Using transcranial direct current stimulation to identify distinct rhythm perceptions for commonly used rhythmic tasks

Sophia Klassen

Department of Psychology, Western University

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Thesis Advisor: Dr. Jessica Grahn

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Abstract

Humans are rhythmic by nature–we walk in rhythm, talk in rhythmic structure, and we coordinate our movements with rhythms in music through dance. Many different rhythmic tasks have been used in previous research to measure the same thing, but this may not be the case. Recent behavioural research has suggested a distinction between tasks that measure beat-based rhythm perception and sequence memory-based rhythm perception. We wanted to know to what extent do commonly used rhythmic tasks reflect beat-based rhythm perception or sequence memory based rhythm perception? This study aims to look at two target brain areas–the supplementary motor area (SMA) and the right supramarginal gyrus (rSMG)–to investigate distinct rhythm perceptions in rhythmic tasks. The SMA is involved in timing and timing of future movements (beat-based rhythm perception) while the rSMG is involved in rhythm memory (sequence memory-based rhythm perception). Transcranial direct current stimulation (tDCS) was used to alter neural excitability in the SMA or the rSMG. We would expect anodal stimulation to the SMA would enhance performance on the Beat Alignment Task (BAT) while anodal stimulation on the rSMG would enhance performance of the Rhythm Reproduction Task. Participants completed two blocks of three rhythmic tasks–BAT-Production Task, BAT-Perception Task, and the Rhythm Reproduction Task–first with no current (sham condition) and then second with anodal stimulation to either the SMA or rSMG. We found a significant main effect of stimulation for the SMA in the BAT-Production Task, where participants performed worse when anodal stimulation was applied to the SMA. However, underpowered, future work will collect more data, then this study will conduct a multi-session study where the sessions are counterbalanced and cathodal stimulation is included as a condition. This study highlights the possibility that commonly used rhythm tasks may measure different types of rhythmic abilities.

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Statement of Contribution

Dr. Jessica Grahn oversaw the project and provided feedback throughout. Dr. Karli Nave proposed the research topic and the research question. Karli, River Hua and I edited the programming, and completed the data analyses. River and I collected the data, River collected data for the SMA, while I collected the data for the rSMG. Karli created the demographics survey. I created my figures and wrote the report, with feedback throughout the project from Karli.

Using transcranial direct current stimulation to identify distinct rhythm perceptions for commonly used rhythmic tasks

Imagine you are at a music festival and a well-known band is playing live music. People are moving around, screaming the lyrics as the music floods the crowd. As you take a look around at the people surrounding you they are tapping their feet, bobbing their heads, jumping or swaying to the music. It is then evident that people have the ability to perceive patterns in music and respond to them.

Rhythm can be defined as a pattern of events in time. More specifically, it is the ordered pattern of time intervals in a stimulus sequence (Fiveash, et al., 2022) such as a song from the previous example. The times when the person is likely to want to tap their feet or bob their head can then be seen as perception of the beat. Beat then can be defined as the periodic pulse in music where individuals want to move in time with the rhythm (Lerdahl & Jackendoff, 1983). It is important to understand the neural mechanisms behind rhythm and beat perception as many cognitive processes are involved, such as time and duration processing, working memory and attention (Leow & Grahn, 2014; Grahn & Brett, 2007).

The primary purpose of the present study was to determine if different neural structures support the distinct types of rhythm perception found in Fiveash and colleagues (2022) study. Specifically, we wanted to examine if the two types of rhythm processing found, beat-based rhythm perception and sequence memory-based rhythm perception, are found in commonly used rhythmic tasks by examining neural structures using transcranial direct current stimulation (tDCS).

Beat-based rhythm perception versus sequence memory-based rhythm perception

Beat-based rhythm perception tasks require a participant to extract a beat or synchronize to a rhythm while sequence memory-based rhythm perception tasks require a participant to try to remember or reproduce a rhythm (Fiveash, et al., 2022). The study

conducted by Fiveash and colleagues was one of the first to empirically suggest that the rhythm tasks that are typically used in research may draw on different neural processes. They found this distinction between beat-based rhythm perception and sequence-memory based rhythm perception, which other studies have evidence that points to this conclusion as well.

Tierney and Kraus (2015) examined the performance of 67 adults on four separate tasks to test the potential divergence of beat-based and sequence memory-based production tasks. It should be noted that although these were production tasks, perception was involved. Two of the tasks were designed to assess beat-based skills. These were drumming to a metronome and a tempo adaptation task. The other two tasks involved memory/sequencing skills. These included drumming along to repeated rhythmic sequences and reproducing previously heard rhythms. Performance on two beat-tapping tasks correlated with each other, and the two memory sequencing tasks correlated with each other. There were no correlations between the beat-tapping and memory sequencing tasks, which implies there is a distinction between the two.

Similarly, Bonacina and colleagues (2019) also had four tasks for production measures of beat-based and sequence memory-based rhythm in 68 children. The children were asked to drum in time with an isochronous beat, drum to the beat of music, remember and reproduce rhythms, and clap in time with visual feedback. Drumming to an isochronous beat and remembering and reproducing rhythms were not correlated, which was consistent with the results from Tierney and Kraus (2015). Although these studies found correlations for tasks that seem to be more beat-based or more sequence memory-based, these distinctions from both studies have not yet been systematically investigated in a group of participants across various rhythmic tasks until Fiveash and colleagues (2022) investigated the differences.

Fiveash and colleagues (2022) used various rhythmic tasks to understand perception and production of rhythms. The study aimed to provide insight into the complexity and variation of rhythmic skills. This study was one of the first to use a variety of rhythm perception and production tasks to empirically suggest a distinction between beat-based and sequence memory-based rhythm perception, supporting these are distinct processes. Using nine perception and production tasks allowed them to get a global perspective on distinguishable rhythm competencies across both perception and production of rhythm. A principal component analysis revealed that some rhythmic tasks loaded onto one factor, which they called beat-based rhythm perception, and other tasks loaded onto another factor, which they called sequence memory-based rhythm perception. These results imply that future research investigating rhythmic abilities should not be limited to a single task but should involve various tasks capable of assessing different processes involved.

