* = 1.90 *S.D* = 1.50*)* and the inhibitory tDCS stimulation group *(M* = .20 *S.D* = .37*)* was not statistically significant; $t(3.35) = 2.201$, $p = >.05$. See Figure 11 for the mean pitch range for both tDCS stimulation groups and between the two blocks.

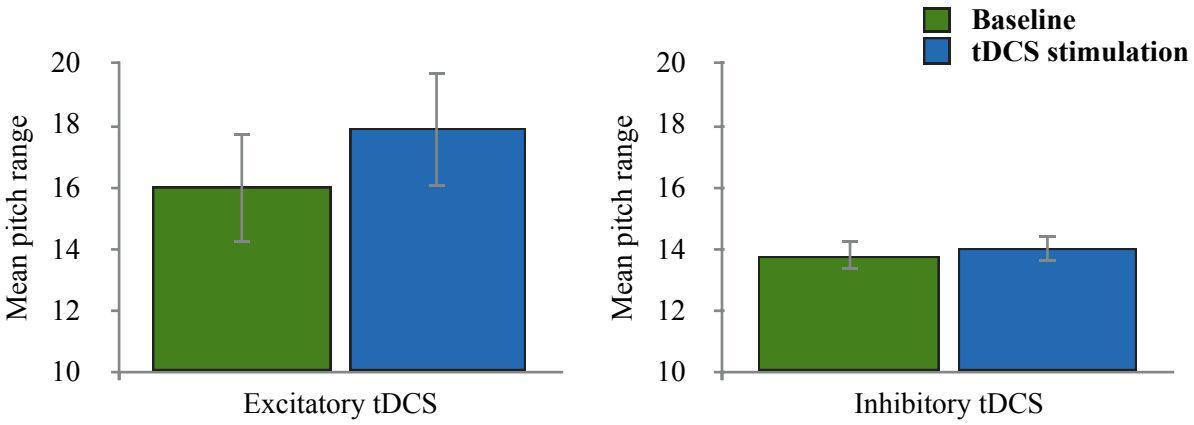


Figure 11. Mean pitch range used in the improvisation section. The left figure illustrates the mean pitch range used in the first and second blocks for the excitatory tDCS stimulation group. The right figure illustrates the mean pitch range used in the first and second blocks for the inhibitory tDCS stimulation group.

3.5.3 Number of different notes used

The difference score between the two blocks for both tDCS stimulations groups was calculated and used for analysis. The difference score for the number of different notes used between the excitatory tDCS stimulation group *(M* = 1.20 *S.D* = .43*)* and the inhibitory tDCS stimulation group *(M* = .60 *S.D* = .71*)* was not statistically significant; *t(6)*= 1.441, *p* = >.05. See Figure 12 for the mean number of different notes used for both tDCS stimulation groups and between the two blocks.

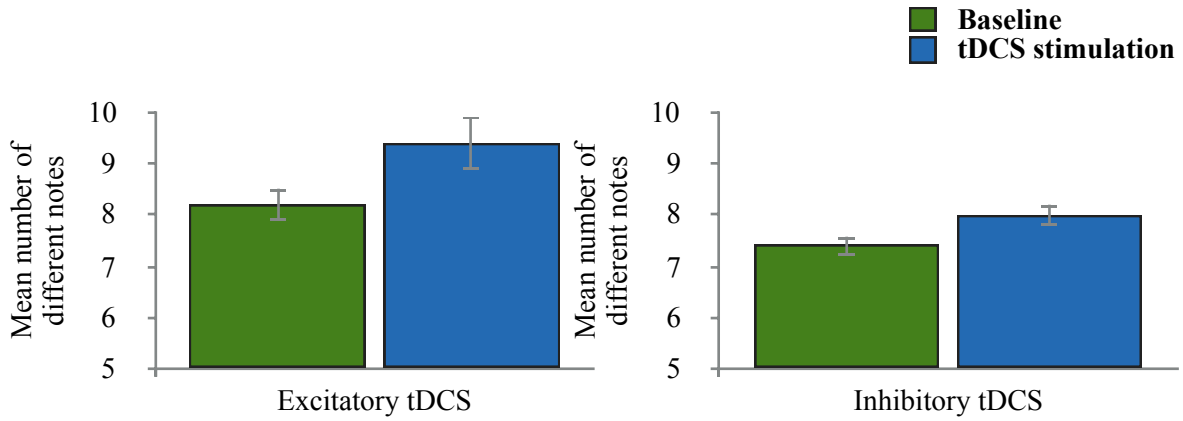


Figure 12. Mean number of different notes used in the improvisation section. The left figure illustrates the mean pitch range used in the first and second blocks for the excitatory tDCS stimulation group. The right figure illustrates the mean number of different notes used in the first and second blocks for the inhibitory tDCS stimulation group.

3.6 Multiple regression analysis: Melodic features

A multiple regression was conducted on the number of notes, different notes and pitch range to determine the creativity difference score between the two blocks and across all participants. The multiple regression showed no statistical significance between the three predicators and the creativity score, *F(*3,4*)* = .899, *p* = >.05, R^2 = .403. The three predictors was also analysed using a multiple regression to predict the technical fluency difference score. The multiple regression has shown no statistical significance between the three predicators and technical fluency, *F(*3,4*)* = .463, *p* = >.05, R^2 = .258. The R squared score delineates the level of variance in the dependent variable (creativity) that is accounted by the independent variable (technical fluency) (Field, 2013). The results from the multiple regression have demonstrated that the number of notes, pitch range and the number of different notes utilised in a musical improvisation does not mediate the adjudication of creativity and technical fluency. See Appendix J for the individual data for each tDCS stimulation group pertaining to the three performance features analysed.

3.7 Sight reading accuracy

3.7.1 Pitch note accuracy

To measure pitch note accuracy, the notes performed by the participants in the sight reading component of the stimuli was compared to the notes presented to the participants. The measurement metric used for analysis was the deviation from the notes presented measured in semi-tones. See Table 6 for the measurements used in the analysis. The mean number of pitch note accuracy was calculated for block one and block two and a difference scored was generated for analysis for each participant. See Table 7 for the mean and standard deviation pitch note and timing accuracy for each participant in both tDCS stimulation groups and the difference score between the two blocks. See Figure 13 for the mean pitch note accuracy for the two tDCS stimulation groups. There was no statistical difference between the excitatory tDCS stimulation group *(M = .039, S.D = .10)* and the inhibitory tDCS stimulation group *(M =* .12*, S.D =* .21*) conditions; t(*6*)* = -.654*, p* =>.05 in pitch note accuracy.

Table 6. Scoring metric utilised to measure pitch note accuracy. This scoring metric was only utilised in the 'sight-reading' section to analyse pitch note accuracy.

Increase in Pitch		**Decrease in Pitch**	
Correct	0	Correct	0
Incorrect (one semitone)	+1	Incorrect (one semitone)	-1
Incorrect (two semitones)	+2	Incorrect (two semitones)	-2
Incorrect (three semitones)	+3	Incorrect (three semitones)	-3
Incorrect (four semitones)	+4	Incorrect (four semitones)	-4
Incorrect (five semitones)	+5	Incorrect (five semitones)	-5

Table 7. Mean pitch note and timing accuracy for both tDCS stimulation groups and the difference between the two groups. Pitch accuracy measured in semitones; timing accuracy measured in milliseconds.

Group	Pitch note (Block 1)	Pitch note (Block 2)	Pitch note difference	Timing (Block 1)	Timing (Block 2)	Timing difference
Excitatory tDCS	0.021	0.060	0.039	40.623	29.087	-11.536
Inhibitory tDCS	0.211	0.327	0.116	425.524	277.394	-148.130

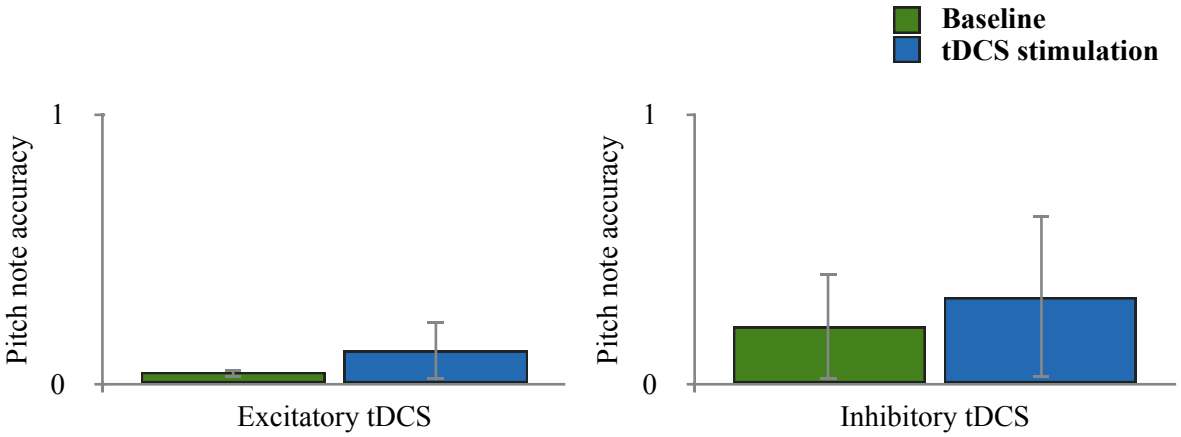


Figure 13. Pitch note accuracy for all participants in both tDCS stimulation groups. Pitch note accuracy was measured in semi-tones.

3.7.2 Timing accuracy

To measure timing accuracy, the timing onset of each note from sight reading stage from the stimuli was calculated in milliseconds and was measured against the onset of each note generated by the participants in the sight reading stage. There was no statistical significance between the excitatory tDCS stimulation group *(M = -11.54, S.D = 15.05)* and the inhibitory tDCS stimulation group *(M* = -148.13*, S.D* = 242.60*); t(*3.023*)* = 1.124*, p* =>.05 for timing. In the inhibitory tDCS stimulation group, mean timing accuracy *improved* between the two blocks. These results are of particular interest and will be elaborated on further in the subsequent discussion section. See Figure 14 for the mean timing accuracy for both tDCS stimulation groups. The results suggest that, irrespective of the stimulation group, pitch note accuracy and timing in proficient musicians is not significantly affected. Differences in timing accuracy between the two tDCS groups demonstrated a significant discrepancy in musical abilities measured by the timing accuracy and must be analysed with caution. See Appendix K for the individual data for each tDCS stimulation group pertaining to pitch note and timing accuracy analysed.

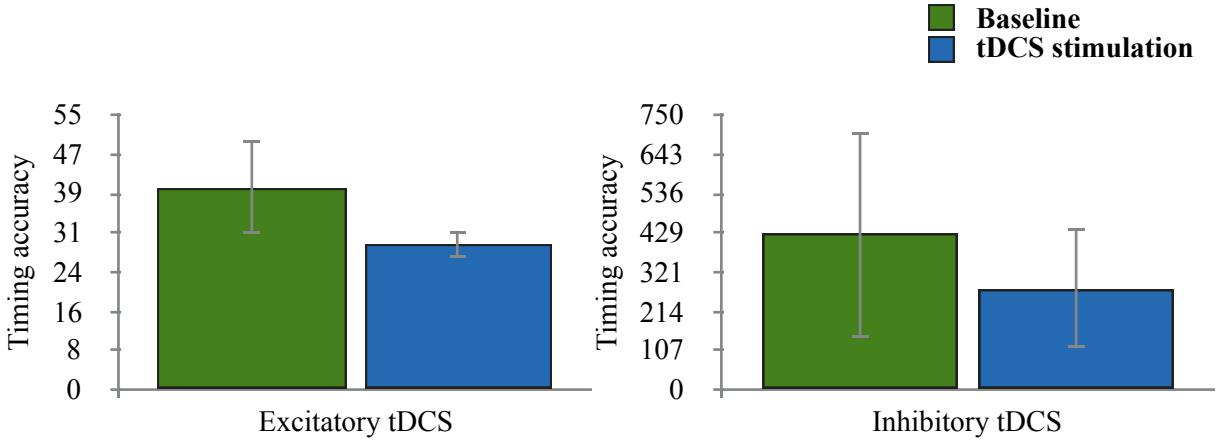


Figure 14. Mean timing accuracy for both tDCS stimulation groups in both blocks. Timing accuracy was measured in milliseconds.

3.8 Correlation between creativity and timing accuracy

A Pearson's r correlation coefficient was computed to determine if there is a relationship between creativity and timing accuracy. For the excitatory tDCS group, the results show that there is a statistically significant relationship between creativity and timing accuracy, $r = -.963$, $n = 4$, $p = < .05$. The results show a very strong negative correlation between creativity and timing accuracy. Another correlation was conducted for the inhibitory tDCS group, the results show that there is no statistically significant relationship between creativity and timing accuracy, $r = .220$, $n = 4$, $p = >.05$. See Table 8 for the mean timing accuracy, creativity and difference score for the excitatory tDCS stimulation group. See Table 9 for the mean timing accuracy, creativity and difference score for the inhibitory tDCS stimulation group.

Table 8. Mean timing accuracy and creativity scores for the excitatory tDCS stimulation group. The difference score was calculated for all participants in the excitatory tDCS stimulation group.

Participants	Group	Mean timing (block one)	Mean timing (block two)	Difference	Creativity (block one)	Creativity (block two)	Difference
1	Excitatory tDCS	28.939	21.872	-7.067	5.2	6.4	1.200
2	Excitatory tDCS	27.822	30.593	2.772	8	8.2	0.200
3	Excitatory tDCS	38.146	29.031	-9.116	5.6	6.8	1.200
4	Excitatory tDCS	67.583	34.852	-32.731	4.2	6.4	2.200
	Mean	40.623	29.087	-11.536	5.750	6.950	1.200

Table 9. Mean timing accuracy and creativity scores for the inhibitory tDCS stimulation group. The difference score was calculated for all participants in the inhibitory tDCS stimulation group.

Participants	Group	Mean timing (block one)	Mean timing (block two)	Difference	Creativity (block one)	Creativity (block two)	Difference
1	Inhibitory tDCS	1218.843	770.502	-448.341	4.2	4.2	1
2	Inhibitory tDCS	425.551	184.531	-241.020	5	5.2	0.2
3	Inhibitory tDCS	31.447	96.404	64.956	6	6.8	-0.2
4	Inhibitory tDCS	26.256	58.139	31.883	5.2	4.8	-0.2
	Mean	425.524	277.394	-148.130	5.100	5.250	0.200

3.9 Correlation between technical fluency and timing accuracy

A Pearson's r correlation coefficient was conducted to determine if there is a relationship between technical fluency scores from the improvisation section and timing accuracy in the sight reading section for the excitatory tDCS stimulation group. The expert adjudicator scored technical fluency on a Likert scale. There was no statistically significant effect between the two variables, r = -.693, n = 4, p = >.05. The Pearson's r value generated does demonstrate some evidence that there is a strong negative correlation between technical fluency and timing accuracy. To further elaborate, when technical fluency scores increase (by the expert adjudicator), timing accuracy decreases, which is interpreted as the participants being *more* accurate in the sight reading section.

A Pearson's r correlation coefficient was conducted to determine if there is a relationship between technical fluency scores from the improvisation section and timing accuracy in the sight reading section for the inhibitory tDCS stimulation group. The expert adjudicator scored technical fluency on a Likert scale. There was a statistically significant effect between the two variables, r = -.965, n = 4, p = <.05. However, the results require careful interpretation, the large variability in the means between the two blocks could have accounted for the results. Two outlier scores happen to fall into this group, which could have skewed the the distribution of scores. There is preliminary evidence that suggests that sight reading accuracy, measured in timing accuracy, is correlated to technical fluency, scored by an expert adjudicator. See Table 10 for the mean timing accuracy and technical fluency scores for each participant in the excitatory tDCS stimulation group. See Table 11 for the mean timing accuracy and technical fluency scores for each participant in the inhibitory tDCS stimulation group.

Table 10. Mean timing accuracy and technical fluency scores for the excitatory tDCS stimulation group. The difference score was calculated for all participants in the Anodal-Left/Cathodal-Right tDCS stimulation group.

Participants	Group	Mean timing (block one)	Mean timing (block two)	Difference	Technical fluency (block one)	Technical fluency (block two)	Difference
1	Excitatory tDCS	28.939	21.872	-7.067	5.2	6.6	1.400
2	Excitatory tDCS	27.822	30.593	2.772	7.6	8.2	0.600
3	Excitatory tDCS	38.146	29.031	-9.116	6.6	7.4	0.800
4	Excitatory tDCS	67.583	34.852	-32.731	5.6	7	1.400
	Mean	40.623	29.087	-11.536	6.250	7.300	1.050

Table 11. Mean timing accuracy and technical fluency scores for the inhibitory tDCS stimulation group. The difference score was calculated for all participants in the Cathodal-Left/Anodal-Right tDCS stimulation group.

Participants	Group	Mean timing (block one)	Mean timing (block two)	Difference	Technical fluency (block one)	Technical fluency (block two)	Difference
1	Inhibitory tDCS	1218.843	770.502	-448.341	5.2	6.2	1
2	Inhibitory tDCS	425.551	184.531	-241.020	6.2	6.4	0.2
3	Inhibitory tDCS	31.447	96.404	64.956	7.2	7	-0.2
4	Inhibitory tDCS	26.256	58.139	31.883	6.4	6.2	-0.2
	Mean	425.524	277.394	-148.130	6.250	6.450	0.200

3.10 Regression on technical fluency and timing accuracy

A regression was conducted on timing accuracy to determine its influence on the technical fluency score for the excitatory tDCS stimulation group. The regression showed no statistical significance in predicting the technical fluency score by timing accuracy for the excitatory tDCS stimulation group, $F(1,2) = 1.845$, $p = >.05$, $R2 = .480$. Timing accuracy did not statistically add significance to the technical fluency score, $p = >.05$. A regression was computed on timing accuracy to determine its influence on the technical fluency score for the inhibitory tDCS stimulation group. The regression showed statistical significance in predicting the technical fluency score with timing accuracy for the inhibitory tDCS stimulation group, *F(1,2)*

= 27.302, p = <.05, R^2 = .932. Timing accuracy was a statistically significant predictor in technical fluency. However, these results require careful interpretation, large variability in timing accuracy in the inhibitory tDCS stimulation group could have skewed the results presented. See Table 11 for the mean timing accuracy and difference between the two blocks for the inhibitory tDCS stimulation group.

4. Discussion

The aims of the current study were: (1) to investigate the M1 region as a possible site for mediating creativity and technical fluency in an improvised jazz context; (2) to assess whether creativity and technical fluency are interrelated concepts in musical improvisations; and (3) to assess the level of sight reading accuracy, measured with pitch note and timing accuracy. The primary hypothesis was that excitatory tDCS over the M1 region will enhance the perceived creativity and technical fluency of improvisations, as well as sight reading accuracy of performances compared to inhibitory tDCS. The key finding was that excitatory tDCS over the dominant M1 region of proficient pianists enhanced both technical fluency and creativity in an improvised jazz context. This result supports the primary hypothesis that the M1 region plays a significant role in creativity and technical fluency in musical improvisations. Previous research has focused on two other brain networks, the ECN and DMN, and their respective brain areas, the DLPFC and the MPFC, as neural markers of creativity (e.g., Bengtsson, Csıkszentmihalyi & Ullén, 2007; Limb & Braun, 2008; Pinho et al., 2014, 2016; Bashwiner et al., 2016; Beaty et al., 2016). Other research has examined the premotor cortices (the vPMD and dPMD) and the pre-SMA to better understand the higher level of motor planning in musical performances (Berkowitz, & Ansari, 2008; de Manzano & Ullén, 2012a; Sosnik et al., 2014). The current research adds to this growing body of literature by investigating the M1 region and its possible role for creativity and technical fluency.

4.1 Creativity and technical fluency

When excitatory tDCS was applied to the left M1 region, creativity in musical improvisations increased by 12%, compared to 1.5% when excitatory tDCS was applied to the right M1 region, with a mean difference approaching statistical significance *(p = .07)*. Technical fluency in the musical performances between the two blocks for the excitatory tDCS stimulation group increased by 10.5% compared to 2% in inhibitory tDCS stimulation group, with a mean difference that was statistically significant *(p = .05)*. Highlighted in Sections 3.1 and 3.2, the large effect sizes demonstrated adds to the inferences and validity of these two results.

The improvement in creativity and technical fluency for the excitatory tDCS stimulation group suggests that the dominant (left) M1 region, when stimulated with excitatory tDCS, enhances both creativity and technical fluency. In light of the preliminary evidence from the current study, creativity and technical fluency are related concepts that are both required for musical improvisations in a jazz context. The evidence from the current study demonstrates that technical fluency and creativity are positively correlated irrespective of the tDCS stimulation ($r = .765$, $p < .001$). That is, an increase in one factor coincides with an increase in the other. However, subsequent analysis has revealed that the positive correlation is stronger when excitatory tDCS is applied ($r = .820$, $p < .001$) compared to inhibitory tDCS ($r = .732$, $p < .001$). To gain an understanding of the direction of influence between creativity and technical fluency, evidence from the current study suggests that excitatory tDCS ($p < .001$, $R2 = .672$) influences technical fluency more as a mediator for creativity in musical improvisations compared to inhibitory tDCS ($p < .001$, $R2 = .536$).

In other words, based on the R squared value for the excitatory tDCS group, 67.2% of the creativity score can be explained by technical fluency, whereas, the R squared value for the inhibitory tDCS group, 53.6% of the creativity score can be explained by technical fluency (Field, 2013). In light of the preliminary evidence, the cognitive mechanisms for creativity encapsulates technical fluency in an artistic behaviour such as musical improvisations. To gain an understanding of these results for creativity and technical fluency and how the M1 region underpins the enhancement of these concepts, we investigated the possible relationship between technical fluency and sight reading accuracy, which is mediated by the M1 region (Sosnik et al., 2014; Karok & Witney, 2014).

4.2 Technical fluency and sight reading accuracy

The preliminary evidence from the current study has demonstrated that the M1 region improved technical fluency. We explored the possible link between technical fluency and sight reading accuracy, which would incorporate the possible role of the M1 region in underpinning creativity. Our results provide some evidence that there is a correlational link between technical fluency and sight reading accuracy, which is mediated by the M1 region (Sosnik et al., 2014; Karok & Witney, 2014). To emphasise, there is a strong negative correlation between technical fluency and timing accuracy for the excitatory tDCS group. Although statistical significance was not reached, a tentative interpretation of these results based on the r value demonstrate the negative correlation ($r = -.693$, $n = 4$, $p = >.05$). The negative correlation indicates that the timing asynchrony *decreases,* meaning a more accurate performance, and this is coupled with an *increase* in

technical fluency. There is also a very strong negative correlational relationship between technical fluency and timing accuracy for the inhibitory tDCS group (r = -.965, n = 4, p = <.05). However, these results require careful interpretation. The timing accuracy data for the inhibitory group contained a wide range of variability (see Table 11 for the mean timing accuracy for the inhibitory tDCS group for all four participants). We speculate that sight reading accuracy, which encompasses timing and key stroke accuracy, is mediated by the M1 region and is the foundation of technical fluency. However, for the purposes of developing a conceptual model explaining these results, timing accuracy in sight reading accuracy will be used for analysis due to the more comprehensive data available. The timing accuracy from the preliminary study allows stronger inferences to be made about sight reading accuracy and technical fluency. The preliminary evidence from the current study suggests that sight reading accuracy is a mediator of technical fluency and that there may be a relationship between these two concepts. As a result, a conceptual model has been developed to gain an understanding of the M1 region and its role in underpinning creativity in musical improvisations by mediating sight reading accuracy and technical fluency. This is schematically presented in Figure 15 and will be explored in more detail below.

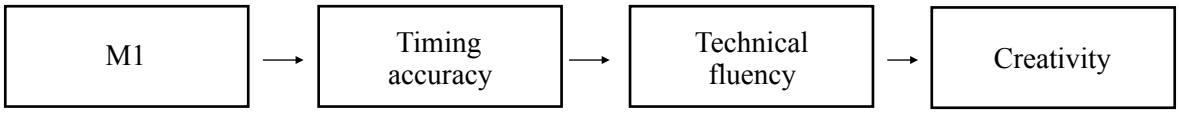


Figure 15. Schematic representation of a model of the hypothesised relationship between the M1 region, sight reading accuracy, technical fluency, and creativity in the context of musical improvisation. The manipulation of the M1 region with excitatory tDCS over the dominant (left) hemisphere enhances sight reading accuracy, here measured as timing accuracy, which in turn enhances technical fluency. An enhancement of technical fluency is then hypothesised to have a direct effect on creativity.

4.3 Conceptual model of the relationship between the M1 region, technical fluency and creativity

4.3.1 The M1 region and timing accuracy

The M1 region is involved in the consolidation and stabilisation of newly learnt motor skills, such as motor performance of the hand (Karok & Witney, 2013; Jelic, Sladjan & Filipovic, 2015; Apolinário-Souza, Romano-Silva, de Miranda, Malloy-Diniz, Benda, Ugrinowitsch & Lage, 2016; Reis & Fritsch, 2011). Motor performance can be measured by various parameters that include: timing accuracy in a motor task, such as pressing keys on a piano, and the number of errors made (Sosnik et al., 2014; Karok & Witney, 2014; Kim &

Shin, 2014). The manipulation of the M1 region with tDCS results in motor performance behavioural changes (Karok & Witney, 2013; Reis & Fritsch, 2011). In the current study, sight reading accuracy, which encapsulates timing and pitch note accuracy can be objectively measured. Therefore, in a musical context, sight reading accuracy can be measured behaviourally by assessing differences in timing and errors made in a performance task. In the following section, we argue that timing accuracy as measured from the sight reading task is a foundation of technical fluency in musical performances, and that variations in technical fluency influences variations in creativity.

4.3.2 Timing accuracy and technical fluency

Timing accuracy and technical fluency are two factors that are important for musical performance. An artistic behaviour, such as piano playing, requires high levels of finger coordination, which encapsulates hand orientation and velocity (Kim & Shin, 2014; Sosnik et al., 2014). The properties of motor performance (e.g., timing accuracy) are mediated by the M1 region (Sosnik et al., 2014; Kim & Shin, 2014; Reis & Fritsch, 2011). Timing accuracy, we speculate, is related to technical fluency due to sight reading accuracy being a foundation for technically fluent behaviours. In other words, in the context of the present study, if sight reading accuracy is related to technical fluency, a change in timing accuracy should result in a change in technical fluency. The results demonstrate that there is some evidence to suggest that timing accuracy is a predicator of technical fluency and are interrelated.

4.3.3 Technical fluency and creativity

We further argue that technical fluency directly affects creativity in musical performances. To illustrate, technical fluency should predict a change in creativity. The preliminary results provide some evidence that there is a positive correlation between technical fluency and creativity. Excitatory tDCS over the dominant (left) M1 region enhanced both technical fluency and creativity in participants' performances. The M1 region, which underpins motor performance and distinct properties of the hand, is enhanced when excitatory tDCS is applied. This effect cascades to enhance the level of technical fluency in the participants' musical performances. As a result, the ability to perform to a higher creative level is driven by an enhancement in technical fluency and sight reading accuracy.