More recently then, research on rhythm perception has proven to exhibit multidimensionality rather than unidimensionality by demonstrating there are distinct rhythmic abilities in individuals that may have implications that rhythm perception is not one measure, but rather there are different types of rhythm perception (Fiveash, et al., 2022). These rhythmic abilities have been studied previously, using different methodologies. Using functional magnetic resonance imaging (fMRI) beat perception was found to be strongly linked to motor brain areas, as just listening to a beat or rhythmic pattern activates (pre)motor areas in the brain even when the participant is not moving (Grahn & Brett, 2007). The suggestion of multidimensionality in rhythm perception, where rhythm perception involving memory is distinct from rhythm production which involves reproducing a rhythm, can then provide insight into the different potential underlying neural mechanisms for rhythm perception. However, the findings of Fiveash and colleagues (2022) suggesting these distinct competencies are based on correlational results. This idea can then be studied using

transcranial direct current stimulation (tDCS) which uses electrodes to stimulate a current to enhance or inhibit activity in a specific brain region to identify a causal relationship between a brain area and a particular behaviour rather than obtaining correlational results using fMRI or behavioural studies. We can then use tDCS to stimulate brain areas that are expected to be involved in both rhythmic competencies to allow us to provide causal evidence for the distinct processes.

Transcranial direct current stimulation (tDCS) for modulating brain activity

Transcranial direct current stimulation is a non-invasive, painless, reversible stimulation that can either enhance or inhibit performance on various tasks by emitting a weak electrical current through electrodes placed on the scalp of a participant (Thair, et al., 2017). The use of tDCS has recently become a more promising tool for modulating cognitive and motor skills. It is generally assumed then that an anodal (positive) current will temporarily enhance behaviours, while a cathodal (negative) current will temporarily inhibit behaviours (Thair, et al., 2017). Active stimulation can be compared then with a sham (no current) protocol to act as a control.

The effectiveness of tDCS for determining more causal relationships between specific brain regions and behaviour has been demonstrated. Studies using tDCS have shown the supramarginal gyrus (SMG) affects memory. A study done by Vines and colleagues (2006) used tDCS to examine the left SMG using cathodal and sham current for short-term pitch memory. Participants completed a pitch-memory task, where they had to identify whether first and last tones in a sequence were the same or different. The cathodal tDCS reduced excitability in the left SMG which disrupted its contribution for short term pitch. As a consequence, the cathodal stimulation proved significant detrimental effects on behaviour in participants while the sham condition has no effect. Another study done by Schall and colleagues (2013) demonstrated the effect of anodal current using tDCS on the left SMG and

found that the group of participants with anodal stimulation over the left SMG did enhance performance on a pitch recognition task significantly more than the sham group, further supporting the effectiveness of tDCS.

These studies demonstrated the effectiveness of using tDCS as a causal application for investigating specific brain regions in all conditions, cathodal, anodal, and sham. Our study will use tDCS for various rhythmic tasks to determine if different rhythmic perception tasks are causally associated with specific brain regions.

Neural regions involved in rhythm perception

Previous literature has shown the importance of the supplementary motor area (SMA) in rhythm perception. In a study to examine motor areas in relation to rhythm and beat perception, participants had to determine if the third rhythm played was the same or different as the first two rhythms they just heard (Grahn & Brett, 2007). While the participants completed the trials they were instructed not to move. A bilateral network of motor areas was activated when rhythms were perceived, even when participants did not move. The basal ganglia and the SMA were more active when hearing rhythms with a beat than without a beat, which indicates their role in beat induction is consistent with motor prediction, where the spontaneous response to hearing a beat is often to move when the next beat is predicted. There was lack of motor activation in the primary motor cortex further supporting that participants complied with the instructions not to move when a rhythm was presented, thus the activation that did occur was due to rhythm perception only. The discrimination of auditory sequences with a beat has implicated both the basal ganglia and the SMA in beat processing using fMRI. This study has provided correlational results that could be further followed up to test for causal relationships between these motor areas and beat perception. However, the SMA is cortical and thus accessible via tDCS, whereas the basal ganglia are deeper in the brain and thus not a viable target.

Additional research has shown the importance of the right supramarginal gyrus (rSMG) in rhythm perception. One study (Schall, et al., 2017) identified the role of the SMG in pitch and rhythm processing. This study used tDCS to examine the role of the left and the right SMG for rhythm and pitch memory. Two tasks were done, a pitch memory task and a rhythm memory task while the active electrode was placed on either the lSMG or the rSMG. This study found the rSMG had more involvement in rhythm memory, while the lSMG had more involvement in pitch memory. While other studies demonstrating the lSMG is involved in pitch memory (Schall, et al., 2013), this was the one of the first studies revealing a more causal relationship between the rSMG and rhythm memory. Examining the behavioural effects of the rSMG specifically could further determine if there is causal relationship between the rSMG and the sequence-memory based rhythmic tasks mentioned previously.

Current study

The aim of our study is to use tDCS with two rhythm tasks–a beat-based rhythm task and a sequence memory-based rhythm task–to examine dissociable neural pathways for the distinct rhythmic competencies. Many rhythm tasks are thought to measure the same thing, but this may not be the case as there may be different underlying processes in rhythm perception, so it is important to explore the differences. Using tDCS allows for a more causal investigation of the neural regions distinctly related to beat-based rhythm processing and sequence memory-based rhythm processing because we can determine if the behavioural effects of the corresponding rhythmic tasks to their neural regions are affected. We then want to know to what extent do commonly used rhythmic tasks reflect beat-based rhythm perception or sequence memory-based rhythm perception as revealed by tDCS?

Three rhythmic tasks will be completed: Beat Alignment Task (BAT)-Production, BAT-Perception Task, and the Rhythm Reproduction Task. The BAT-Production Task required a participant to tap along to the beat of various musical excerpts. As no information

would need to be held in the memory we can predict that the SMA would be more involved and there should be no change in performance when stimulating the rSMG. The BAT-Perception Task looks at how accurately a participant can determine if the beat superimposed on a music excerpt was on or off the beat. Again, nothing needs to be held in memory for this task, and thus we can predict this task would be more affected by the SMA and there would be no performance change when stimulating the rSMG for the same reason mentioned before. The Rhythm Reproduction Task requires a participant to listen to a rhythm three times before tapping the rhythm back. Memory would be involved in this task, since the participant has to hold the rhythm in their memory for a brief period before reproducing the rhythm. Thus, we can predict the rSMG would enhance performance when stimulated and there should be no change in performance when stimulating the SMA. Comparing the behavioral performance on the BAT-Production, BAT-Perception, and Rhythm Reproduction Task between sham and anodal tDCS stimulation will allow us to further extend the results of the Fiveash and colleagues study (2022) by applying a more causal application for the distinctions between the beat-based and sequence memory-based rhythm perception. Examining these neural structures–the SMA and the rSMG–we first hypothesize that modifying brain activity using tDCS in the SMA will selectively modulate beat-based rhythm tasks. Similarly, our second hypothesis is that modifying brain activity using tDCS in the rSMG will selectively modulate sequence memory-based rhythm tasks.