4.4 Melodic feature analysis

Further analyses were conducted on the melodic features of the musical performances to gain an insight on the factors that mediated the levels of creativity and technical fluency. Three melodic features were analysed: total number of notes, pitch range and number of different notes. These melodic features were chosen for analysis because they can provide an insight on the participants' repertoire and expertise in musical improvisations. The results demonstrate that the three predicators (number of notes, pitch range and number of different notes) did not significantly influence the level of creativity and technical fluency in the musical performances. The small sample size and high level of variation of participants' performances could be factors that explain these non-significant results. However, although statistical significance was not achieved with the three predicators on the adjudication of creativity and technical fluency, there was a numerical trend that was apparent between the two tDCS stimulation groups. Participants in the excitatory tDCS group demonstrated an overall numerical increase in all three melodic predicators compared to inhibitory tDCS. Further research with a greater sample size will determine whether this trend is reliable or not.

4.5 Sight reading accuracy

Participants in the excitatory tDCS stimulation group demonstrated an overall improvement in timing accuracy by 28.4% in the sight reading task with excitatory tDCS over the dominant (left) hemisphere between the two blocks. This result is in direct contrast to the findings presented in Furuya et al's (2014) study. They report that excitatory tDCS over the hemisphere contralateral to the measured hand degenerates performance in musicians. These contradictory results between the current study and the Furuya et al. (2014) could be accounted by the differing methodologies and the experimental paradigm employed in the studies. For instance, Furuya et al. (2014) employed a bi-hemispheric *offline* tDCS montage over the M1 region, which separates the stimulation and performance stages of the experimental paradigm. The current study employed a bi-hemispheric *online* tDCS montage, which combines the stimulation and performance stages and has been determined as a superior methodology to elicit effects in motor performance (Karok & Witney, 2013). This result addresses the main methodological aims outlined previously, which purports that bi-hemispheric online tDCS is the most prominent montage to assess the modulation of motor performance by stimulating the M1 region. Furthermore, the tasks utilised between the Furuya et al. (2014) and the current study differ in ecological validity. The Furuya et al. (2014) study utilised a key stroke task for both hands,

whereas the current study employed a more ecologically valid sight reading task to measure motor performance.

Interestingly, participants in the inhibitory tDCS stimulation group also elicited an overall improvement in timing accuracy by 34.81% between the two blocks. This result was mediated by individual differences in the inhibitory tDCS stimulation group (See Table 11 for the mean timing accuracy for the participants in the inhibitory tDCS group). Two participants in the inhibitory tDCS stimulation group improved in timing accuracy with inhibitory tDCS whilst the other two participants within the same group worsened with inhibitory tDCS. The participants that worsened in timing accuracy were right-handed, which according to the current literature on the architecture of the M1 and tDCS, is concomitant (Vines et al., 2008). The two participants that performed better with inhibitory tDCS were left handed and ambidextrous. To gain an understanding of the discrepancy in timing accuracy within the inhibitory tDCS stimulation group, the architecture of the M1 region was explored by Vines et al. (2008) using uni-hemispheric tDCS. They found that tDCS stimulation over the dominant (left) hemisphere modulated motor performance in both the right (ipsilateral) and left (contralateral) hands.

However, tDCS stimulation over the non-dominant (right) hemisphere only affected the left (contralateral) hand. It has been shown that the M1 region operates in an asymmetrical fashion (van den Berg, Swinnen & Wenderoth, 2011; Vines et al., 2008). For instance, right-handed individuals using their non-dominant (left) hands in a task activate their ipsilateral (left) M1 region more than the contralateral (right) M1 region (van den Berg, Swinnen & Wenderoth, 2011). The results gathered from the current study pertaining to the left-handed participant with right hemisphere dominance supports the findings by Vines et al., (2008). Here, applying excitatory tDCS over the dominant (right) hemisphere had profound effects on the ipsilateral (right) hand. This is determined by the profound improvement for the left handed participant in timing accuracy between the two blocks, the timing asynchrony improved by 36.78% even though they performed the task with their right hand. Timing accuracy was also observed for the ambidextrous participant with an overall improvement in timing accuracy by 56.64% between the two blocks.

The two participants who were right-handed in the inhibitory tDCS stimulation group demonstrated a decrease in timing accuracy by an average of 62.66%. It has been shown that inhibitory tDCS reduces corticospinal excitability by hyper polarising the resting membrane potential, which leads to a decrease in neural activity (Vaseghi, Zoghi & Jaberzadeh, 2016; Nitsche, & Paulus, 2000; Jaberzadeh, Bastani, Zoghi, 2014). Previous literature has demonstrated that inhibitory tDCS over the dominant M1 hemisphere decreases motor performance compared to excitatory tDCS over the same M1 hemisphere (Vines et al., 2008). Overall, the discrepancy in timing accuracy in the inhibitory tDCS stimulation group can be explained by the M1 hemispheric dominance between the participants.

4.6 Implications

The main implication that can be derived from the current study is that the M1 region is a part of the complex neural network across various brain regions that underpin creativity and technical fluency in musical improvisations. To further elaborate, the cognitive mechanisms that underpin creativity is purported to be mediated by technical fluency and sight reading accuracy based on the preliminary evidence from the current study. As mentioned, previous literature has investigated the areas of the brain that underpin higher-level cognition and motor planning (e.g., Bengtsson, Csıkszentmihalyi & Ullen, 2007; Sosnik et al., 2014). This study argues that the M1 region, which mediates low-level motor control and properties of the hand *also* contributes to the neural substrates of creative cognition (Sosnik et al., 2014). Another implication from the current study is related to the methodological aims proposed earlier; namely, the effect of online bi-hemispheric tDCS as an experimental montage. Previously, this tDCS montage has been shown to be superior to offline uni-hemispheric tDCS in neurotypical participants (Karok & Witney, 2013). The present study demonstrates that sight reading accuracy with excitatory tDCS over the dominant M1 region of proficient musicians improves in an ecologically valid task.

4.7 Limitations and future directions

One main limitation of the current study was its small sample size (n = 4 per tDCS group). A greater sample of musicians would provide a greater basis for statistical significance and provide a more comprehensive evaluation of technical fluency and creativity in musical improvisations. In light of the experimental design, employing a control group will allow inferences to be made about any potential practice effects that could be present in the paradigm. The addition of the control group would strengthen the experimental paradigm and would allow stronger conclusions to be made about the effect of tDCS over the

M1 region in mediating creativity and technical fluency. In light of the recruitment process of proficient musicians, a more rigorous and controlled level of recruitment with respect to the level of musicianship will provide more consistent and reliable results for analysis. To further illustrate, the questionnaire that was administered to the participants should have addressed whether they were trained in jazz or classical music. As de Manzano & Ullén (2012a) have argued, differences in musical experience and training could elicit different results in the experiment that was designed and implemented. Furthermore, recruiting two expert adjudicators will provide more reliability in the assessment of scoring in the musical performances with respect to inter-rater reliability.

To expand upon the direction of the current study, applying online bi-hemispheric tDCS over the DLPFC, which corresponds to the F3 & F4 electrode sites on the International EEG system will be an interesting and pertinent direction for investigating creativity in an improvised jazz context (Herwig, Satrapi & Schonfeldt-Lecuona, 2003). Recently, two studies (Colombo et al., 2015; Zmigrod et al., 2015) utilised tDCS over the DLPFC area and examined its effect on convergent and divergent creative behavioural tasks. Investigating the effects of tDCS over the DLPFC in an ecologically valid creative exercise, namely, jazz improvisation will add to the body of literature examining creativity with tDCS (Bengtsson, Csıkszentmihalyi & Ullén, 2007). As the previous fMRI studies have demonstrated, there is a discrepancy in the activation patterns of the DLPFC and DMN (Limb & Braun, 2008; de Manzano & Ullén, 2012a; Pinho et al., 2014; Bengtsson, Csıkszentmihalyi & Ullén, 2007). However, recent studies (e.g., Pinho et al., 2016; Beaty et al., 2016) are demonstrating a concurrency between these two distinct brain regions: the ECN and DMN in musical and non-musical contexts, respectively. Therefore, investigating the operations of the DLPFC with tDCS will provide a more comprehensive analysis of its role in creativity in a musical context.

Furthermore, stimulating both the DLPFC and M1 region concurrently with tDCS in a motor task that encapsulates creativity (e.g., musical improvisation) will be an important direction for future investigations. It has been established that the M1 region and DLPFC are connected (Vaseghi, Zoghi & Jaberzadeh, 2016) and previous investigations have demonstrated the significant role of the DLPFC in musical improvisations (e.g., Bengtsson, Csıkszentmihalyi & Ullén, 2007). Therefore, examining the effects of concurrent tDCS stimulation over the DLPFC and M1 region in musical improvisations will provide an insight on how these two brain areas operationalise musical creativity. Furthermore, this proposed direction will directly test the conceptual model formulated in the current study with respect to the possible link between the M1 region

and musical creativity. As the preliminary evidence suggests, technical fluency and creativity are positively correlated, and sight reading accuracy is linked to technical fluency. Therefore, in light of the proposed direction, applying dual tDCS to the M1 and DLPFC regions will allow inferences on behavioural changes in musical improvisations. To further test the conceptual model proposed, an fMRI study can be conducted to measure the BOLD activity between the M1 region and the DLPFC during a musical improvisation task, which would provide a stronger foundation on whether there is a co-activation of these two regions during a musical task and determining the functional connectivity between these two regions.

Finally, dissecting the aspects of technical fluency to be tested with sight reading accuracy in an ecologically valid task is a significant and pertinent future direction to better understand the relationship between sight reading accuracy and technical fluency. To test the conceptual model proposed, aspects of technical fluency, in a musical context, that includes: dynamics, articulation, and phrasing needs to be experimentally tested with sight reading accuracy (e.g., timing and key stroke accuracy). An experiment that utilises an ecologically valid artistic behaviour (e.g., piano playing) can be dissected into its sight reading and technically fluent constituents. For instance, measuring timing accuracy can be conducted by identifying the temporal placement of a note and assessing the participants' timing accuracy of that note and its asynchrony. Key stroke errors can be assessed by measuring the number of key stroke errors made during the task. Aspects of technical fluency (e.g., dynamics and phrasing) can be behaviourally measured by assessing the fluctuations and levels of consistency that is performed by the participants.

4.8 Conclusion

This preliminary study has demonstrated that excitatory tDCS over the dominant hemisphere of the M1 region enhances creativity and technical fluency in an improvised jazz context compared to inhibitory tDCS over the same M1 region. This is the first study to demonstrate an enhancement of creativity and technical fluency by stimulating the M1 with bi-hemispheric, online tDCS. The preliminary results add to the creativity literature by purporting that the M1 region contributes to the expression of creativity by enhancing motor performance and technical fluency in an improvised jazz context.

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Appendices

Appendix A. Ethics approval letter

Office of the Deputy Vice-Chancellor
(Research)

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http://www.research.mq.edu.au/
ABN 90 952 801 237

MACQUARIE University
SYDNEY·AUSTRALIA

23 June 2016

Dear Professor Thompson

Reference No: 5201600392

Title: *Measuring creativity in an improvisational jazz context: a tDCS study*

Thank you for submitting the above application for ethical and scientific review. Your application was considered by the Macquarie University Human Research Ethics Committee (HREC (Medical Sciences)).

I am pleased to advise that ethical and scientific approval has been granted for this project to be conducted at:

- Macquarie University

This research meets the requirements set out in the *National Statement on Ethical Conduct in Human Research* (2007 – Updated May 2015) (the *National Statement*).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the *National Statement,* which is available at the following website:

http://www.nhmrc.gov.au/book/national-statement-ethical-conduct-human-research

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol.

3. All adverse events, including events which might affect the continued ethical and scientific acceptability of the project, must be reported to the HREC within 72 hours.

4. Proposed changes to the protocol and associated documents must be submitted to the Committee for approval before implementation.

It is the responsibility of the Chief investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Ethics Secretariat on 9850 4194 or by email ethics.secretariat@mq.edu.au

The HREC (Medical Sciences) Terms of Reference and Standard Operating Procedures are available from the Research Office website at:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics

The HREC (Medical Sciences) wishes you every success in your research.

Yours sincerely

Professor Tony Eyers
Chair, Macquarie University Human Research Ethics Committee (Medical Sciences)

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research* (2007) and the *CPMP/ICH Note for Guidance on Good Clinical Practice*.

Details of this approval are as follows:

Approval Date: 21 June 2016

The following documentation has been reviewed and approved by the HREC (Medical Sciences):

Documents reviewed	Version no.	Date
Macquarie University Ethics Application Form		Received 11/5/2016
Correspondence responding to the issues raised by the HREC (Medical Sciences)		Received 17/6/2016
MQ Participant Information and Consent Form (PICF) entitled *"tDCS and Musicians"* – Musicians (Clean & Tracked versions)	1	20/5/2016
MQ Participant Information and Consent Form (PICF) entitled *"tDCS and Musicians"* – External Judges (Clean & Tracked versions)	1	11/5/2016
SONA Advertisement (Pianists, MQ) – Clean & Tracked versions	1.3	17/6/2016
SONA Advertisement (Pianists, Other Institutions) – Clean & Tracked versions	1.3	17/6/2016
TMS Screener	1	11/5/2016
Advertising Flyer (MQ)	1	17/6/2016
Request for Amendment Form		8/6/2016
Telephone/voice message correspondence with organisation	1	8/6/2016
Questionnaire for External Judges	1	11/5/2016
Sample email to recruit External Judges	1	11/5/2016

***If the document has no version date listed one will be created for you. Please ensure the footer of these documents are updated to include this version date to ensure ongoing version control.**

Appendix B. Advertisements

Faculty of Human Sciences

Department of Psychology

MACQUARIE UNIVERSITY, NSW 2109 AUSTRALIA

Email: aydin.anic@students.mq.edu.au

Musicians who play the piano are invited to participate in a new research project

We are recruiting students who currently play the piano and have played for at least 1 year to investigate the brain's motor control of technical fluency and creativity. Participants who have experience in playing jazz or are familiar with jazz, music reading, and improvisation are invited to participate. We require people without speech, hearing, language or neurological impairments to play the piano in our laboratory at Macquarie University. The total time for the study will take no more than two hours. As part of this experiment, participants will undergo a safe and painless brain stimulation technique called tDCS while playing the piano. Participants will be reimbursed $50 for their time.