Methods

Participants

The participants were 18 individuals (mean age = 19.72, *SD* = 5.41) recruited using the online SONA system and word of mouth. Participants were pre-screened through SONA to ensure they were fluent in English, above 18 years old, no hearing impairments, and no

neurological impairments. They were compensated for their time with either 1.0 research participation credits/hour or $10 CAD/hour.

A total of 18 participants completed this study to have their SMA (n = 11) stimulated or their rSMG (n = 7) stimulated. Some participants' data (n=6) were not collected for the Rhythm Reproduction task due to technical issues (see results section). The exclusion criteria for this study includes subjects with metallic implants, such as pacemakers, cerebral aneurysm clips or other electronic implants; female subjects who are pregnant, trying to conceive, or who are sexually active and are not practicing an effective method of contraception; subjects with a history of psychiatric or neurological problems such as epileptic seizures, Tourette's syndrome, ADHD, depression; subjects who require prescribed psychotropic medication or currently take other medication that makes them drowsy; subjects who get migraines and/or are susceptible to headaches; subjects who are more susceptible to skin irritation, such as subjects with eczema. All procedures were approved by Western University's Research Ethics Board (see Appendix A).

Procedure

Upon arrival, participants were given a Medical Screening Questionnaire (see Appendix B) as well as the Letter of Information (see Appendix C). The three rhythmic tests were administered through E-prime software (version 2.0) on a laptop and participants will be listening to the tests with headphones (Sennheiser 280 Pro). Prior to starting the rhythmic tests, participants will have the tDCS electrodes placed and secured on their scalp.

TDCS Parameters

The measurements were taken of the participants' scalp using the 10-20 system electroencephalogram electrode placement. The SMA was positioned 2 cm anterior to Cz and the rSMG was located using CP4. The active electrode was placed over the targeted site, the SMA or the rSMG respectively, and the reference electrode was adjusted over the

contralateral supraorbital area. The two 4 x 6 cm rubber electrodes were placed in saline-soaked sponges and were positioned on the scalp using rubber headbands. For the sham condition, the Chattanooga Ionto Dual Channel Electrophoresis System (tDCS) was initially turned on, with a current set to 2.0 mA. Once that current was reached, the tDCS was turned off to begin the sham session. This evokes the sensation of being stimulated but does not lead to any neurophysiological changes. Approximately 10 minutes into the 20 minute session, more saline was added to the sponges with a syringe. Before beginning the anodal brain stimulation session, the current is again turned on to allow it to ramp up to 2 mA. Halfway through, at about 10 minutes, more saline was added to the sponges. Each participant first completed the three rhythmic tasks with the sham condition and then completed the three tasks again with anodal stimulation.

Rhythmic Tasks

The task order was counterbalanced between participants, and participants completed the same order for both sham and anodal blocks so participants acted as their own control. Participants started with the practice trials for all three rhythmic tasks before the tDCS was turned on for the sham and stimulation conditions. There was one practice trial for the BAT-Production Task, three practice trials for the BAT-Perception Task (one on-beat, one tempo-error, and one phase-error), and one Rhythm Reproduction practice trial. The Beat Alignment Test (BAT) stimuli were retrieved from Iversen & Patel (2008). The Rhythm Reproduction Task used a shortened list of stimuli retrieved from Grahn & Brett (2007). Completion of all three rhythmic tasks was approximately 20 minutes for each block (sham, anodal), for a total of 40 minutes.

BAT-Production Task. Participants listened to the 13 musical excerpts and were required to tap their finger on the keypad of the laptop to the beat. This task measures the asynchrony of a participant's ability to tap on the beat of the musical excerpt presented. After

each trial participants were asked to rate their familiarity of the excerpt, where 1 = never heard of it, 2 = somewhat familiar, 3 = very familiar (Figure 1).

Stimuli. There were 13 musical excerpts presented in randomized order which lasted approximately six minutes. Each musical expert averaged to approximately 16 seconds each.

BAT-Perception Task. Participants listened to the 17 musical excerpts to assess beat perception without moving to the beat. This task required participants to determine if the beat that was superimposed on the musical excerpt was on the beat or off the beat, by answering yes or no (clicking Y = yes or N = no). While listening to the musical excerpts, participants were also asked to hit the spacebar as soon as they knew their answer. After each trial, participants were then asked to rate the confidence of their judgement, where 1 = guessing, 2 = somewhat sure, 3 = completely certain. Note that participants are instructed not to move in any way to keep the beat. This task measures the ability of the participant to determine if the beat is "on" or "off" compared to the musical excerpt.

Stimuli. This test had a total of 17 musical excerpts in randomized order which was approximately seven minutes in length. There were three conditions the musical excerpts could be presented in, on-beat, tempo-error, or phase-error. There were a total of four musical excerpts that were on-beat, so beats that are superimposed on the musical excerpt are on the beat with the music. Of the 17 songs played, eight were in tempo-error and five were in phase-error. In the tempo-error condition the beat that is superimposed on the musical excerpt is 10% shorter or longer than the on-beat condition. In the phase-error condition, the beats superimposed on the musical excerpts are advanced or delayed by 25% of the on-beat condition.

Rhythm Reproduction Task. This test requires the participant to reproduce the rhythm as accurately as possible. Each rhythm is played three times and after the third time the rhythm is played the participant taps the rhythm from memory on a key from the

keyboard. The participants had 4.5 seconds to tap the rhythm before the next one was played. This is done for all 18 rhythms, presented in random order. This task measures the average percent error in the participants' reproduced rhythm, compared to the original rhythm heard.