If you are interested, please contact: Mr. Aydin Anic on 0422 643 570 or aydin.anic@students.mq.edu.au

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If you are interested, please contact: Mr. Aydin Anic on 0422 643 570 or aydin.anic@students.mq.edu.au

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Appendix C. Sample email to adjudicators

Sample email to recruit external judges

Subject: Requesting your involvement in the adjudication of musical performances

Dear xxxx,

My name is Aydin Anic and I am conducting research at Macquarie University investigating musical improvisational performances using neurostimulation, namely, transcranial direct current stimulation (tDCS). I am asking for your involvement in adjudicating these musical performances. This should take no more than two hours in total over a one-week period and you will be remunerated a total of $50 for your participation. You will be provided with the musical notation and audio files of all performances (approximately 90-150 performances of a duration of 30 seconds each). Using the questionnaire we provide, your task will be to assess musical creativity and technical fluency of each performance. Your involvement is completely voluntary and if you do decide to participate, you are free to withdraw at any time without penalty. If you do not wish to participate, you do not need to reply to this email and no further measures will be taken to ask for your involvement. However, if you have any questions or would like to participate, please do not hesitate to contact me at the address provided below.

Thank you for your time and consideration.

Kindest regards,

Aydin Anic

Email: aydin.anic@students.mq.edu.au
Mob: 0422-643-570

Appendix D. Participant information and consent forms

Faculty of Human Sciences
Department of Psychology
MACQUARIE UNIVERSITY NSW 2109 AUSTRALIA
Email: aydin.anic@students.mq.edu.au

Participant Information and Consent Form

tDCS and External Judges

Title:	**Measuring creativity in an improvisational jazz context: a tDCS study**
Short title:	
Protocol number:	
Principal Investigator (PI):	**Professor Bill Thompson**
Sites:	**The Department of Psychology, Macquarie University**

1. Introduction

You are invited to take part in Measuring creativity in an improvisational jazz context: a tDCS study in order to discover how the brain processes information in order to perform cognitive functions such as technical fluency and creativity.

This Participant Information and Consent Form (PICF) tells you about the research project. It explains what taking part in this study will involve. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative or friend.

Our research team are happy to go through this information with you and answer any questions you may have. Please feel free to ask questions about anything that you do not understand or that you wish to know more about.

Conducting this research are members of the Department of Cognitive Science: Dr. Paul Sowman, and researchers from Psychology Prof. William Thompson, Mr. Aydin Anic, and Dr. Kirk Olsen.

Members of this research team, Mr. Aydin Anic, contribute to this research, as part of a requirement to meet their Masters degree requirements under the supervision of Prof. Thompson.

2. Purpose of the research

Aims

The aim of this research is to understand more about how the human brain controls musical creativity and technical fluency. The research uses a neurostimulation technique known as transcranial direct current stimulation (tDCS), which modulates brain activity to better understand technical fluency and creativity. You will be asked to judge musical performances by listening to and analysing audio and musical scores generated by participants administered tDCS. This will be achieved by a questionnaire that will be administered.

3. Why have I been chosen?

You have been chosen for the study as part of a group to judge technical fluency and creativity due to your musical ability and knowledge of musical performances.

4. Do I have to take part in this research project?

Participation in any research project is voluntary. If you decide you want to take part, you will first be asked to sign the consent section at the end of this form prior to any study assessments being performed. By signing it you are telling us that you:

- Understand what you have read
- Consent to take part in the research project
- Consent to have the tests and treatments that are described
- Consent to the use of your personal and health information as described

You will be given a copy of this form to keep.

If you decide to take part and later change your mind, you are free to withdraw from the project at any stage for any reason.

Your decision whether or not to take part in the study will not affect your relationship with Macquarie University.

5. What does participation in this research involve?

You may have heard about this study through an advertisement or have been contacted via email or telephone. Once you have contacted us or we have made contact with you, Mr. Aydin Anic will determine whether you are suitable as outlined above.

We then ask for you to attend one meeting at our laboratory at a time suited to you. Upon arrival at our laboratory at Macquarie University, we ask you to read through this consent form and ask any questions that you may have. If you are happy to proceed, we will ask you to sign two copies of the attached consent form, one which you may yourself keep. You will then be provided with the audio and/or musical scores to assess through a questionnaire that will be administered. We request that you complete the questionnaires within a week after administration.

After the Experiment

We may ask you to converse in a relaxed manner with the researcher for a 10 minute audio-recording to allow the speech pathologist connected with this study to determine that you do not stutter. We may ask you to complete one or two short standardised assessments of your language, cognitive and motor ability and your experience of stuttering.

The session may cease quickly and with minimal effort if requested by the participant, in the event of any discomfort.

The cost of the procedure will be borne by the researchers.

Remuneration

If you agree to participate in the study, it will take about 2 hours of your time, you will be provided a week to complete the assessment of the musical scores. To compensate you for the time you will expend, we will pay you $50.

Bias

This research project has been designed to make sure the researchers interpret the results in a fair and appropriate way. The study is undertaken as part of this research program are in part funded by the National Health and Medical Research Council (NHMRC) and by the Australian Research Council (ARC). Support is also provided by the ARC Centre of Excellence in Cognition and its Disorders (CCD) which is hosted by Macquarie University.

6. What do I have to do?

What will the behavioural tasks involve?

You will be asked to listen to audio recordings of musical improvisations and read the notated music as a reference, and then complete a questionnaire based on each musical performance. Specifically, you will be required to rate the level of creativity and technical fluency of each performance. This task does not carry any risks or discomfort, and regular rest breaks will be encouraged to avoid fatigue.

You will be asked to participate in a single session, which can be completed at your own pace and in your own time within a one-week period. On average the total time commitment will be approximately 2 hours.

As your participation in this research is voluntary, you are free to withdraw from the study at any time. If you choose to withdraw you do not have to offer an explanation for your decision, and you may request that any unprocessed data collected from you be removed from the database.

7. What are the possible benefits of taking part?

We cannot guarantee or promise that you will receive any benefits from this research, however, possible benefits to participants may include:

Enhanced understanding of the brain’s creative ability and/or motor skills in technical fluency in a musical improvisation.

8. What are the risks of taking part in this research?

There are no perceived risks in participating in this research.

9. What do I do if I wish to withdraw from the research?

Participation in any research is voluntary. If you do not wish to take part you do not have to. If you decide to take part and later change your mind, you are free to withdraw. You may withdraw even after you have commenced your participation. If you wish to withdraw from this study, please advise the study team. Once the results are published, you will not be able to withdraw from the study but you may ask that you not be invited to participate in future research.

10. What will happen when the study ends?

We will provide you with a link to our website where we publish our latest findings. You may arrange alternative methods of feedback by contacting the Principle Investigator.

11. What will happen to the information collected about me?

By signing this consent form you have consented for the study team and relevant research staff to collect and use your data and the information you give to us for the research project. We will ask you for your name, date of birth, education level, musical experience, and adjudication experience. Any information obtained during the course of this study will remain confidential.

Only your data will be used in publication of results. Typically only group data will be included in which you cannot be identified. Occasionally, a case study of one or a comparison of a small number of participants may be published. In these cases, no identifiable characteristics will be published.

Each participant's data is identified by code rather than name. All computers on which data is stored is password protected so may only be accessed by the researchers involved in this study. Paper forms are stored in locked box, so that only researchers involved in this study will have access. The data from the study will be stored for a period of ten years.

In some or all cases, data collected as part of this study may be shared with other researchers. With your consent, we would like to keep your data for the purposes of future, unspecified research projects. Any research that will be conducted using your data will be approved by a Human Research Ethics Committee and conducted in accordance with the *National Statement on Ethical Conduct in Human Research* (2007 – Updated March 2014)

It is expected that the results of this study will be published or presented in a variety of forums such as books, journal articles or at conferences. In any publication or presentation, information about you will be provided in a way that you cannot be identified, except with your express permission.

Any information obtained during this research project is subject to inspection for the purpose of verifying the study procedures or the data. This review may be done by the relevant authorities and authorised representatives of Macquarie University, or as required by law. By signing this consent form you authorise release of, or access to, this confidential information relevant to the research to authorised personnel and regulatory authorities as noted above.

12. Who has reviewed this study?

All research in Australia involving human participants is reviewed by an independent group of people, called a Human Research Ethics Committee (HREC). HRECs must review research in accordance with a set of ethical guidelines called the *National Statement on Ethical Conduct in Human Research* (2007 – Updated March 2014) and other relevant legislation and guidelines.

This study has been reviewed and given ethical approval by the Macquarie University HREC (Medical Sciences). This research meets the requirements of the National Statement which is available at the following website:

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf

If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

13. Further information and contacts

If you would like any further information on this study please do not hesitate to contact Mr. Aydin Anic, Mob. 0422-643-570; email: aydin.anic@students.mq.edu.au

Participant Consent

Title:

Project sponsor (if relevant)

Investigator:

Site:

1. I have read the attached Participant Information Form outlining the nature and purpose of the research study and I understand what I am being asked to do.
2. I have discussed my participation in this study with a member of the study team. I have had the opportunity to ask questions and I am satisfied with the answers I have received.
3. I have been informed about the possible risks of taking part in this study.
4. I freely consent to participate in the research project as described in the attached Participant Information Sheet.
5. I understand that my participation is voluntary and that I am free to withdraw at any time during the study.
6. I have been given a copy of this information and consent form to keep.

Participant's Name:_____

(Block letters)

Participant's Signature: _____Date:_____

Principal Investigator's Name:_____

(Block letters)

Investigator's Signature:_____ ___Date:_____

Withdrawal of Participation

Title: .....

Project sponsor (if relevant) .....

Investigator : .....

Site: .....

I hereby wish to **WITHDRAW** my intent to participate further in the above research project and understand that such withdrawal will not jeopardise my future health care.

Participant's Name (printed) .....

Signature .....

Date .....

<u>If a verbal withdrawal</u>:
In the event the participant decided to withdraw verbally, please give a description of the circumstances. Coordinating Investigator to provide further information here:

Participant's Name (printed) .....

Signature of Investigator .....

Date .....

Coordinating Investigator to sign the withdrawal of consent form on behalf of a participant if verbal withdrawal has been given:

Faculty of Human Sciences
Department of Psychology
MACQUARIE UNIVERSITY NSW 2109 AUSTRALIA
Email: aydin.anic@students.mq.edu.au

Participant Information and Consent Form

tDCS and Musicians

Title:	**Measuring creativity in an improvised jazz context: a tDCS study**
Short title:	
Protocol number:	
Principal Investigator (PI):	**Professor Bill Thompson**
Sites:	**The Department of Psychology, Macquarie University**

1. Introduction

You are invited to take part in Measuring creativity in an improvised jazz context: a tDCS study in order to discover how the brain processes information in order to perform cognitive functions such as creativity.

This Participant Information and Consent Form (PICF) tells you about the research project. It explains what taking part in this study will involve. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative, friend or local doctor.

Our research team are happy to go through this information with you and answer any questions you may have. Please feel free to ask questions about anything that you do not understand or that you wish to know more about.

Conducting this research are members of the Department of Cognitive Science: Dr. Paul Sowman, researchers from Psychology Prof. William Thompson, Mr. Aydin Anic, and Dr. Kirk Olson.

A Member of this research team, Mr. Aydin Anic contribute to this research, as part of a requirement to meet their Masters degree requirements, under the supervision of Prof. Thompson.

2. Purpose of the research

Aims

The aim of this research is to understand more about how the human brain controls musical creativity and technical fluency. The research uses a neurostimulation technique known as transcranial direct current stimulation (tDCS). You will also be given a tCS or a TMS form to sign, which will explain what the tCS or TMS technique involves.

3. Why have I been chosen?

You have been chosen for the study as part of a group of people due to your musical ability. We have determined that you do not have, or have not in the past had, any other speech, hearing, language or learning problem that might impact upon the results of the study, you are not on any medication which may affect the chemistry of your brain in a way that might impact upon the results of the study, and you do not have any metal in your body which may potentially risk damage to yourself or to the scanners, and you have passed the safety screener provided.

4. Do I have to take part in this research project?

Participation in any research project is voluntary. If you decide you want to take part, you will first be asked to sign the consent section at the end of this form prior to any study assessments being performed. By signing it you are telling us that you:

- Understand what you have read
- Consent to take part in the research project
- Consent to have the tests and treatments that are described
- Consent to the use of your personal and health information as described

You will be given a copy of this form to keep.

If you decide to take part and later change your mind, you are free to withdraw from the project at any stage for any reason.

Your decision whether or not to take part in the study will not affect your relationship with Macquarie University.

5. What does participation in this research involve?

You may have heard about this study through an advertisement. Once you have contacted us, a member of our research team will have contacted you in order to determine whether you are suitable as outlined above. We then asked for you to attend one or more brain recording/ stimulation sessions at times suited to you. Upon arrival at our laboratory at Macquarie University, we ask you to read through this consent form and ask any questions that you may have. If you are happy to proceed, we will ask you to sign two copies of the attached consent form, one which you may yourself keep.

tDCS

You will sit comfortably on a chair while the researcher gently places a cap over your head. The researcher may attach several electrodes to the cap. The researcher may need to dampen a

sponge, which is placed under the cap, to aid transference of the signal, or use conductive gel, for the same purposes. You will then be asked to perform the musical improvisational task.

After the Experiment

You will be required to complete a questionnaire where you will have the opportunity to make comments about your participation experience. .

The cost of the procedure will be borne by the researchers.

Parking is free of charge.

Remuneration

If you agree to participate in the study, it will take about 2 hours of your time per session for one session plus any travel or waiting time. To compensate you for the time you will expend, we will pay you $50.

Bias

This research project has been designed to make sure the researchers interpret the results in a fair and appropriate way.