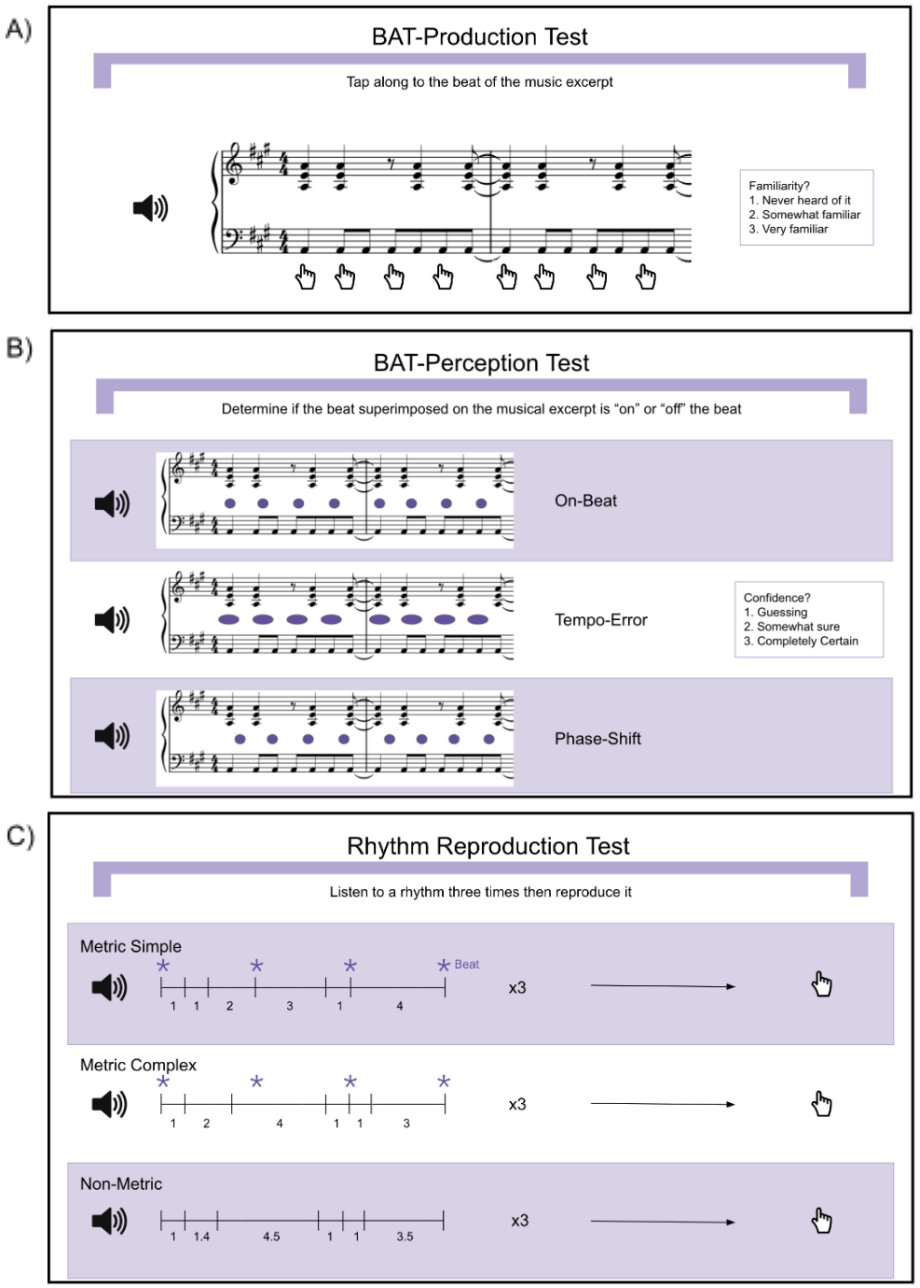
Stimuli. This test consists of 18 rhythmic sequences ranging from five to seven intervals. Of these 18 sequences, six were constructed of five intervals, six were constructed of six intervals, and six were constructed of seven intervals all of which were presented in approximately seven minutes. Of the six rhythms that were constructed of five intervals, two were non-metric, two were metric simple, and two were metric complex. This was the same for the six rhythms constructed of six intervals and the six rhythms constructed of seven intervals (see Figure 1 for examples of the rhythm types). In the metric simple condition, there was a strong beat that was simple to remember. For example, a six interval rhythm of 1:1:2:3:1:4 is arranged to induce a perceptual accent at the beginning of the group and nothing is added to this sequence to produce the perceptual accents as they would arise automatically from the temporal context. A single interval length ranged from 220 to 270 msec.

In the metric complex condition, the intervals were identical to those from the metric simple condition, however, they were rearranged so they are not as regularly grouped. This produced irregular perceptual accents on the rhythm so it becomes harder for the participant to determine the rhythm. The metric simple interval of 1:1:2:3:1:4 would be 1:2:4:1:1:3 for the metric complex condition.

The non-metric condition had the same rhythmic arrangements as the metric complex condition but used noninteger ratio interval lengths. The metric complex interval of 1:2:4:1:1:3 would be 1:1.4:4.5:1:1:3.5 in the non-metric condition. One of six pitches, varying from 294 to 587 Hz, was random for each trial and held constant for that trial to cue the participants the start of a new rhythm.

Figure 1

Schematic of the Experimental Tasks



Note. A) BAT-Production Task: participants are required to tap along to the beat of the musical excerpt. B) BAT-Perception Task: participants determine whether the beat superimposed on the musical excerpt is "on" or "off" the beat. The beat superimposed on the musical excerpt can either be on-beat, tempo-error, or phase-shift. C) Rhythm Reproduction Task: participants listen to a rhythm three times then are required to tap that rhythm back.

There are three conditions: metric simple, metric complex, and non-metric. The "*" indicated where perceptual beats should be heard.

Demographic Survey

When all three tasks were completed for both the sham and stimulation blocks, the participants were given a demographic questionnaire to determine their age, gender, ethnicity, etc. and musical and/or dance background (see Appendix D). After the questionnaire was completed, the participants were given a debriefing form (see Appendix E).

Statistical Analyses

Coefficient of variation and asynchrony were examined for the BAT-Production Task, with higher scores indicating worse performance. Coefficient of variation was calculated by examining how consistent a participant was with themself and averaging their scores. Asynchrony examined how asynchronous a participant was when tapping along to the beat. Their scores were averaged. Accuracy was examined for the BAT-Perception Task by averaging correct responses across trial types. Average percent error was examined for the Rhythm Reproduction Task to determine a participants average error in tapping the rhythm back across trial types. All data was analyzed using MATLAB R2022b, and SPSS (version 24).

Statistical Tests

We conducted a 2x2 mixed-model ANOVA for each rhythmic task with 2(Stimulation Type: Sham and Anodal) x 2(Brain Region: SMA and rSMG). We conducted a separate ANOVA for each dependent variable of interest: BAT-Production coefficient of variation (CoV), BAT-Production asynchrony, BAT-Perception accuracy, Rhythm Reproduction average percent error. Further analyses using paired sample t-tests were conducted for follow up significant results.

Results

Demographics

The data of 7 males and 11 females was collected for the BAT-Production and BAT-Perception Task, while 4 males and 8 females data was collected for the Rhythm Reproduction Task. All 18 participants completed all three tasks, however, the data of the first 6 participants was not recorded for the Rhythm Reproduction Task. For the 12 participants there is data for on the Rhythm Reproduction Task, 6 had their SMA stimulated and 6 had their rSMG stimulated. Of the 18 participants two were left-handed. As well, 11 had played an instrument or sang at some point in their life and 15 of the participants indicated they could read music. The individuals who sang or played an instrument did so from a range of 4 to 12 years. A total of 6 participants have formally danced as well.

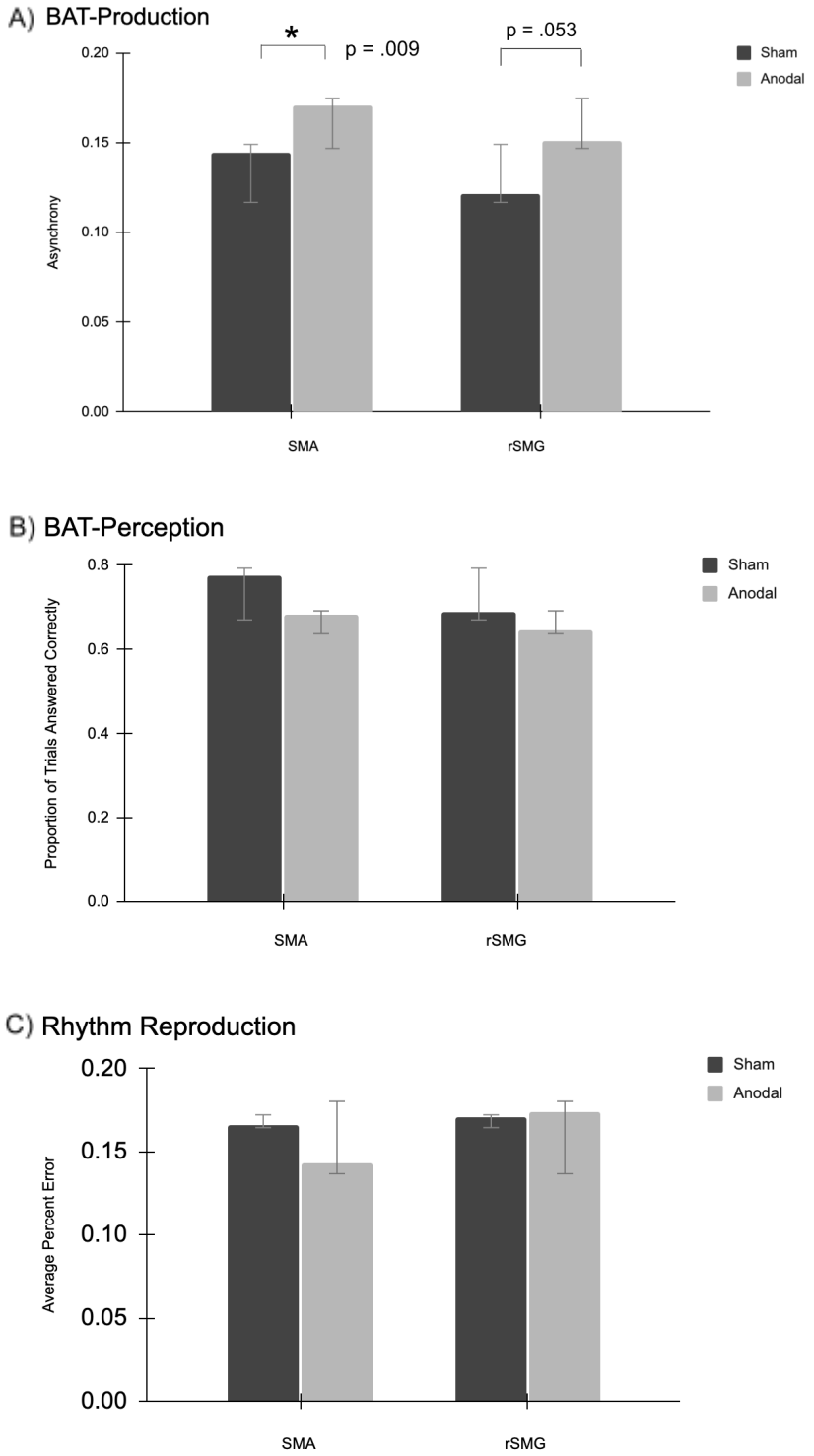
BAT-Production

Two mixed-model ANOVA were conducted for the BAT-Production Task, one to examine coefficient of variation and one to examine asynchrony. The within-subjects variable of stimulation (sham vs. anodal) and the between-subject variable of brain region (SMA vs. rSMG) were analyzed. The ANOVA analysis for covariance revealed no significant main effect of stimulation ($F(1, 16) = 1.66$, $p > .05$, $n^2 = .09$, power = .23), brain region ($F(1, 16) = 2.18$, $p > .05$, $n^2 = .12$, power = .28), or for an interaction of stimulation type and brain region ($F(1, 16) = 0.51$, $p > .05$, $n^2 = .03$, power = .10). The ANOVA analysis of asynchrony revealed a significant main effect of stimulation ($F(1, 16) = 15.59$, $p = .001$, $n^2 = .49$, power = .95), with participants performing better in the sham block ($M = 0.14$, $SD = 0.07$) compared to the anodal block ($M = 0.16$, $SD = 0.08$). There were no main effects of brain region or interactions ($p>.05$). To further investigate, we conducted paired sample t-tests for each brain region respectively. We found a significant difference in asynchrony between sham and anodal stimulation for the SMA ($t(10) = -3.22$, $p = .009$), with better performance for the

sham condition (M = 0.14, SD = 0.09) than for the anodal condition (M = 0.17, SD = 0.09) (Figure 2). Note that lower asynchrony is indicative of better performance. There was a marginal effect of stimulation for the rSMG ($t(10) = -2.41$, $p = .053$), with better performance for the sham block (M = 0.12, SD = 0.04) compared to the anodal block (M = 0.15, SD = 0.07).