The studies undertaken as part of this research program are in part funded by the National Health and Medical Research Council (NHMRC) and by the Australian Research Council (ARC). Support is also provided by the ARC Centre of Excellence in Cognition and its Disorders (CCD) which is hosted by Macquarie University.

6. What do I have to do?

We will ask you to try to have a good night sleep the night before your scans and to minimise any alcohol and caffeine use prior to your participation on the day of the experiment.

What will the behavioural tasks involve?

You will be asked to perform a musical task involving playing the piano whilst reading music and improvising to a backing track. An investigator will describe the specific requirements of each task to you verbally. Stimuli will appear as musical notation on a computer monitor with sounds of the piano presented through computer speakers. This task does not have any risks or discomfort, and regular rest breaks will be offered to avoid fatigue.

You will be asked to participate in a single testing session. On average the total time commitment is approximately 2 hours per session. You will be randomly allocated into one of two groups, both of the groups will contain true stimulation and no stimulation. The tDCS will be applied for no more than 20 minutes during the study.

As your participation in this research is voluntary, you are free to withdraw from the study at any time, and for any reason. If you choose to withdraw you do not have to offer an explanation for your decision, and you may request that any unprocessed data collected from you be removed from the database.

7. What are the possible benefits of taking part?

We cannot guarantee or promise that you will receive any benefits from this research, however, possible benefits to participants may include:

- Enhanced understanding of the brain's creative ability and/or motor skills.

8. What are the risks of taking part in this research?

What is Transcranial Direct Current Stimulation (tDCS)?

Transcranial direct current stimulation (tDCS) is a form of neurostimulation which uses constant, low current delivered directly to the brain area of interest via small electrodes. The current is applied via electrodes embedded in a small head-cap. Specifically, two electrodes will be placed on both sides of the scalp, one being positively charged and the other being negatively charged. The arrangement of the electrodes will determine the effect on your motor performance during the study. Fatigue, headaches, nervousness are all possible side-effects that may occur, which can be caused by the duration of the experiment and tDCS.

Are there any risks associated with tDCS?

There are no known risks of tCS at this time, however, because tCS is a brain stimulation technique we will still require you to pass a TMS safety screen to assess your susceptibility to seizures, such as a personal or family history of epilepsy. Although seizures do not seem to be a risk for healthy individuals, those with a tendency towards seizures may react differently.

Other potential adverse effects of tDCS

There are a few minor side effects that can be felt by the person while receiving the tCS stimulation. A recent study of over 500 subjects using the currently accepted protocol reported only a slight skin irritation and a phosphene as side effects from the potential effect of tDCS and will likely occur, however, should cause no significant discomfort. A phosphene is a brief flash of light that can be seen if an electrode is placed near to the eye. However, the electrodes in this study will not be placed near the eyes. In the scientific literature, other possible side-effects of tDCS may include: slight pain, nervousness, headaches, tingling, fatigue, and mild burning sensations. However, another study has demonstrated that the only side-effect of tDCS is slight skin irritation (mentioned above).

9. What do I do if I wish to withdraw from the research?

Participation in any research is voluntary. If you do not wish to take part you do not have to. If you decide to take part and later change your mind, you are free to withdraw. You may withdraw even after you have commenced your participation. If you wish to withdraw from this study, please advise the study team. Once the results are published, you will not be able to withdraw from the study but you may ask that you not be invited to participate in future research.

10. What will happen when the study ends?

We will provide you with a link to our website where we publish our latest findings. You may arrange alternative methods of feedback by contacting the Principle Investigator.

You may also request to ask which condition that you were placed in.

The effects of tDCS could last up to 1 hour after the completion of the study, to ensure your safety, we request that you do not operate heavy machinery for 1 hour after the completion of the study. Please take this time in consideration.

You will be notified of the condition in which you were placed in, the purpose of informing after the completion of the study is to ensure that your performance is not effected by your knowledge of the condition. We will check whether you will consent for the data gathered to be utilised in our research.

11. What will happen to the information collected about me?

By signing this consent form you have consented for the study team and relevant research staff to collect and use your data and the information you give to us for the research project. We will ask you for your name, date of birth and handedness. We will ask on the TMS screener, which will be provided with this form to determine your suitability for tDCS. Any information obtained during the course of this study will remain confidential.

Only your data will be used in publication of results. Typically only group data will be included in which you cannot be identified. Occasionally, a case study of one or a comparison of a small number of participants may be published. In these cases, no identifiable characteristics will be published.

Each participant's data is identified by code rather than name. All computers on which data is stored is password protected so may only be accessed by the researchers involved in this study. Paper forms are stored in lockable box accessible only by the researchers via a key, so that only researchers involved in this study will have access.

The data from the study will be stored for a period of ten years.

In some or all cases, data collected as part of this study may be shared with other researchers and external judges. With your consent, we would like to keep your data for the purposes of future, unspecified research projects. Any research that will be conducted using your data will be approved by a Human Research Ethics Committee and conducted in accordance with the *National Statement on Ethical Conduct in Human Research* (2007 – Updated March 2014).

It is expected that the results of this study will be published or presented in a variety of forums such as books, journal articles or at conferences. In any publication or presentation, information about you will be provided in a way that you cannot be identified, except with your express permission.

Any information obtained during this research project is subject to inspection for the purpose of verifying the study procedures or the data. This review may be done by the relevant authorities and authorised representatives of Macquarie University, or as required by law. By signing this consent form you authorise release of, or access to, this confidential information relevant to the research to authorised personnel and regulatory authorities as noted above.

12. Who has reviewed this study?

All research in Australia involving human participants is reviewed by an independent group of people, called a Human Research Ethics Committee (HREC). HRECs must review research in accordance with a set of ethical guidelines called the *National Statement on Ethical Conduct in Human Research* (2007 – Updated March 2014) and other relevant legislation and guidelines.

This study has been reviewed and given ethical approval by the Macquarie University HREC (Medical Sciences). This research meets the requirements of the National Statement which is available at the following website:

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf

If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

13. Further information and contacts

If you would like any further information on this study please do not hesitate to contact Mr. Aydin Anic email: aydin.anic@students.mq.edu.au

Participant Consent

Title:

Project sponsor (if relevant)

Investigator:

Site:

1. I have read the attached Participant Information Form outlining the nature and purpose of the research study and I understand what I am being asked to do.
2. I have discussed my participation in this study with a member of the study team. I have had the opportunity to ask questions and I am satisfied with the answers I have received.
3. I have been informed about the possible risks of taking part in this study.
4. I freely consent to participate in the research project as described in the attached Participant Information Sheet.
5. I understand that my participation is voluntary and that I am free to withdraw at any time during the study.
6. I have been given a copy of this information and consent form to keep.

Participant's Name:_____

(Block letters)

Participant's Signature: _____Date:_____

Principal Investigator's Name:_____

(Block letters)

Investigator's Signature:_____ ___Date:_____

Name of Participant: ……(block letters)

Date of Birth……. ……..……..

Right or left handed……..

Address……..

Phone…….……(HM)……(MOB)

Email……

Withdrawal of Participation

I hereby wish to **WITHDRAW** my intent to participate further in the above research project and understand that such withdrawal will not jeopardise my future health care.

Participant's Name (printed) .....

Signature .....

Date .....

<u>If a verbal withdrawal</u>:

In the event the participant decided to withdraw verbally, please give a description of the circumstances. Coordinating Investigator to provide further information here:

Participant's Name (printed) .....

Signature of Investigator .....

Date .....

Coordinating Investigator to sign the withdrawal of consent form on behalf of a participant if verbal withdrawal has been given:

Appendix E. Questionnaire for pianists

Questionnaire for New Participants - Musicians

Subject No: _____ **Date: _____**

Age: _____

Gender: _____

Handedness: _____

1. What age were you when you first started playing the piano?

   _____ years

2. Highest level of education attained

   - **Undergraduate** ☐
   - **Postgraduate** ☐
   - **TAFE/polytechnic** ☐
   - **High School** ☐
   - **Middle school** ☐

3. Years of formal musical education

   _____ years

4. How many hours per week do you spend practising/playing the piano?

   _____ per week

5. Have you completed any formal/informal musical examinations? If yes, can you provide some details on the examination and when it was completed?

_____
_____
_____
_____

6. How many hours per week do you listen to music?

_____

7.

Did you feel any discomfort during the task? Please indicate on a scale from 1 - 10, 1 indicating no discomfort and 10 being extreme discomfort. Can you describe the discomfort if any was experienced?

1 2 3 4 5 6 7 8 9 10

Comments:

_____
_____
_____
_____
_____

___

8.

Did you feel that you could perform to the best of your abilities?

Comments:

_____
_____
_____
_____

9. Did you feel that you could express your creativity in during the task?

Comments:

_____
_____
_____
_____

Notes:

_____
_____
_____
_____

Project Code _____ **Researcher** _____

Appendix F. TMS screener

TMS SCREENING FORM

Date of birth…… UNIQUE IDENTIFIER: ……

Transcranial Magnetic Stimulation (TMS) is a method for producing an electric current in a small part of the brain. During TMS, a current passes through a copper coil that is wound inside a plastic casing and held over the participant's head. The current in the coil produces a magnetic field, which passes safely through the scalp and causes electrical activity in brain tissue.

Before receiving TMS, please read the following questions carefully and provide answers. For a small number of individuals, TMS may carry an increased risk of causing a seizure. The purpose of these questions is to make sure that you are not such a person. You have the right to withdraw from the screening and subsequent scanning if you find the questions unacceptably intrusive. The information you provide will be treated as strictly confidential and will be held in secure conditions.

If you are unsure of the answer to any of the questions, please ask the person who gave you this form or the person who will be performing the study. Definitions of some of technical terms are given overleaf.

	Please tick
Have you ever had an adverse reaction to TMS?	**Yes No**
Do you experience claustrophobia?	**Yes No**
Have you had a seizure?	**Yes No**
Have you had a stroke?	**Yes No**
Have you had a serious head injury (including neurosurgery)?	**Yes No**
Do you have any metal in your head (outside the mouth) such as shrapnel, surgical clips, or fragments from welding or metalwork?	**Yes No**
Do you have any implanted devices such as cardiac pacemakers, aneurysm clips, cochlear implants, medical pumps, deep brain stimulators, or intracardiac lines?	**Yes No**
Do you suffer from frequent or severe headaches?	**Yes No**
Have you ever had any other brain-related condition?	**Yes No**
Have you ever had any illness that caused brain injury?	**Yes No**
Are you taking any psychiatric or neuroactive medications, or do you have a history of drug abuse?	**Yes No**
Are you pregnant?	**Yes No**
Do you, or does anyone in your family, have epilepsy?	**Yes No**
Do you hold a heavy goods vehicle driving license or bus license?	**Yes No**

I have read and understood the questions above and have answered them correctly.

SIGNED…… DATE……

In the presence of …….. (Name) …….. (Signature)

Appendix G. Instructions for participants

Instructions

General procedure:

In this study, we are interested in how musicians improvise on a theme during different forms of brain stimulation.

Each trial will consist of a *music reading* phase and an *improvisation* phase. In the music reading phase, you will play the displayed melody on the monitor, playing as accurately as possible. The accompaniment will be delivered through computer speakers, and you should also attempt to sight-read the melody part from the musical score provided. You will be provided two opportunities on each trial. Each musical piece will contain eight bars. The first four bars will be the melody and accompaniment, which you will have to sight-read and complete as accurately as possible. The remaining four bars are allocated to your improvisation, you will be asked to improvise in a manner that is inspired by that theme and the harmonic structure (chord progression).

Practice trials:

Before starting the actual experiment, you will be given two practice trials that resemble the exact structure of the trials in the experiment. This is to ensure that you are familiar with the task.The practice trials will follow this procedure:

Familiarisation: 2 playings of the stimuli

1st playing: Listening only (the whole piece)
2nd playing: Play the displayed melody on the screen; listen to the B section

Performance:

2 full attempts of the music piece will be completed *without* the piano accompaniment.

After the completion of the practice trials, the actual trial will now begin, please note: In the actual trial the accompaniment will remain the same, however, the piano part *will* be removed. You will be asked if you are ready to begin the actual trial.

Actual trial:

Familiarisation: 2 playings of the stimuli

1st playing: Listening only (the whole piece)
2nd playing: Play the displayed melody on the screen; listen to the B section

Performance:

2 full attempts of the music piece will be completed.

The first five improvisations will be performed without brain stimulation. The next five improvisations will be performed while you are receiving brain stimulation.

Before taking part in this experiment, you will be asked if you have any cuts and/or injuries on your scalp and will be visually inspected by the experimenter for any sign of soreness or redness. In the event that no visual signs of cuts, injury or irritation is present, brain stimulation will be applied on your scalp and delivered via two saline-soaked electrodes and held by a tightly secured cap. After the completion of the improvisations, the cap and the electrodes will be removed. A small towel will be provided to dry your hair at the electrodes sites on your scalp.

Instructions:

Each trial will consist of eight bars of music and will be performed by your right hand only. The first four bars of musical will be a melody that you will have to perform as accurately as possible. The remaining four bars will be allocated for you to perform your improvisation. Your only instruction is to base your improvisation on the melody presented in the first four bars. Please do not copy the melody you heard in your improvisation. You may modify the melody in your improvisation as much as you wish. You will play the entire musical score twice and then will continue to the next trial. The duration of the experiment should take no more than 2 hours.

Instructions for judges

By participating as external adjudicators for this study, your role is to examine and evaluate the technical fluency and creative levels of the performances that were generated. You will be presented with the musical score and corresponding audio stimuli for all of the performances in the experiment. You will *not* be informed of the condition which the participants were placed in. This document is to provide you instructions for scoring the performances.

Creativity:

Firstly, the definition of creativity in a general sense is something that is *novel* and *appropriate* within a specific context. In this study, the musical performances were within a jazz context, therefore, the improvisations *must* be congruent to the jazz genre and the harmony presented in the pieces.

You will firstly listen to the pieces whilst reading the scores generated from those performance and are instructed to rate from 1 to 10 on the performances level of creativity in a general sense.

1 = not creative at all
2
3
4
5 = moderate creativity
6
7
8
9
10 = highly creative

You will also be encouraged to articulate in the comments section on specific parts of the piece that you believe is creative. For example, you can highlight that in bar 3 the note sequences utilised over the harmony is interesting and constitutes a creative approach and is not just a generic sequence.

Technical fluency:

Secondly, you will be asked to rate the technical fluency of the performances. A general definition of technical fluency is the level of accuracy and musicianship of the performances. You will firstly listen to the pieces whilst reading the scores generated from those performance and are instructed to rate from 1 to 10 on the performances level of technical fluency in a general sense.

1 = not technically fluency
2
3
4
5 = moderate technical fluency
6
7
8
9
10 = high technical fluency

You will also be encouraged to articulate in the comments section on specific parts of the piece that you believe is creative. For example, you can highlight that in bar 4 the level of musicianship and performance ornaments (trills, articulation, phrasing) demonstrates a high level of technical fluency.

Appendix H. Questionnaire and scoring for adjudication

Questionnaire for external judges

Subject No: _____ **Date: _____**

1. Highest level of education attained?

- ☐ Undergraduate
- ☐ Postgraduate
- ☐ Doctorate

2. Years of formal music education?

_____

3. What is your principal instrument?

_____

4. Approximate number of hours practicing/performing an instrument per week?

_____

5. Have you previously judged musical performances? If yes, can you please provide some detail of the context? For example, a musical performance competition.

_____

Performance code: **Date:**

Participant number:

Block number:

Trial number:

Instructions for judging pieces:

Please rate the technical fluency and creativity of the pieces below on the scales provided. Feel free to provide additional comments on certain aspects of the recording that you believe are technically fluent and creative. Please only judge the **improvisation** section of the piece (the last 4 bars of the piece). You can also refer to the scores for each piece if necessary.

1. Using your best judgement, please rate (circle) the number that best represents the technical fluency of this piece (1 = not technical fluency; 5 = moderate technical fluency; 10 = high technical fluency).

_____

1 2 3 4 5 6 7 8 9 10

1B. Please elaborate on your response. Consider issues such as individual notes against harmony, places in bars, performance, and melodic and rhythmic elements that you deem to be technically fluent.

Comments:

_____

_____

2A. Using your best judgement, please rate (circle) the level of creativity in this piece (1 = not creative at all; 5 = moderate creativity; 10 = highly creative).

_____

1 2 3 4 5 6 7 8 9 10

2B. Please be as specific as possible when providing your comments, refer to individual notes against the harmony, places in bars, performance, melodic and rhythmic elements that you deem to be creative.

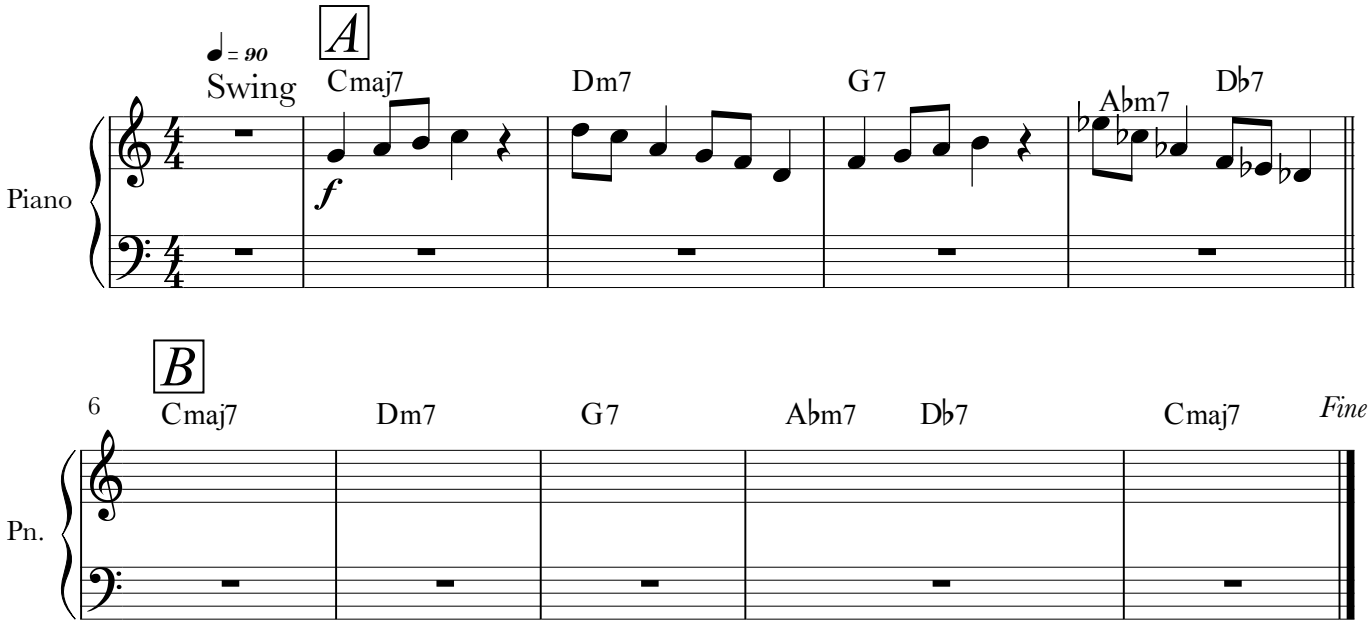
Comments:

_____

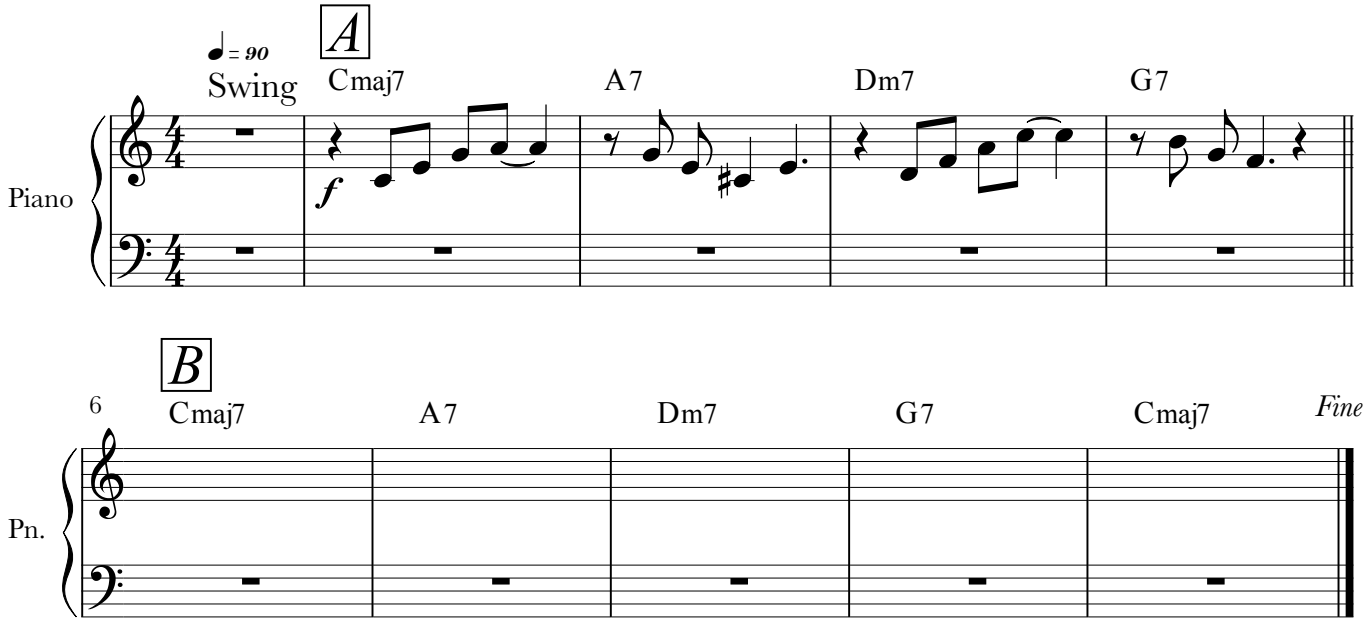
_____

Appendix I. Musical stimuli

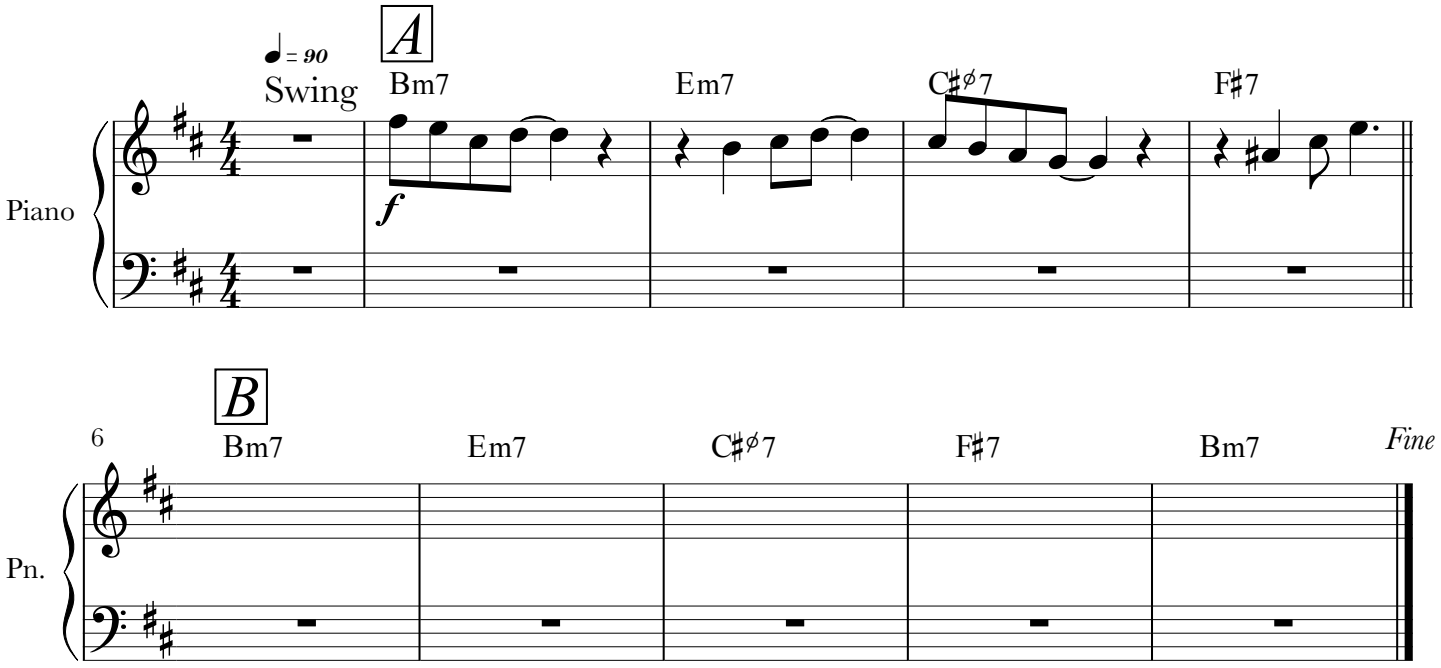
#1 C Major



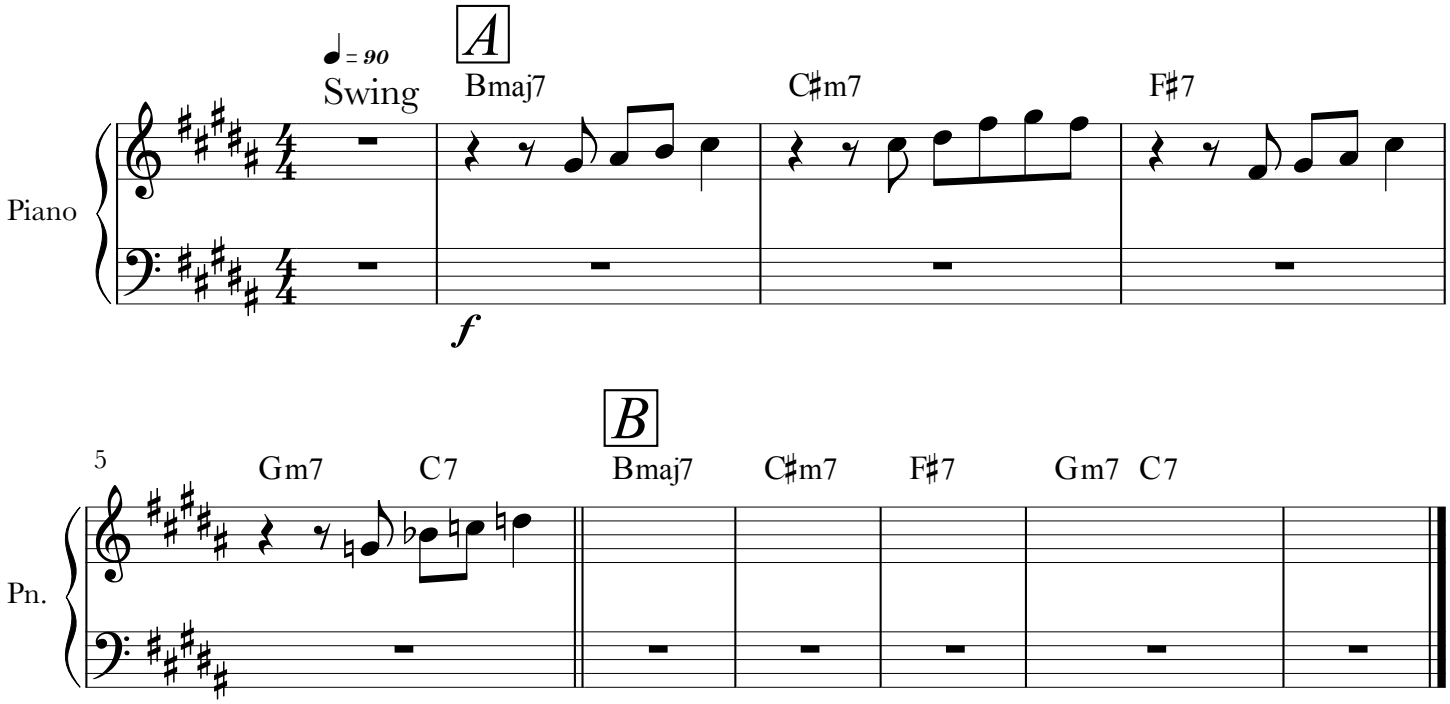
#2 - C Major


♩= 90
Swing
A
Cmaj7
A7
Dm7
G7
Piano
f
B
6
Cmaj7
A7
Dm7
G7
Cmaj7
Fine
Pn.

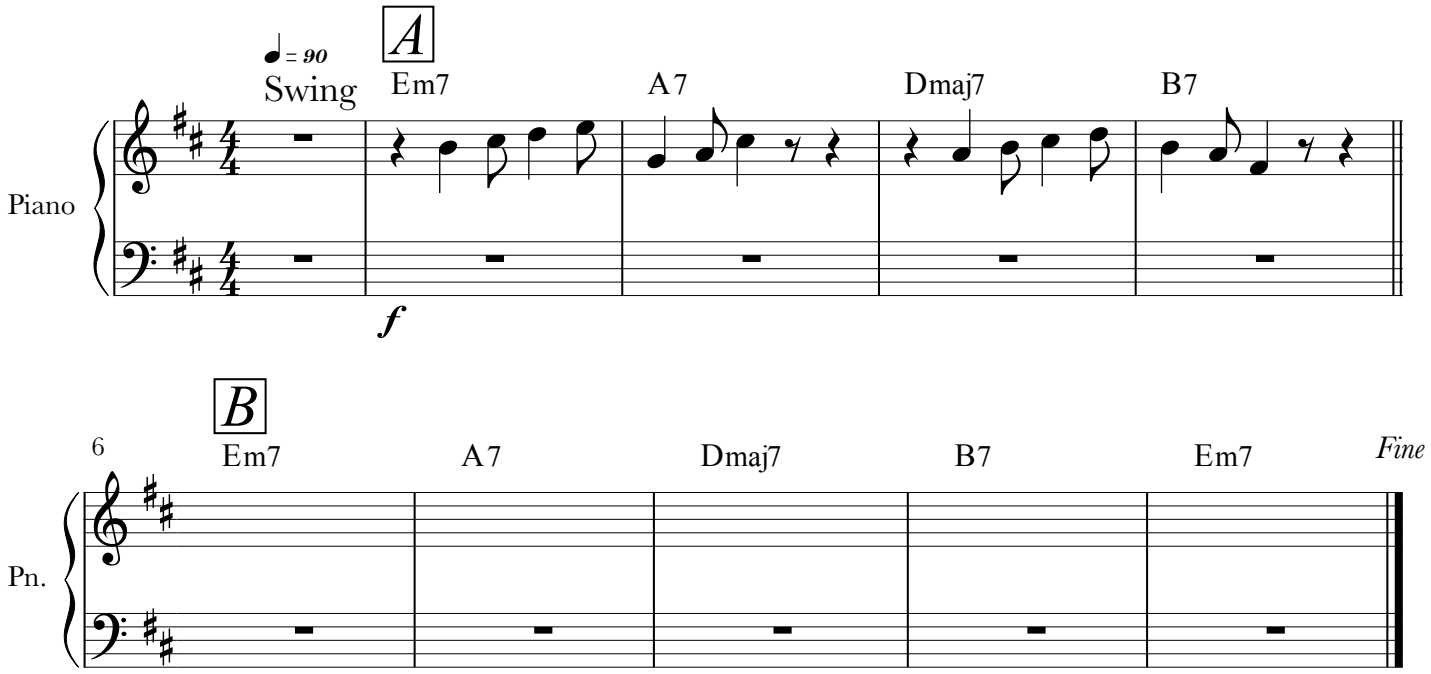
#3 - B Minor



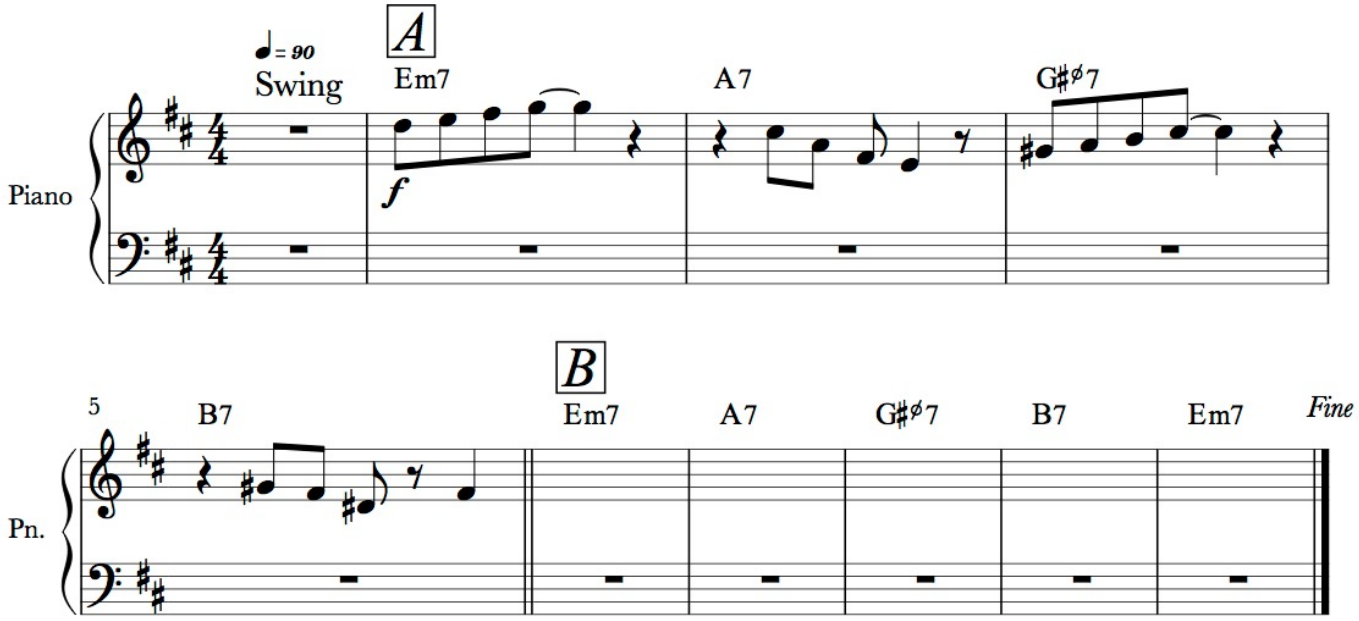
#4 - B Major



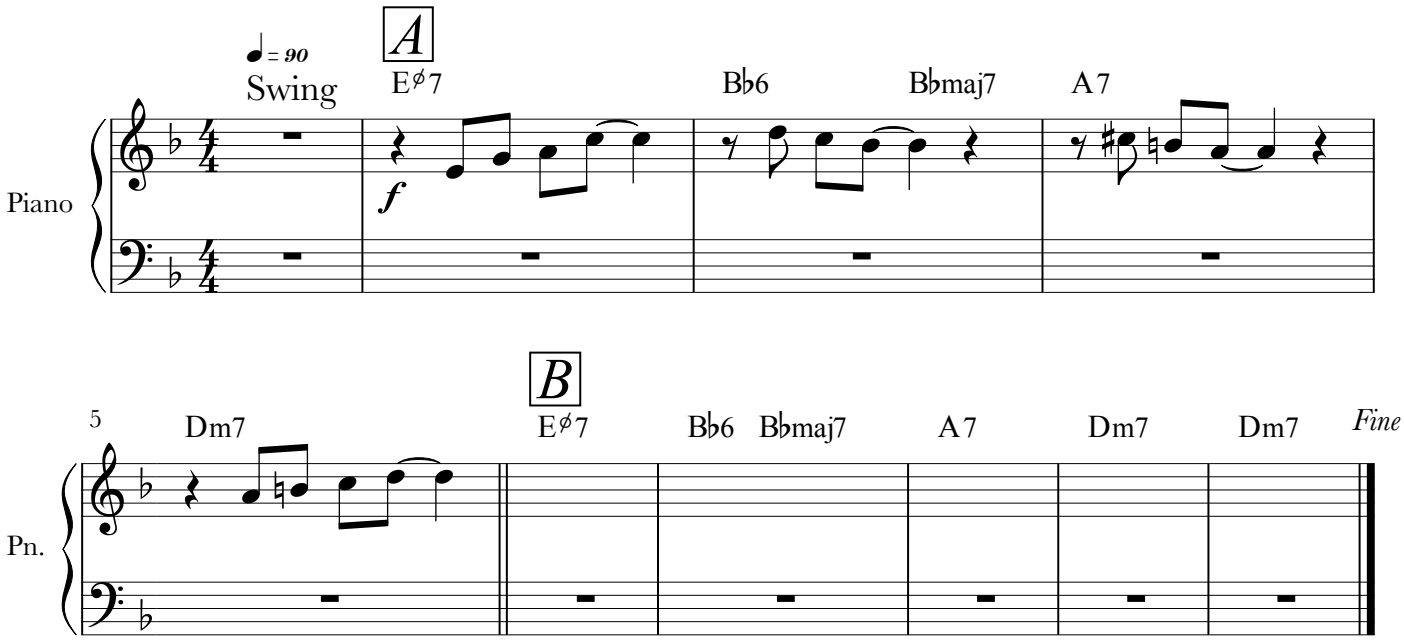
#5 - D Major



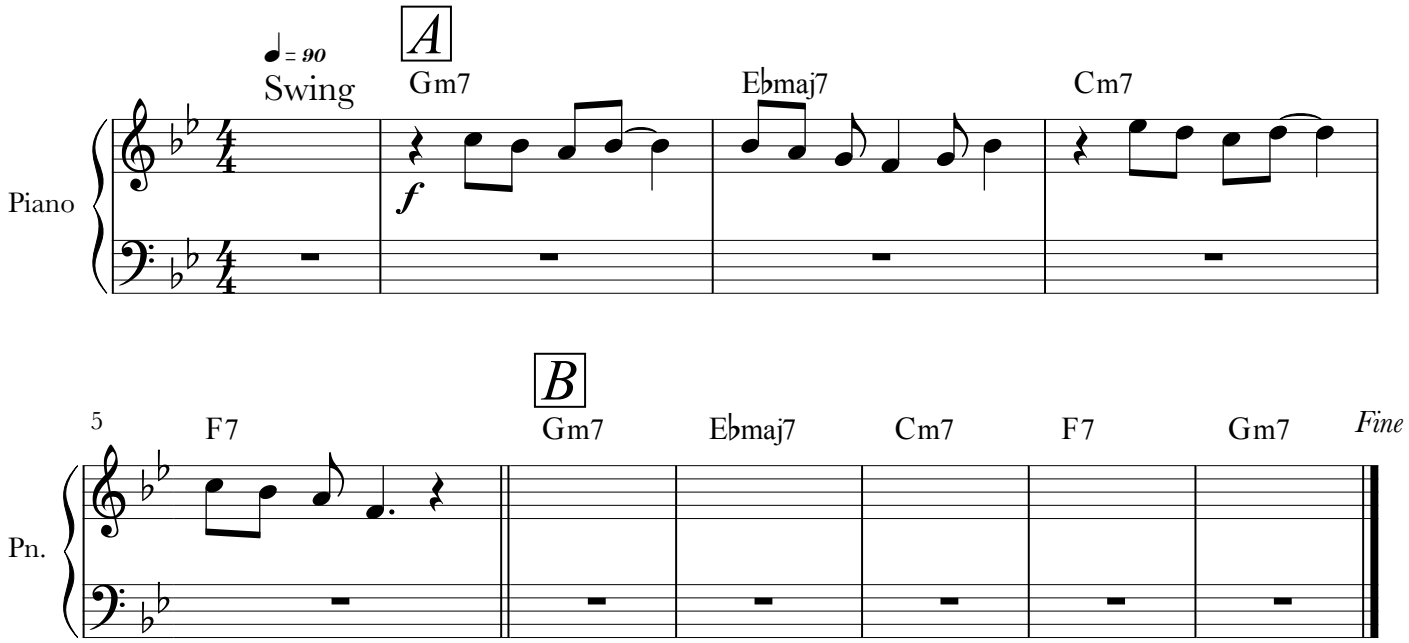
#6 - D Major



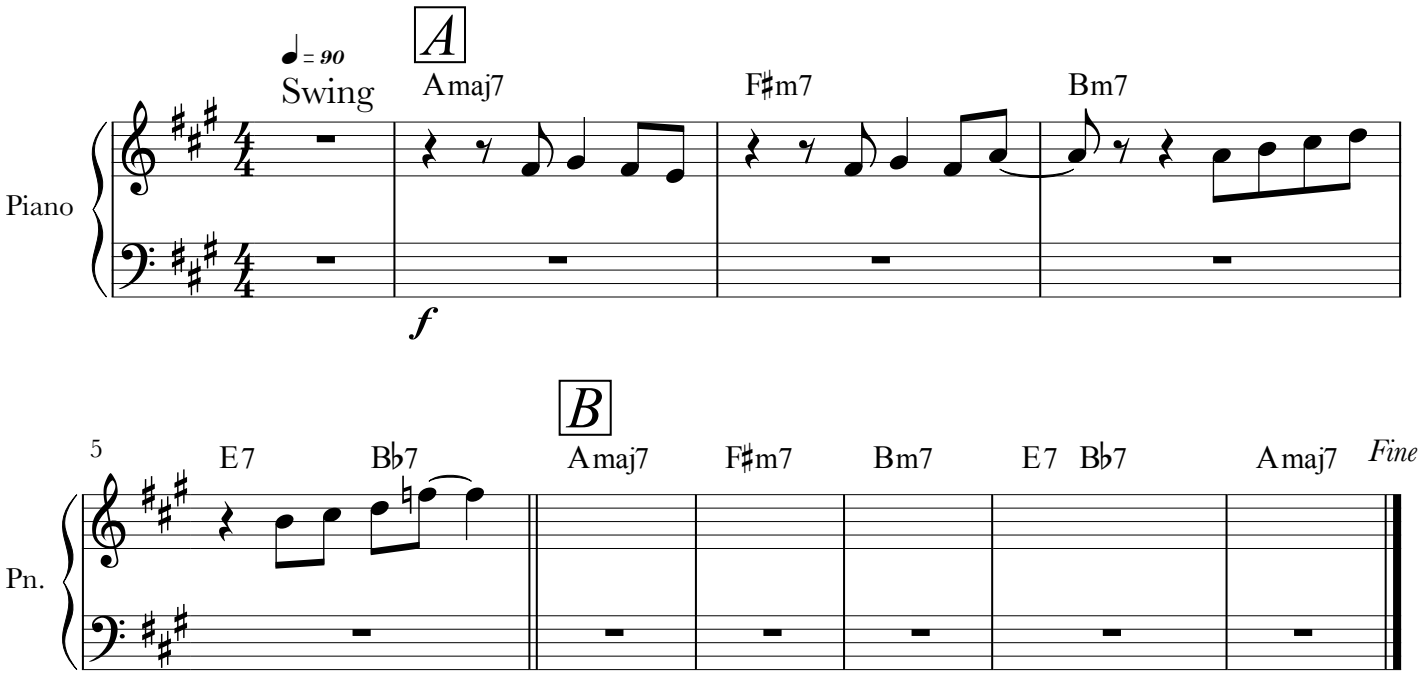
#7 - D Minor


♩ = 90
Swing
A
E♯7
B♭6
B♭maj7
A7
Piano
f
5
Dm7
B
E♯7
B♭6
B♭maj7
A7
Dm7
Dm7
Fine
Pn.

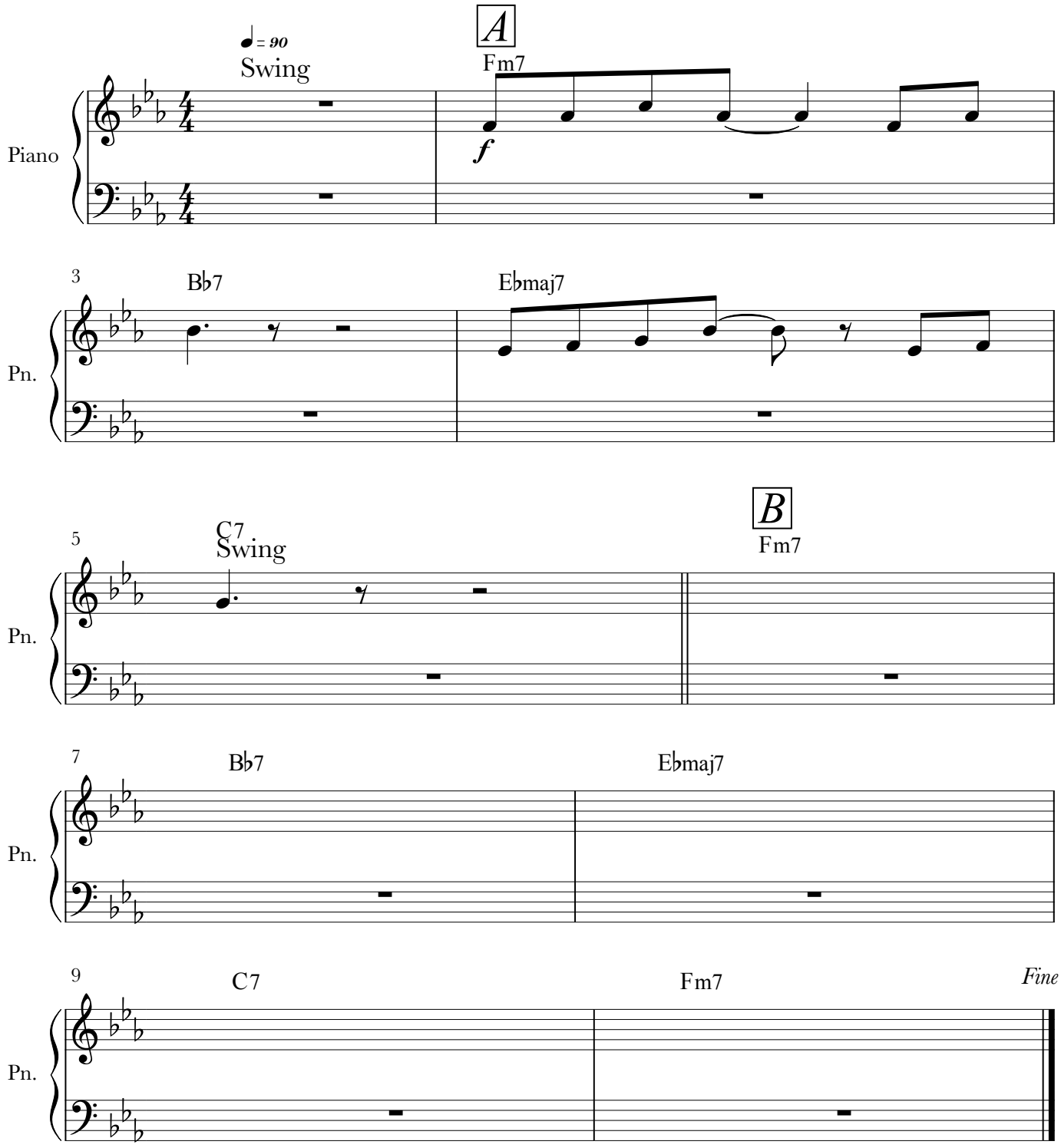
#8 - G Minor


♩ = 90
Swing
A
Gm7
Ebmaj7
Cm7
Piano
f
B
5
F7
Gm7
Ebmaj7
Cm7
F7
Gm7
Fine
Pn.

#9 - A Major


♩ = 90
Swing
A
Amaj7
F♯m7
Bm7
Piano
f
B
5
E7
B♭7
Amaj7
F♯m7
Bm7
E7
B♭7
Amaj7
Fine
Pn.

#10 - Eb Major


♩= 90
Swing
A
Fm7
f
Piano
3
B♭7
E♭maj7
Pn.
5
C7
Swing
B
Fm7
Pn.
7
B♭7
E♭maj7
Pn.
9
C7
Fm7
Fine
Pn.

Appendix J. Individual data for melodic features

Mean number of notes

Table 1. Mean and standard deviation for the number of notes in the improvisation section for the Anodal-Left/Cathodal-Right tDCS stimulation group and the difference score between the two blocks.

Participants	Group	Mean number of notes (Block 1)	Mean number of notes (Block 2)	Difference
1	Anodal-Left/Cathodal-Right	25.400	33.600	8.200
2	Anodal-Left/Cathodal-Right	25.400	29.600	4.200
3	Anodal-Left/Cathodal-Right	27.000	25.400	-1.600
4	Anodal-Left/Cathodal-Right	32.400	34.600	2.200
	Mean	27.550	30.800	3.250
	S.D	3.320	4.198	0.878

Table 2. Mean and standard deviation for the number of notes in the improvisation section for the Cathodal-Left/Anodal-Right tDCS stimulation group and the difference score between the two blocks.

Participants	Group	Mean number of notes (Block 1)	Mean number of notes (Block 2)	Difference
1	Cathodal-Left/Anodal-Right	17.000	17.400	0.400
2	Cathodal-Left/Anodal-Right	16.600	21.000	4.400
3	Cathodal-Left/Anodal-Right	21.600	21.800	0.200
4	Cathodal-Left/Anodal-Right	20.800	19.800	-1.000
	Mean	19.000	20.000	1.000
	S.D	2.566	1.918	-0.648

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Pitch range

Table 3. Mean and standard deviation for the pitch range in the improvisation section for the Anodal-Left/ Cathodal-Right tDCS stimulation group and the difference score between the two blocks.

Participants	Group	Mean pitch range (Block 1)	Mean pitch range (Block 2)	Difference
1	Anodal-Left/Cathodal-Right	20.000	21.400	1.400
2	Anodal-Left/Cathodal-Right	17.600	20.800	3.200
3	Anodal-Left/Cathodal-Right	11.800	14.800	3.000
4	Anodal-Left/Cathodal-Right	14.600	14.600	0.000
	Mean	16.000	17.900	1.900
	SD	3.566	3.704	0.138

Table 4. Mean and standard deviation for the pitch range used for each participant in the improvisation section for the Cathodal-Left/Anodal-Right tDCS stimulation group and the difference score between the two blocks.. Pitch range was measured in semi-tones.

Participants	Group	Mean pitch range (Block 1)	Mean pitch range (Block 2)	Difference
1	Cathodal-Left/Anodal-Right	13.400	14.000	0.600
2	Cathodal-Left/Anodal-Right	13.000	13.400	0.400
3	Cathodal-Left/Anodal-Right	13.600	13.400	-0.200
4	Cathodal-Left/Anodal-Right	15.200	15.200	0.000
	Mean	13.800	14.000	0.200
	S.D	0.966	0.848	-0.118

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Mean number of different notes used

Table 5. Mean and standard deviation for the number of different notes used in the improvisation section for the Anodal-Left/Cathodal-Right tDCS stimulation group and the difference score between the two blocks.

Participants	Group	Mean number of different notes used (Block 1)	Mean number of different notes used (Block 2)	Difference
1	Anodal-Left/Cathodal-Right	9.000	10.400	1.400
2	Anodal-Left/Cathodal-Right	8.400	10.000	1.600
3	Anodal-Left/Cathodal-Right	7.600	8.200	0.600
4	Anodal-Left/Cathodal-Right	7.800	9.000	1.200
	Mean	8.200	9.400	1.200
	SD	0.632	0.993	0.361

Table 6. Mean and standard deviation for the different notes used for each participant in the improvisation section for the Cathodal-Left/Anodal-Right tDCS stimulation group.

Participants	Group	Mean number of different notes used (Block 1)	Mean number of different notes used (Block 2)	Difference
1	Cathodal-Left/Anodal-Right	7.800	8.000	0.200
2	Cathodal-Left/Anodal-Right	7.000	8.200	1.200
3	Cathodal-Left/Anodal-Right	7.200	8.400	1.200
4	Cathodal-Left/Anodal-Right	7.600	7.400	-0.200
	Mean	7.400	8.000	0.600
	S.D	0.365	0.432	0.067

Appendix K. Individual data for sight reading accuracy

Pitch note accuracy

Table 7. Mean and standard deviation pitch note accuracy for each participant for the Anodal-Left/Cathodal-Right tDCS stimulation condition. Pitch accuracy measured in semitones; timing measured in milliseconds.

Participants	Group	Mean pitch note accuracy (block one)	Mean pitch note accuracy (block two)	Difference
1	Anodal-Left M1/Cathodal-Right M1	0.000	0.000	0.000
2	Anodal-Left M1/Cathodal-Right M1	0.027	0.000	-0.027
3	Anodal-Left M1/Cathodal-Right M1	0.033	0.224	0.192
4	Anodal-Left M1/Cathodal-Right M1	0.025	0.014	-0.011
	Mean	0.021	0.060	0.039

Table 8. Mean and standard deviation pitch note accuracy for each participant for the Cathodal-Left/Anodal-Right tDCS stimulation condition. Pitch accuracy measured in semitones; timing measured in milliseconds.

Participants	Group	Mean pitch note accuracy (block one)	Mean pitch note accuracy (block two)	Mean pitch note accuracy difference score
1	Cathodal-Left M1/Anodal-Right M1	0.809	1.238	0.430
2	Cathodal-Left M1/Anodal-Right M1	0.028	0.000	-0.028
3	Cathodal-Left M1/Anodal-Right M1	0.000	0.071	0.071
4	Cathodal-Left M1/Anodal-Right M1	0.009	0.000	-0.009
	Mean	0.211	0.327	0.116

Timing accuracy

Table 9. Mean and standard deviation pitch note accuracy for each participant for the Anodal-Left/Cathodal-Right tDCS stimulation condition. Pitch accuracy measured in semitones; timing measured in milliseconds.

Participants	Group	Mean timing (block one)	Mean timing (block two)	Difference
1	Anodal-Left M1/Cathodal-Right M1	28.939	21.872	-7.067
2	Anodal-Left M1/Cathodal-Right M1	27.822	30.593	2.772
3	Anodal-Left M1/Cathodal-Right M1	38.146	29.031	-9.116
4	Anodal-Left M1/Cathodal-Right M1	67.583	34.852	-32.731
	Mean	40.623	29.087	-11.536

Table 10. Mean timing accuracy for each participant for the Cathodal-Left/Anodal-Right tDCS stimulation condition. Pitch accuracy measured in semitones; timing measured in milliseconds.

Participants	Group	Mean timing (block one)	Mean timing (block two)	Difference
1	Cathodal-Left M1/Anodal-Right M1	1218.843	770.502	-448.341
2	Cathodal-Left M1/Anodal-Right M1	425.551	184.531	-241.020
3	Cathodal-Left M1/Anodal-Right M1	31.447	96.404	64.956
4	Cathodal-Left M1/Anodal-Right M1	26.256	58.139	31.883
	Mean	425.524	277.394	-148.130