Figure 2.

Mean and SD's for the BAT-Production Task, BAT-Perception Task, and Rhythm Reproduction Task.



Note. This figure demonstrates the mean scores and SD's for each rhythmic task. A) BAT-Production Task: there was a significant main effect of stimulation for the SMA (p = .009). No other significant effects were found. n = 11 for the SMA, n = 7 for the rSMG. B) BAT-Production Task: no significant effects found. n = 11 for the SMA, n = 7 for the rSMG. C) Rhythm Reproduction Task: no significant effects found. n = 7 for the SMA, n = 6 for the rSMG.

BAT-Perception

The mixed model ANOVA analysis revealed no significant main effects of stimulation ($F(1, 16) = 2.46$, $p > .05$, $n^2 = .13$, power = .31), or of brain region ($F(1, 16) = 0.47$, $p > .05$, $n^2 = .03$, power = .09). There was no interaction found between stimulation and brain region ($F(1, 16) = 0.32$, $p > .05$, $n^2 = .02$, power = .08).

Rhythm Reproduction

The mixed model ANOVA analysis revealed no significant main effects of stimulation ($F(1, 11) = 1.77$, $p > .05$, $n^2 = .14$, power = .23) or of brain region ($F(1, 11) = 0.51$, $p > .05$, $n^2 = .04$, power = .10). There was no interaction found between stimulation and brain region ($F(1, 11) = 2.95$, $p > .05$, $n^2 = .21$, power = .35).

Discussion

The aim of this study was to determine to what extent do commonly used rhythmic tasks reflect beat-based rhythm perception and sequence memory-based rhythm perception as revealed by tDCS. We predicted that the BAT would be more affected by the SMA in beat-based rhythm perception while the Rhythm Reproduction Task would be more affected by the rSMG in sequence memory-based rhythm perception. This study highlights the possibility of different underlying processes that may be involved in rhythmic tasks.

Effects of tDCS on the SMA in Beat-Based Rhythm Perception

While there were no effects on CoV, there was a significant effect of stimulation of asynchrony. Contrary to our prediction and previous literature, participants performed worse on BAT-Production with anodal stimulation compared to sham, regardless of the brain region stimulated. This finding is inconsistent with previous literature as Grahn and Brett (2007) found the SMA is involved in timing, duration perception and rhythm perception and production. The SMA is not only involved in attention to timing, but is responsible for the detection and generation of an internal beat. This inconsistency could possibly be due to a weaker sample size as this study was underpowered. There is also the possibility of fatigue as anodal stimulation always occurred after the sham condition. So participants could have been more alert for the first 20 minutes during the sham condition, but more fatigued when completing the tasks during the last 20 minutes with anodal stimulation. Our results from the BAT-Perception Task cannot confirm that SMA plays a causal role in the perception of beats as the study was underpowered.

The SMA is suggested to be involved in a broad range of cognitive domains (Cona & Semenza, 2017). The SMA is implicated in beat perception (Grahn & Brett, 2007), working memory (Cañas, et al., 2018), language (Segaert, et, 2012), timing (Coull, et al., 2016), spatial processing (Bahlmann, et al., 2009), and numerical cognition (Arsalidou & Taylor, 2011). Therefore, while the SMA could be necessary for processing beat-based rhythm perception, it may not be directly involved in perceiving a beat. It is also important to consider that the SMA is only one component of the striato-thalamo-cortical loops that are involved in timing (Ferrandez, et al., 2003). Grahn and Brett (2007) found through neuroimaging that the basal ganglia was another structure part of this loop found to strongly be involved in timing as well as timing of future movements. However, tDCS cannot modulate activity in deeper brain regions so it is important to keep in mind that the SMA is the brain region we have targeted as it is most accessible using tDCS.

Effects of tDCS on the rSMG in Sequence Memory-Based Rhythm Perception

The mixed model ANOVA results also revealed no significant main effect of stimulation or brain region for the Rhythm Reproduction Task. There was also no significant interaction of stimulation and brain region. Our results suggest that participants short-term memory did not improve when applying anodal stimulation over the rSMG. This finding is inconsistent with previous literature as Schall and colleagues (2017) used tDCS to enhance performance on a rhythm memory task on the rSMG however, this inconsistency could be due to a very small sample size, smaller than the BAT.

Similar to the SMA, the rSMG is also responsible for other cognitive domains. Lesions to the rSMG affect proprioception-related brain activation (Ben-Shabat, et al., 2015), as well as phonological processing (Hartwigsen, et al., 2010). However, this brain region was used as it was accessible for using tDCS to investigate sequence memory-based rhythm perception in a rhythm memory task.

As a whole, the results of the current study do not support our hypotheses. We predicted that the SMA would enhance performance on both the BAT-Production Task and the BAT-Perception Task and that performance on the Rhythm Reproduction Task would be enhanced when applying anodal stimulation over the rSMG but our results did not support this. The various rhythmic tasks somewhat reflected beat-based rhythm perception and sequence memory-based rhythm perception, but results may change as this study is currently ongoing.

Limitations and Future Directions

One limitation of this study is the effectiveness of tDCS. Some studies have shown significant results using tDCS (Schall, et al., 2017; Leow, et al., 2021) while other literature questions the effectiveness, specifically precision of target specific neural structures (Alam, et al., 2016; Reinhart, et al., 2017). As tDCS is more accessible to causally investigate neural

regions, this was used instead of transcranial magnetic stimulation (TMS) which would allow for more precision in targeting neural structures yet is much more expensive. As well, although tDCS is generally flexible in terms of protocol and electrical dosage, it is still unclear the most effective design for a given experiment as there is much variability in the little literature there currently is (Thair, et al., 2017). In addition, while tDCS requires the use of the 10:20 EEG System for neural measurements, neuro-navigation software would be more accurate to determine the exact location of a participant's SMA or rSMG and thus could be considered for future studies.

Another limitation was the lack of counterbalancing the sham and anodal conditions. Due to lack of time and resources, both blocks were done in one session so the sham condition always had to precede the anodal stimulation to avoid stimulation contamination with sham following anodal stimulation. This study is currently underpowered as there was a small sample size, especially for the Rhythm Reproduction Task. As this is a pilot study, data collection is currently still ongoing. The next step of this study would be to run a multi-session study where sham and anodal conditions are counterbalanced and cathodal current is added as a condition. Performance on rhythmic tasks would have strong causal implications in distinct rhythm perception if performance can be enhanced and inhibited, rather than just enhanced.

Further examination of rhythmic distinction in the brain could have implications for other processes, such as language patterns and processing in the brain. There are also large clinical differences in rhythmic ability. For example, therapeutic interventions for treatments such as music therapy for individuals with Parkinson’s disease. The basal ganglia executes voluntary movements and individuals with Parkinson’s disease have degeneration of dopaminergic neurons of the substantia nigra pars compacta triggering a cascade of functional changes affecting the whole basal ganglia network (Blandini, et al., 2000). This

may be beneficial in future clinical treatment as activating areas of the brain (i.e. beat-based rhythm perception), that are associated with motor movements, may improve rhythmic limb movements (Pacchetti, et al., 2000). Similarly, children with dyslexia exhibit timing difficulties in language, music, perception, as well as motor control (Overy, 2003). If we can determine a difference between beat-based and memory-based rhythm perception, the distinction may be useful later on to help with motor control in children or in individuals with Parkinson's. It is important to explore the individual differences in relation to other cognitive factors.

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Appendix A

Ethics Approval Letter

Western Research

Date: 5 January 2022

To: Dr. Jessica Grahn

Project ID: 104725

Study Title: Effects of brain stimulation on beat perception and motor performance

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Date Approval Issued: 05/Jan/2022

REB Approval Expiry Date: 09/Jan/2023

Dear Dr. Jessica Grahn,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

Western University REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The REB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

The Office of Human Research Ethics

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B

Medical Screening Questionnaire

MEDICAL SCREENING QUESTIONNAIRE

Do any of the following apply to you?

- Any neurological or psychiatric problem, such as ADHD, epilepsy, Tourette's syndrome, etc.
- Implantation of metallic objects in the brain (e.g., deep brain stimulators).
- Use of psychoactive medication
- Any active skin problems (such as eczema)
- Any unstable medical condition
- Migraine or other frequent headaches
- Any history of episodes of faintness
- Any metal implants or devices in your body (e.g. surgical clip, coronary stent)
  These do not include metal dental fillings and metal dental braces.
- Current use of a hearing aid
- Pregnant, or trying to become pregnant

☐ **None of the above apply to me.**

Appendix C

Letter of Information

Western The Brain and Mind Institute Department of Psychology Western SocialScience

LETTER OF INFORMATION FOR PARTICIPANTS

The Effects of Transcranial Current Stimulation on Beat Perception and Motor Performance

Principal Investigator:

Jessica Grahn, Ph.D.
Brain and Mind Institute
Room 5118, Western Interdisciplinary Research Building
University of Western Ontario
London, Ontario, N6A 5B7
Email: jgrahn@uwo.ca
Phone: 519-661-2111 x84804

Introduction:

You are invited to voluntarily participate in a research study investigating the role of brain areas known to contribute to the perception of the beat in music and to motor performance, using transcranial current stimulation, or tCS. The purpose of this study is to determine how specific brain regions may be responsible for different aspects of musical perception and experience. This letter of information will provide you with further information about behavioural tasks and techniques that will be used during the experiment allowing you to make an informed decision regarding participation in this research.

Research Procedures:

If you agree to participate in this study, you will complete a demographic questionnaire that will request information such as your age, music and dance training, hearing status, handedness, and language experience. Your participation will also involve behavioral tasks that include:

Rhythm/ Beat Perception Tasks:

During the study, you may hear stimuli that fall into three categories: metronomic/ isochronous beeps, metric or non-metric rhythms, and music clips (e.g. clips from recorded musicians). Tasks fall into five categories: discrimination, passive listening, beat-tapping, walking, and reproduction tasks. You will hear stimuli and may be asked to simply listen passively, or to make perceptual judgments about the sounds, and/or make responses to the sounds. If the task is complex, you will be given a chance to practice before the session begins. You may be completing these tasks before and after tCS is applied to the scalp (offline tCS), or at the same time as tCS is applied (online tCS). Overall, these experiments will inform us about the role of different brain areas in music processing.

Walking Tasks:

If you agree to participate in this study component, you will undergo behavioral tasks where you will listen to stimuli and make judgments about the stimuli (e.g., 'Does it have a beat? Is it the same rhythm as the previous stimulus?). Once complete you will listen to various auditory

stimuli while (1) walking on an electronic sensor walkway or (2) reaching to a target by moving a hand-held recording cursor, depending on study assignment. Both reaching and walking study paradigms will record the timing and distance of your movements.

As you are walking, you will be asked to listen to music at a comfortable volume of your choice. You may choose to take rest breaks at any time during the study. If at any time the task becomes too physically demanding or you become tired, you can end the experiment at any time.

Visual Tasks:
During the study, you may be asked to complete a visual task, either separate from or simultaneous with the presentation of rhythms/music. The task involves making perceptual judgments about visual stimuli (for example whether a visual stimulus briefly changed its orientation or color) and making button presses to indicate your responses.

Transcranial current stimulation (tCS)
First, we will estimate the scalp area overlying the cortical areas that will be stimulated using the international electroencephalographic 10-20 system. Subsequently, a set of electrodes will be applied to the scalp. There are two types of transcranial current stimulation possible. For transcranial *direct* current stimulation (tDCS), one electrode (the anode) will be placed onto the target brain area, while the other electrode (the cathode) will be placed on a reference location, such as your forehead. These sponge electrodes will be saline-soaked to increase comfort, and the electrode positions on the scalp will be secured with rubber straps. A 2 milliampere direct current will be applied between the electrodes. For transcranial *alternating* current stimulation, two electrode arrangements are possible: 1) two larger electrodes will be positioned close to the target brain area, or 2) 5–8 smaller electrodes will be positioned close to the target brain area. In both cases, the rubber electrodes will be held in place with conductive paste. A 1–2 milliampere alternating current will be applied between the electrodes. In the proposed research, stimulation will be applied for 20-40 minutes. Depending on experimental protocol, you will either be performing a behavioral task during stimulation, or you will be at rest during stimulation. Stimulation will cease at a predetermined point after a maximum of 40 minutes. You may feel the stimulation as an itching or a tingling sensation

Electromyography (EMG):
Surface EMG is a non-invasive measure of electrical activity produced by skeletal muscles. Surface EMG will allow us to measure motor evoked potentials (MEP's), or muscle movement caused by direct stimulation of the motor cortex. Small electrodes will be placed on specific hand, arm, foot, or leg muscles. These electrodes require a small amount of sticky gel-like substance to conduct the electrical current.

Electroencephalography (EEG):
EEG will be recorded for some participants. EEG is a non-invasive, risk-free technique for recording electrical brain activity. Electrodes placed on the scalp (sometimes mounted in a special cap or net) detect electrical signals that brain cells use for communication. Since saline solution or electrode gel is necessary for the electrodes to pick up brain activity, facilities are available for hair washing after the experiment.

Transcranial Magnetic Stimulation

Like tDCS, TMS is a safe, well studied, non-invasive brain stimulation method that affects the depolarization and hyperpolarization of brain cells. TMS uses electromagnetic induction to induce weak electric currents using a rapidly changing magnetic field; this can cause activity in specific areas of the brain. A TMS pulse is felt as a light tap on the head. TMS will be used to localize the scalp area overlying the motor cortex. By estimating the scalp area overlying the motor cortex, we will be able to estimate other candidate brain areas for tDCS stimulation, such as the premotor cortex and the supplementary motor area.

Risks:
Some participants may find the tingling or itching sensation of tCS brain stimulation uncomfortable. In very rare cases, tCS stimulation can cause minor skin abrasions or burns (expected to heal completely). Individuals with skin problems who are more susceptible to skin irritation will also be excluded from participating.
Susceptible individuals may experience a mild headache after brain stimulation. To reduce the likelihood of this, individuals who report susceptibility to migraines or frequent headaches will be excluded from participating.
All participants will be reminded that they may withdraw at any time without giving any reason and without any negative consequences.

Benefits:
There is no direct benefit to you from participating in this study. The results from this study may help us to better understand the brain regions underlying human motor performance and beat perception.

Voluntary Participation:
Participation in this study is voluntary. You may refuse to participate, refuse to answer questions, or withdraw from the study at any time.

Discontinuation of the Study by the Investigator:
At any time during the study, the investigators have the right to stop the study for any reason.

Participant Exclusion Criteria:

This study is intended for healthy individuals. You should not participate in this study if you fall into one of the following categories

- Participants with metallic implants, such as pacemakers, cerebral aneurysm clips or other electronic implants
- Female participants who are pregnant, trying to conceive, or who are sexually active and are not practicing an effective method of contraception
- Participants with a history of psychiatric or neurological problems such as epileptic seizures, Tourette's syndrome, ADHD, depression.
- Participants who require prescribed psychotropic medication or currently take other medication that makes them drowsy
- Participants who get migraines and/ or are susceptible to headaches
- Participants who are more susceptible to skin irritation, such as participants with eczema.

Estimate of Participant's Time and Compensation:

Depending on which experiment you have been assigned to, you may be asked to come in for one session or for multiple sessions (up to ten). Each session will last one to two hours. Each experiment within the research project will involve approximately 25 participants. The entire research project will involve multiple experiments, and may require up to 300 participants.

Upon completion of all parts of the study, you will receive monetary compensation ($5 per half hour) or participants signing up through SONA will receive course credit (1 credit per hour) for your participation in this study. If the study has to be stopped for any reason, compensation will be adjusted according to the fraction of the study that was completed.

Confidentiality:

Any information obtained from this study will be kept confidential. Any data resulting from your participation will be identified by a number, without any reference to your name or personal information. Data will be stored on a secure computer in a locked room. After completion of the experiment, data will be archived on storage disks and stored in a locked room for a minimum of five years and a maximum of 15 years, after which they will be destroyed. Representatives of the University of Western Ontario Health Research Ethics Board may require access to your study-related records or may follow up with you to monitor the conduct of the study. If you choose to withdraw from this study, your data will be removed and destroyed from our database.

Open Data:

All identifiable information will be deleted from the dataset collected so that individual participant's anonymity will be protected. The de-identified data will be accessible by the study investigators as well as the broader scientific community. More specifically, the data may be posted on a database OR made available to other researchers upon publication so that data may be inspected and analyzed by other researchers. The shared data will not contain any information that can identify you.

Consent Form

You do not waive any legal rights by signing the consent form. In the event of a study-related injury, your consent does not waive any medical or legal rights you may be entitled to. You will be provided with a copy of this letter of information and the consent form. You also reserve the

right to withdraw any data collected from you, with no limitations on the feasibility of that withdrawal. You do not need to give any reason to withdraw, and there will be no implications on your medical or legal rights.

Contact Information

If you would like to receive a copy of the overall results of the study, or if you have any questions about the study please feel free to contact the Principal Investigator at the contact information provided above.

For questions about your rights as a research participant or the conduct of the study you may contact:
Office of Research Ethics

University of Western Ontario
519-661-3036 E-mail: ethics@uwo.ca

 Participant's Initials: _____

CONSENT FOR RESEARCH STUDY

The Effects of Transcranial Direct Current Stimulation on Beat Perception and Motor Performance

I have read the Letter of Information, have had the nature of the study explained to me, and I agree to participate. All questions have been answered to my satisfaction.

Name of Participant (Please print): _____

Signature of Participant: _____

Date: _____

Person Obtaining Informed Consent (Please print): _____

Signature: _____

Date: _____

Dated at Western University, London, Ontario.

Appendix D

Demographic Questionnaire

What is your sex?

- ◯ Male
- ◯ Female
- ◯ Non-binary / third gender
- ◯ Prefer not to say

What is your age (in years)?

Handedness:

- ◯ Left Handed
- ◯ Right Handed
- ◯ Ambidextrious

Do you have a hearing impairment?

- ◯ No
- ◯ Yes - Please Describe:

Have you ever been diagnosed with a neurological or psychological disorder?

- ◯ No
- ◯ Yes - Please Describe:

Are you currently taking any drugs or medications?

- ◯ No
- ◯ Yes - Please list all:

First language learned as a child:

Other languages learned as a child (please include the age at which you learned each one). Enter NA if none: