Exploring rhythmic abilities in commonly used beat and rhythm tasks using tDCS

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Abstract

Rhythm plays a fundamental role in various aspects of human life, including music, dance, language, and memory. Despite its prevalence, previous studies have often treated rhythmic abilities as a single concept, assessed by a single rhythm task. However, recent behavioral research suggests that rhythmic abilities encompass distinct processes including beat and sequence-memory processes (Fiveash et al., 2022). We seek to investigate to what extent do commonly used rhythmic tasks reflect beat processes and sequence-memory processes as revealed by Transcranial Direct Current Stimulation (tDCS). To assess the results of previous studies with causal manipulation, tDCS is used as a method to generate causal evidence by selectively modulating brain areas thought to be involved in distinct rhythmic behaviours. The brain areas targeted were the supplementary motor area (SMA), which is associated with beat-based timing (Grahn & Brett, 2007) and the right supramarginal gyrus (rSMG), which is associated with rhythm memory (Schaal et al., 2017). The neural excitability in the SMA and rSMG were selectively modulated using tDCS. If the SMA and rSMG do draw on distinct rhythmic processes, we predict that performance on behavioural tasks involving beat processes should improve with anodal stimulation to the SMA, but should not be affected by stimulation to the rSMG. Performance on behavioural tasks involving sequence-memory should improve with anodal stimulation to the rSMG, but should not be affected for the SMA.

Acknowledgements

I want to express my gratitude to my thesis supervisor, Dr. Jessica Grahn, for her support and guidance throughout this project. Her feedback and encouragement have been instrumental in my progress as a researcher and I am fortunate to have her as my advisor.

I also want to thank Dr. Karli Nave, my project supervisor, for her constant assistance and mentorship in and out of the lab. Thank you for teaching me, learning with me and supporting me through this journey. I really could not have done it without you, thank you.

A really special thanks to Abigail Hunt, my fellow undergraduate thesis student and friend, for working alongside me in this project. Having someone to talk to and work with every step of the way was truly what made this project possible. Thank you for all the time and hard work you have dedicated to this project.

Thank you to everyone in Dr. Jessica Grahn's lab for their feedback and support throughout the year on my presentations, as well as to the BMI staff for their assistance and for providing me with the tools and materials needed for this study.

Thank you to all my friends and family for their unwavering support throughout the project. I am so grateful for your encouragement and presence in this journey.

Finally, I owe a heartfelt thank you to music for inspiring this thesis. In the moments when this project felt overwhelming, I found solace in my connection to music. Thank you for accompanying me in this project from inception to completion.

Statement of Contribution

My supervisor, Dr. Jessica Grahn oversaw the project and provided feedback throughout. Dr. Karli Nave proposed the research topic, question and provided all programming materials. Karli also created the demographics survey. I and Abigail Hunt collected data together and analyzed data in collaboration. Abigail collected data for the SMA group and I collected data for the rSMG group. All figures and writing were created myself, incorporating feedback from Karli.

Introduction

Background

Time is everywhere and we are practiced timekeepers. We have a fascinating ability to perceive, remember, respond to and reproduce patterns of time intervals in music. We tap our feet along to the beat or keep count as we waltz with a partner. The beat is the most salient part of sound and can be defined as the most prominent periodicity within a musical piece. For example, where the listener is likely to want to clap their hands or move in time with the rhythm. Rhythm however, is a bit more complex. It can be defined as the serially ordered pattern of time intervals in a stimulus sequence (i.e., time spans marked by event on- sets) (Fiveash et al., 2022). Although rhythm is ubiquitously defined as a single concept, research suggests rhythm is multidimensional, involving two distinct processes; beat process and sequence-memory process.

Although no causal evidence has been generated yet, multiple correlational studies have found evidence for the distinction between these rhythmic processes. In one such study, Tierney and Kraus (2015) investigated the multidimensionality of rhythmic skills and found that beat tapping and rhythm memory were dissociable rhythmic aptitudes. They tested 67 healthy participants with a battery of two beat-based and two sequence-memory tasks. Beat-based tasks involved drumming to a metronome and a tempo adaptation task. Sequence-memory tasks involved drumming along to rhythmic sequences and reproducing a rhythm. Authors found a correlation between performance on both beat-based tasks and between both sequence-memory tasks, but not between beat tasks and sequence-memory tasks, suggesting that they are separable processes of rhythm. Bonacina et al., (2019) also investigated rhythmic skills using 4 tasks, reflecting different clusters of skills, namely beat-based and sequence-memory based. In their study, 68 children were tasked with

drumming to an isochronous beat, remembering rhythmic patterns, drumming to the beat in music, and clapping in time with feedback. As from Tierney and Kraus (2015), they found that drumming to an isochronous beat and remembering rhythmic patterns were not related, suggesting separable rhythmic processes. They also found that clapping in time with feedback was correlated with performance on the other 3 rhythm-memory tasks. Performance on sequence memory-based and beat-based rhythm tasks are not routinely correlated (Bonacina et al., 2019; Tierney & Klaus, 2015) suggesting separable rhythmic processes. The overall findings of these studies suggest that future studies examining rhythm should utilize multiple tasks to better assess distinct rhythmic abilities.

In subsequent research, Fiveash et al., (2022) furthered our understanding of these distinct processes of rhythm by systematically investigating the correlations from previous studies. They used nine different behavioural tasks in their study to capture separable underlying rhythmic processes that exist above and beyond methodological differences. Principal component analysis (PCA) was used to reduce the dimensionality of the dataset, whilst preserving the unique variability. Rhythmic tasks loaded onto different factors revealing three distinct processes: tapping precision and beat alignment, beat-based rhythm perception and sequence memory-based rhythm perception. Their results generated evidence to suggest that rhythm involves distinct processes but causal evidence is required to make further conclusions.

As previous studies have found evidence to suggest that there are distinct processes of rhythm, it is expected that distinct processes would draw on distinct neural pathways. Investigating the neural underpinning of the beat process, Grahn and Brett (2007) conducted an fMRI study and found that the beat process was strongly linked to motor areas in the brain.

Results suggested the supplementary motor area (SMA) and basal ganglia were involved in the beat process. Investigating the sequence-memory process, Schaal and colleagues (2017) found that anodal stimulation of the right supramarginal gyrus (rSMG) using Transcranial Direct Current Stimulation (tDCS) improved performance on sequence memory tasks. Thus suggesting that the rSMG is involved in the sequence-memory process.

As the findings of previous studies are correlational in nature, casual manipulation can be used to generate causal evidence to further support the conclusion that distinct beat and sequence-memory processes draw on distinct neural pathways. TDCS can be used as a method to demonstrate a causal relationship between specific brain areas and specific rhythmic abilities. By selectively modulating the excitability of brain areas associated with rhythmic tasks tDCS can generate causal evidence to support correlational results of previous research.

Transcranial direct current stimulation (tDCS) for causal manipulation of brain areas involved in beat and sequence-memory processes

TDCS is a non-invasive, painless and temporary method of brain stimulation which emits a weak electrical current to selectively modulate the activity of brain regions (Thair et al., 2017). The use of tDCS has gained popularity and has become a promising tool to study cognitive and motor processes. It consists of two electrodes: one over the brain area of interest and a reference electrode (e.g., on forehead). In anodal stimulation, excitatory current is applied to the target brain area, increasing excitability of the underlying neurons. In cathodal stimulation, inhibitory current is applied to the target brain area, inhibiting excitability of the underlying neurons. It is assumed that excitation of brain areas will enhance performance on behavioural tasks while inhibition will decrease performance.

Active sessions of tDCS stimulation are compared to a sham condition where the participant believes a current is active when it is not, thus serving as a control condition.

The use of tDCS as an effective method to investigate the multidimensionality of rhythmic abilities has been demonstrated by previous studies. In a study by Leow et al., (2021), researchers examined how beat-based timing and non-beat-based sequence timing were affected by modulating excitability of the supplementary motor area, the right cerebellum, and the bilateral dorsal premotor cortices, using tDCS. Participants completed a sham and active, anodal or cathodal 2mA tDCS session and discriminated changes in rhythms which engaged beat-based or non-beat based timing. They found that performance improved by increasing SMA excitability and was impaired by decreasing this excitability, thus demonstrating involvement of the SMA in beat-based timing. The SMA has been associated with beat-based timing in other studies as mentioned previously (Grahn & Brett, 2007). Participants in their study were instructed not to move as they completed a rhythm discrimination task where they determined from a sequence of three rhythms whether the last one was the same or different. Even though they were not moving, a bilateral network of motor areas was activated as participants perceived rhythms. For beat-based rhythms, the basal ganglia and SMA were more strongly involved than non-beat based rhythms. The activation was likely due to rhythm perception alone as there was a lack of activation in the primary motor cortex, suggesting participants complied with instructions to not move.

Research using tDCS to investigate cortical regions involved in the sequence-memory process comes from the previously introduced study by Schaal and colleagues (2017). This study investigated the involvement of the left and right SMG in pitch and rhythm processing using sham and active anodal tDCS sessions. Participants completed a pitch memory and a

rhythm memory task while anodal tDCS was applied to either the lSMG or the rSMG. A significant difference was found where anodal tDCS of the rSMG increased performance on the sequence-memory task, but not for the sham session. Thus, suggesting that the rSMG is involved in the sequence-memory process. By using tDCS to casually manipulate the excitability of brain areas, Schaal et al., (2017) provided causal evidence to support the distinction between pitch memory and rhythm memory. The current study will also use tDCS in beat and sequence-memory processes to generate causal evidence in support of their distinction.

Current Study

The aim of the current study is to provide causal evidence to support previous findings that beat and sequence-memory processes are distinct rhythmic processes, drawing on distinct neural pathways. Participants will be randomly assigned to either the SMA or rSMG group and will complete two counterbalanced sessions (excitatory stimulation and "sham" no stimulation). Casual manipulation will be conducted by applying tDCS stimulation to two distinct brain regions shown to be involved in beat or sequence-memory processes, as subjects complete behavioural tasks. Tasks consist of a beat production task, measuring beat-based timing and a rhythm reproduction task, measuring sequence-memory. The coefficient of variability and asynchrony from the beat production task will serve as our dependent variables. The effects of tDCS stimulation on our dependent variables will be analyzed using a 2x2 repeated measures ANOVA for brain area stimulated (SMA, rSMG) and stimulation type (anodal vs sham). For the sequence-memory task the average production error (PE) serves as our dependent variable. We will conduct a 2x2x3 repeated measures ANOVA to examine differences between stimulation type (anodal vs sham), rhythm type (no beat vs weak beat vs strong beat) and the between-subjects factor, brain area stimulated

(rSMG vs SMA). We hypothesize that anodal stimulation of the SMA will improve performance, decreasing asynchrony and the coefficient of variation for the beat production task. This is because the SMA, not the rSMG, is thought to be involved in the beat process so excitation of this brain area should enhance performance while no stimulation will have no effect on performance. Likewise, we hypothesize that anodal stimulation to the rSMG will enhance performance, decreasing PE for the sequence-memory task. This is hypothesized as the rSMG is thought to be involved in the sequence-memory process so excitation of this brain area should enhance performance while no stimulation will have no effect on performance.

Methods

Participants

The current sample included 19 participants recruited from advertising posters, the undergraduate psychology student participant pool of Western University (SONA), by self-referral and by word of mouth. Interested participants were pre-assessed to ensure they are healthy individuals between 18-45 years old and no history of hearing damage, use of psychoactive drugs/medication, hearing aids, pacemakers or any metal implants in body, susceptible to headaches or migraines, blackouts or seizures, is pregnant, or susceptibility to skin irritation due to eczema. Participants were compensated with 2.0 credits via SONA or $10 for each session ($20 total). The procedure of this study has been approved by Western University's Research Ethics Board (see Appendix A).

Procedure

Eligible participants arrived at the Western Interdisciplinary Research Building at Western University for testing. Upon arrival, subjects were given a medical questionnaire to

confirm eligibility in the study (see Appendix B) and a letter of information (see Appendix C). Participants then had the opportunity to ask any questions prior to obtaining consent. All subjects completed two 1-hr sessions with a minimum of 48 hrs between sessions to minimize carryover effects. Two electrodes for tDCS will be placed on subjects' scalp and forehead prior to completing tasks. Participants will use an Omen laptop and Sennheiser 280 Pro headphones to complete both questionnaires and rhythmic tasks, with rhythmic tasks administered through E-prime software (version 2.0).

TDCS Set-Up

The head is measured to ensure correct electrode placement according to the 10-20 electroencephalogram system. The head is measured from the nasion to the inion, then the inter-auricular distance, with measurements intersecting at the vertex (Cz). Participants are assigned to either the SMA or rSMG group with the appropriate tDCS set-up for the brain area of interest. The SMA is measured 2 cm rostral from the vertex. The rSMG is measured 3 cm caudal to the vertex, then 4 cm laterally to the right (corresponds to CP4). Sponges for electrodes are soaked in a saline solution to ensure they are damp before insertion in electrodes. Electrodes are attached with wires to the tDCS machine (Activadose system). The active electrode is then placed on the target brain area (SMA or rSMG) and the reference electrode is placed on the forehead. Rubber straps and back fasteners are used to comfortably hold the electrodes at the determined target and reference point. Additional saline can be added to sponges using a plastic syringe to minimize discomfort associated with stimulation. The tDCS machine is then turned on, according to tDCS safety guidelines and is set to a mild current of 2.0 mA. Sham and anodal stimulation are counterbalanced according to the order assigned. For the stimulation condition, the stimulation is applied for 20 minutes. For the sham condition, after tDCS ramping up to 2.0 mA, the machine will immediately be turned away from the participants' sight and will be turned off for the full 20 minutes. The sham

condition is intended to simulate the feeling of stimulation without any real neurophysiological effects and acts as a placebo condition. During the stimulation period, the participant will complete either a short demographics questionnaire (anodal condition) (Appendix D) or the Goldsmith Musical Sophistication Index (Gold-MSI) (sham condition) (Appendix E) on the laptop. Participants are only completing questionnaires during this period. Rhythmic tasks will be completed after the 20 minute period of sham/stimulation. After tasks are completed, participants are given a debriefing form (Appendix F) and compensation.

Goldsmith Musical Sophistication Index

During sham, participants are asked to complete the Goldsmith Musical Sophistication Index (Gold-MSI) to obtain information regarding musical and dance experience. As research has shown differential effects of tDCS on musicians vs non-musicians, it is important to obtain this information as musical sophistication could be a potential moderating factor of tDCS (Schaal *et al*., 2015).

Rhythmic Tasks

After the sham or stimulation period, participants are asked to complete two rhythmic tasks counterbalanced according to order assigned. Stimuli from the Beat Alignment Task (BAT) was obtained from Iversen & Patel (2008). Stimuli for the rhythm reproduction task was obtained from Grahn & Brett (2007). Completion of both tasks is about 20 minutes. See Figure 1 for examples.

Beat Task. The beat task (BAT) is used to evaluate the consistency of tapping and how close participants' tap to the beat. Participants were instructed to "Tap along to the beat of the music" using the 'M' key of the keyboard. After 13 trials, participants were asked to rate the familiarity of musical excerpts on a 3-point Likert scale with 1 = never, 2 = somewhat familiar and 3 = very familiar (Figure 1).

Stimuli. Participants listened to 1 practice trial and 13 musical excerpts of various genres (jazz, pop, rock). Stimuli were presented in a random order.

Sequence-Memory Task. A rhythm reproduction task was used to evaluate how accurate participants were in reproducing rhythmic sequences from memory. Participants listen to a rhythmic sequence three times, then are asked to reproduce the sequence by tapping it back on the keyboard. As the SMA is thought to be related to performance on beat tasks, rhythm type is included to further investigate the effect of stimulation to the rSMG with strong, weak and no beats; where rhythms with no beats are expected to have lower production errors.

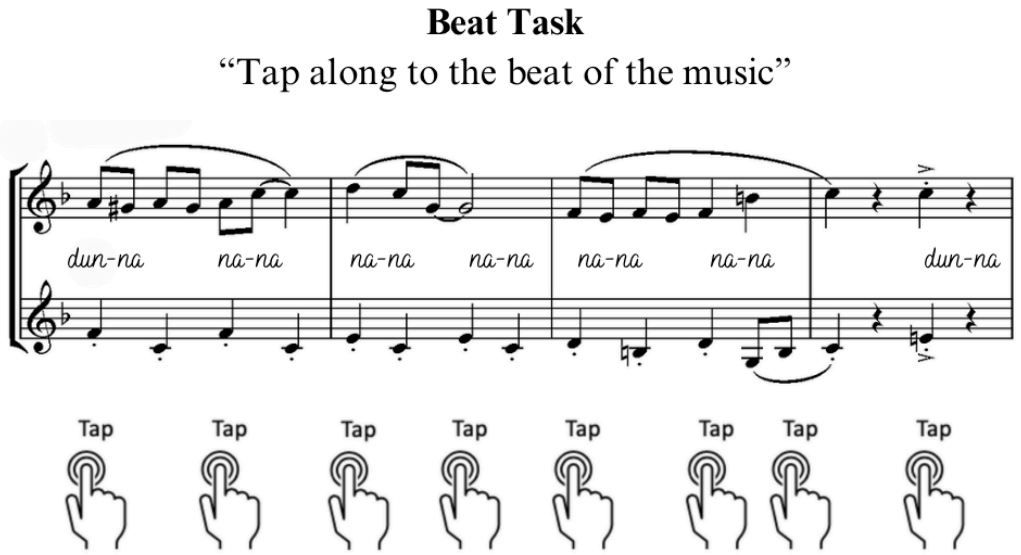
Stimuli. Participants listened to 3 practice trials and 36 rhythmic sequences consisting of three levels of beats: no beat, weak beat and strong beats. Stimuli were presented in a random order for about 20 minutes total. The 36 rhythmic sequences range from five to seven intervals. There were 10 sequences constructed of five intervals where four had a strong beat, three had a weak beat and three had no beat (See Figure 2 for rhythm types). There were 14 sequences constructed of six intervals where five had a strong beat, 4 had a weak beat and five had no beat. Lastly, there were 12 sequences constructed of seven intervals where three had a strong beat, five had a weak beat and four had no beat.

In strong beats, the beat is simple to hear and remember. For example, a five interval rhythmic sequence such as 3:1:4:1:3 is arranged to have a perceptual accent at the beginning. In weak beats, the beat is more difficult to determine as the intervals were rearranged from the strong beat condition to be irregularly grouped. This results in irregular perceptual accents on the rhythm, which makes it more difficult for the participant. For example, a strong beat interval 3:1:4:1:3 would be weakened to 4:1:3:3:1. The no beat condition used the same arrangements from the weak beat condition, but used noninteger ration interval lengths. For example, the weak beat interval 4:1:3:3:1 would have no beat as follows: 4.5:1:1:3.5:3.5.

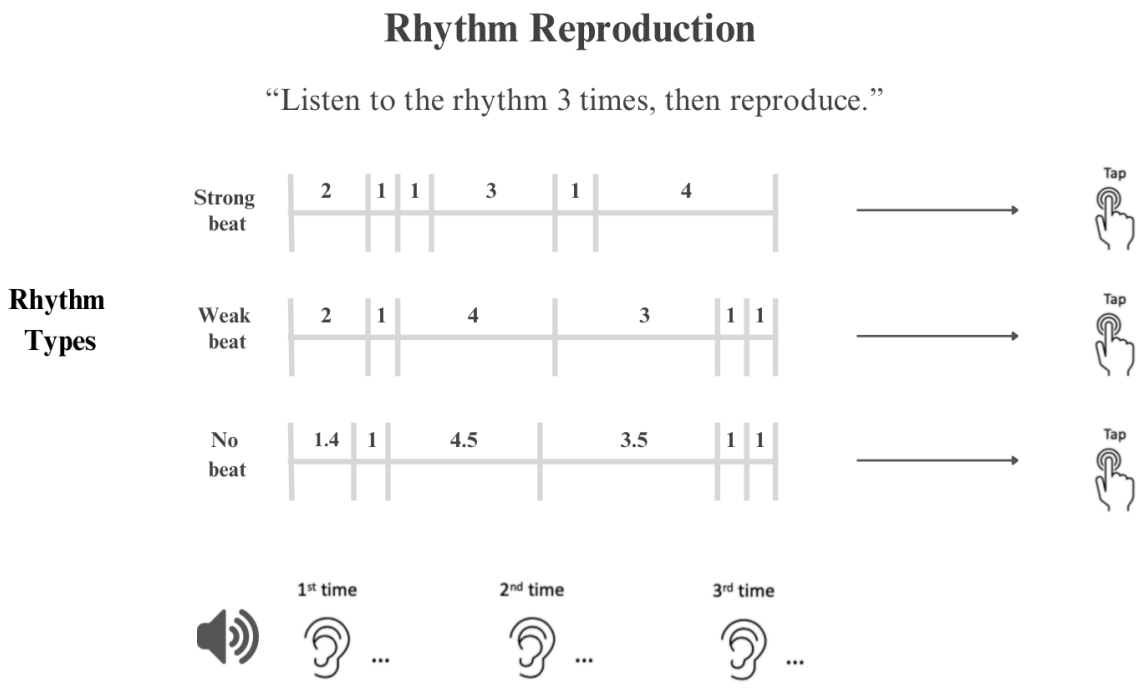
Figure 1

Example of Rhythmic Tasks

A) Beat Task



B) Sequence-Memory Task



Note. A) Beat Task. Participants are asked to tap along to the beat of the music on their keyboard. B) Sequence-memory task. Participants listen to a rhythmic sequence three times

consisting of three rhythm types and then are asked to reproduce the rhythmic sequence using their keyboard.

Data Analysis

Tapping data is converted to a Coefficient of Variation (CoV) and asynchrony for the beat task. CoV measures how regular the taps are, with low CoV reflecting low variation and consistent tapping. Asynchrony is the average milliseconds taps are off beat, with higher asynchrony indicating the participant is tapping far from the beat (positive = tapping before, negative = anticipating). For rhythm reproduction, tapping data is converted to a measure of Average Production Error (PE) for each rhythm type (metric simple, metric complex, non-metric). PE is calculated using the absolute mean difference between reproduced intervals (eg. 220 ms) and the original (eg. 250 ms), divided by each interval ({220 - 250} / 250) in one rhythmic sequence (eg 12312). [KN1] All tapping data were analyzed using MATLAB.

Statistical Analysis

For the beat task, a 2x2 repeated measures ANOVA was conducted for each dependent variable, CoV and asynchrony, to analyze differences between stimulation type (anodal/sham) and brain area (SMA/rSMG). For the rhythm reproduction task, a 2x2x3 mixed-measures ANOVA was conducted for PE to analyze differences in task performance based on brain area stimulated (SMA/rSMG), stimulation type (anodal/sham) and rhythm type (metric simple/metric complex/non-metric). Brain region is a between-subjects factor, as participants were assigned to either SMA or rSMG. Post-hoc tests were used to examine any significant main effects and interactions at the $p < .05$ significance threshold, with a Tukey-Kramer correction for multiple comparisons. All statistical analyses were performed using JASP 0.18.3.0, 2024.

Results

Demographics

The final sample included data from 19 participants in total. The SMA group included data from 13 subjects. There were 4 males and 9 females with a mean age of 19.2(1.7) years old. The rSMG group included data from 6 subjects. There were 2 males and 4 females with a mean age of 20(0.9) years old.

Beat Process

Coefficient of Variation. The repeated measures ANOVA analysis for CoV revealed no significant main effects of stimulation type ($F(1, 17) = 0.24$, $p > .05$, $n^2 = .003$), or brain area ($F(1, 17) = 1.22$, $p > .05$, $n^2 = .054$). There was also no interaction found between stimulation type and brain area ($F(1, 17) = 0.24$, $p > .05$, $n^2 = .003$).

Asynchrony. The repeated measures ANOVA analysis for asynchrony revealed no significant main effects of stimulation type ($F(1, 17) = 1.57$, $p > .05$, $n^2 = .009$), or brain area ($F(1, 17) = 0.24$, $p > .05$, $n^2 = 6.288 \times 10^{-4}$). There was also no interaction found between stimulation type and brain area ($F(1, 17) = 0.01$, $p > .05$, $n^2 = 2.813 \times 10^{-5}$)

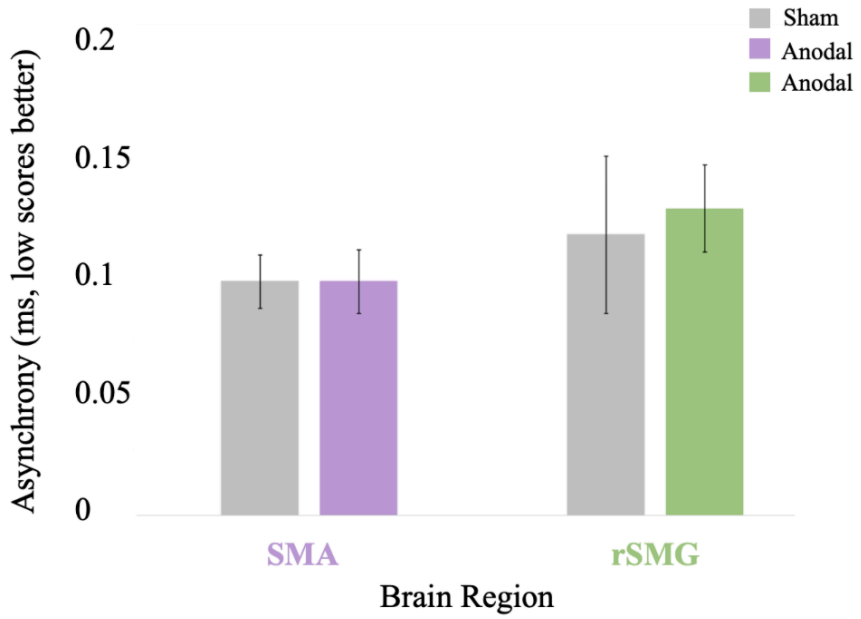
Sequence-Memory Process

Average Production Error. The repeated measures ANOVA analysis for average PE revealed a significant main effect of rhythm type in the SMA group ($F(2, 24) = 9.19$, $p < .001$) and in the rSMG group ($F(2, 10) = 11.06$, $p < .05$). Specifically, there was a significant effect between the strong beat and no beat condition ($F(1, 12) = 13.72$, $p < .05$) where performance was better with a strong beat. There was no significant effect for stimulation type ($F(1, 34) = 0.26$, $p > .05$) or brain area ($F(1, 34) = 0.26$, $p > .05$). There were also no interactions between stimulation type and brain area ($F(1, 17) = 0.029$, $p > .05$).

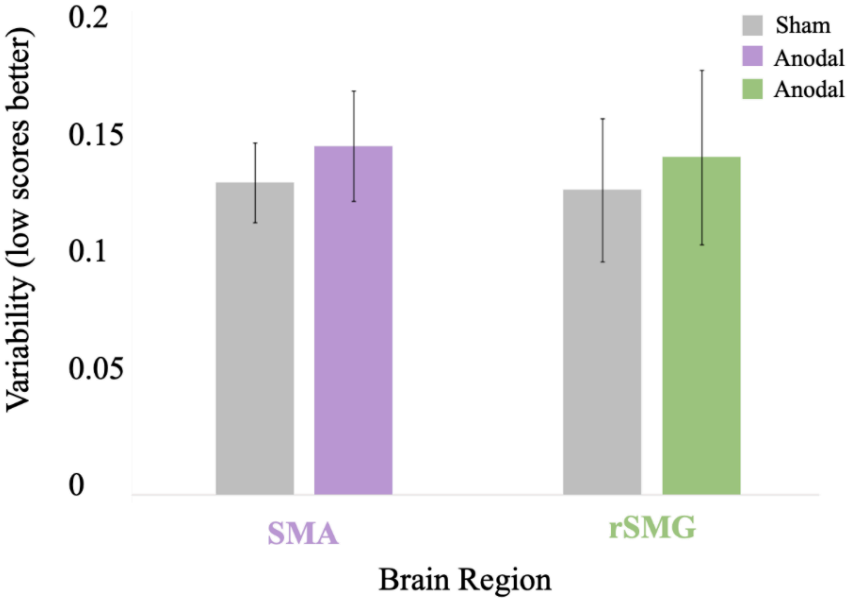
Figure 2

Results of Beat and Sequence-Memory Process

A. Asynchrony



B. Coefficient of Variability (CoV)

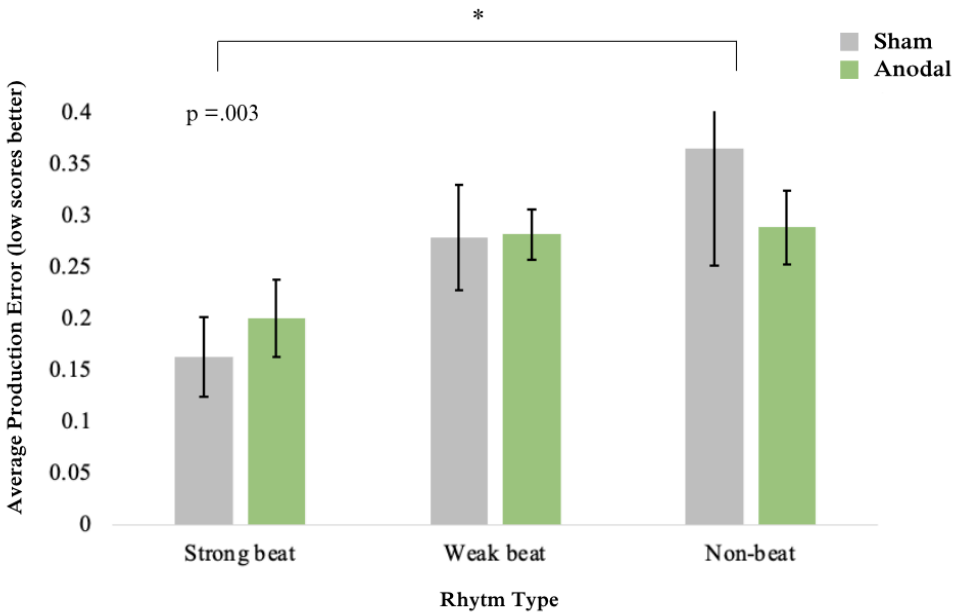


Note. Results of beat process statistical analyses. A) No significant effect of stimulation type on asynchrony or B) CoV, for both SMA and rSMG.

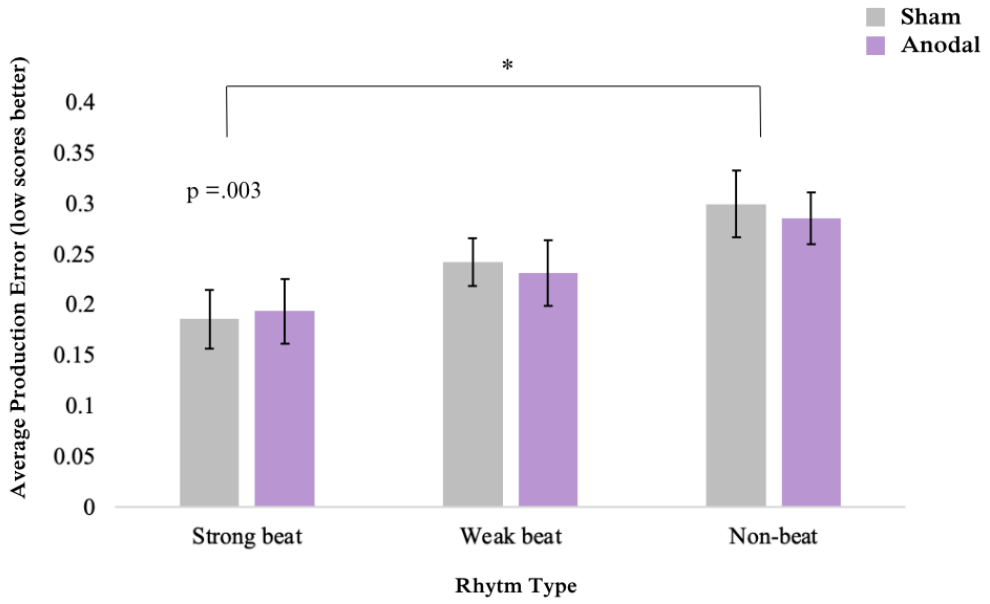
Figure 3

Results of Sequence-Memory Process (average PE)

A. rSMG



B. SMA



Note. Results of sequence-memory process statistical analyses. A) Significant effect ($p < .05$) of rhythm type for SMA ($p < .05$) and rSMG ($p < .001$). Significant difference between strong and no beat for both brain areas ($p < .05$).

Discussion

The current study sought to generate causal evidence to support findings from previous studies which suggest that rhythm consists of distinct processes, drawing on distinct neural pathways. We hypothesized that performance on a beat task would improve with anodal stimulation to the SMA, as previous studies have found that they are correlated (Grahn & Brett, 2007). Additionally, we hypothesized that performance on a sequence-memory task would improve with anodal stimulation to the rSMG, as previous studies have found a correlation between the two (Schaal et al., 2017).

Effects of tDCS on the beat process

As we did not find a significant main effect of stimulation on performance (asynchrony and CoV) on a beat task, we cannot draw causal conclusions distinguishing beat processing from sequence-memory processing in rhythm. Our results are different from previous studies, such as Grahn and Brett (2007), who suggest that the SMA involves timing, attention to timing, duration perception, as well as generating and detecting an internal beat. The discrepancy in our results may be due to a low sample size (N = 19) as our a priori power analysis estimated a minimum sample size of 34 participants to detect an effect. While the SMA is correlated with beat processing, its causal role remains uncertain. Additionally, the SMA only constitutes a portion of beat processing (Leow et al., 2021). As previously mentioned, Grahn and Brett (2007) found that the basal ganglia was another brain area involved in this loop, in timing functions and the anticipation of future movements. However, tDCS cannot target the basal ganglia and deeper brain regions, which is why the current study targeted the SMA despite its singular focus within a broader network.

Effects of tDCS on the sequence-memory process

We did find a significant effect of rhythm type ($p < .001$) where participants performed better on a rhythm reproduction task with a stronger beat, in both the SMA and

rSMG group. However, these results can be attributed to the fact that strong beats are simply just much easier to perceive and produce than weak or no beats. We did not find a significant effect of stimulation or brain region. Our results suggest that anodal stimulation to the rSMG did not improve performance on a sequence-memory task as we predicted. This finding is inconsistent with previous literature, such as Schaal and colleagues (2017), who found evidence using tDCS that the rSMG is involved in sequence-memory processing. As mentioned previously, the inconsistencies of our findings may be due to a low sample size. As the rSMG group only included 6 participants it was significantly underpowered. Taken together, we did not confirm our predictions and cannot make causal conclusions based on our findings.

Limitations and Future Directions

TDCS was used as a method to selectively manipulate the excitability of brain areas thought to be involved in distinct processes of rhythm. However, tDCS cannot target deep brain regions also thought to be involved in the beat process such as the basal ganglia, limiting the scope of our research (Grahn & Brett, 2007). Future studies may consider using transcranial magnetic stimulation (TMS) although it is more expensive, because it is shown to have higher precision to target deep brain regions (Elder & Taylor, 2014).

As the current study only used anodal stimulation (excitatory), future studies should include cathodal stimulation (inhibitory) to better examine the effects of selectively exciting and inhibiting brain areas thought to be involved in dimensions of rhythmic processing.

Many research studies only use a single rhythm test to evaluate participants' overall rhythmic abilities. While this approach may effectively capture the rhythmic aptitude of individuals proficient across multiple rhythmic tasks, it may overlook the performance for those with specific difficulties in certain rhythmic competencies or who rely on alternative skills to perform the task (Tierney & Kraus, 2015). For instance, several studies assess

rhythmic skills solely through tasks like discriminating between different rhythms. However, these tasks may not adequately capture other aspects of rhythm processes, such as beat production and rhythm reproduction (Tierney & Kraus, 2015).

Future research in distinguishing separable rhythmic processes should involve administering a broader range of rhythm tests on a more diverse sample of participants to further current findings in the multidimensionality of rhythmic processes. Additionally, exploring rhythmic abilities among individuals with conditions such as dyslexia or autism spectrum disorder may provide valuable insights into developing tailored interventions for those struggling with rhythm and related skills (Fiveash et al., 2022). These investigations would contribute to a deeper understanding of rhythmic processes which exist above and beyond methodological differences.

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Appendix A

Ethics Approval Letter

Western Research

Date: 16 December 2022

To: Dr. Jessica Grahn

Project ID: 104725

Review Reference: 2022-104725-74213

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

Application Type: HSREB Amendment Form

Review Type: Delegated

Full Board Reporting Date: 10/Jan/2023

Date Approval Issued: 16/Dec/2022 07:36

REB Approval Expiry Date: 09/Jan/2024

Dear Dr. Jessica Grahn ,

The Western University Health Sciences Research Ethics Board (HSREB) has reviewed and approved the WREM application form for the amendment, as of the date noted above.

Documents Approved:

Document Name	Document Type	Document Date
LOI_ConsentForms_104725_12-13-2022	Consent Form	13/Dec/2022
104725_GrahnProtocol_2022	Protocol	15/Dec/2022

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

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil 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 HSREB 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.

Electronically signed by:

Karen Gopaul , Ethics Officer on behalf of Dr. Philip Jones, HSREB Chair, 16/Dec/2022 07:36

Reason: I am approving this document.

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

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 1200 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.

OurBrainsCan Database:

If you would like to be contacted about future research studies for which you (or your child) may be eligible, you can choose to have your information entered into "OurBrainsCAN: University of Western Ontario's Cognitive Neuroscience Research Registry". This is a secure database of potential participants for research at the University of Western Ontario that aims to enroll 50,000 volunteers over a period of 5 years. The records are used only for the purpose of recruiting research participants and will not be released to any third party.

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

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: _____

Do you consent to entering your information into "OurBrainsCAN: University of Western Ontario's Cognitive Neuroscience Research Registry" (REB 111944) to be contacted about future research studies for which you (or your child) may be eligible?

Yes, I already signed-up ☐

Yes ☐

No ☐

Appendix D

Demographics Survey

1. What is your sex?
2. What is your age (in years)?
3. Handedness: Left, right, ambidextrous?
4. Do you have a hearing impairment? - No/Yes
5. Have you ever been diagnosed with a neurological or psychological disorder? No/Yes, Please Describe.
6. Are you currently taking any drugs or medications? - No/Yes, Please Describe.
7. First language learned as a child:
8. Other languages learned as a child (please include the age at which you learned each one). Enter NA if none.
9. Do you sing or play an instrument? No/Yes
10. What types of music have you practices (e.g., Classical, Jazz, Folk, etc.)?
11. What instrument(s) did you play, and for how many years (enter "voice" for singing)? Enter number of years for each listed instrument separately (e.g., cello=4 years, piano = 9 years).
12. Have you ever danced formally (e.g., hip-hop, ballroom, tap, etc.)?
13. What types of dance have you practiced, and for how many years? Enter number of years for each type of dance listed separately (e.g., tap=2 years, ballroom=5 years).
14. Can you read music?

Appendix E

Goldsmith Musical Sophistication Index

Scored using a 7-point agreement scale: Completely Agree, Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree, Completely Disagree

1. I spend a lot of my free time doing music-related activities.
2. I sometimes choose music that can trigger shivers down my spine.
3. I enjoy writing about music, for example on blogs and forums.
4. If somebody starts singing a song I don't know, I can usually join in.
5. I am able to judge whether someone is a good singer or not.
6. I usually know when I'm hearing a song for the first time.
7. I can sing or play music from memory.
8. I'm intrigued by musical styles I'm not familiar with and want to find out more.
9. Pieces of music rarely evoke emotions for me.
10. I am able to hit the right notes when I sing along with a recording.
11. I find it difficult to spot mistakes in a performance of a song even if I know the tune.
12. I can compare and discuss differences between two performances or versions of the same piece of music.
13. I have trouble recognizing a familiar song when played in a different way or by a different performer.
14. I have never been complimented for my talents as a musical performer.
15. I often read or search the internet for things related to music.
16. I often pick certain music to motivate or excite me.
17. I am not able to sing in harmony when somebody is singing a familiar tune.
18. I can tell when people sing or play out of time with the beat.
19. I am able to identify what is special about a given musical piece.

20. I am able to talk about the emotions that a piece of music evokes for me.

21. I don't spend much of my disposable income on music.

22. I can tell when people sing or play out of tune.

23. When I sing, I have no idea whether I'm in tune or not.

24. Music is kind of an addiction for me - I couldn't live without it.

25. I don't like singing in public because I'm afraid that I would sing wrong notes.

26. When I hear a music I can usually identify its genre.

27. I would not consider myself a musician.

28. I keep track of new of music that I come across (e.g. new artists or recordings).

29. After hearing a new song two or three times, I can usually sing it by myself.

30. I only need to hear a new tune once and I can sing it back hours later.

31. Music can evoke my memories of past people and places.

32. I engaged in regular, daily practice of a musical instrument (including voice) for ___ years.

33. At the peak of my interest, I practiced ___ hours per day on my primary instrument.

34. I have attended _ live music events as an audience member in the past twelve months.

35. I have had formal training in music theory for __ years

36. I have had __ years of formal training on a musical instrument (including voice) during my lifetime.

37. I can play ___ musical instruments

38. I listen attentively to music for __ per day.

39. The instrument I play best (including voice) is ____

Appendix F

Debriefing Form

Debriefing Form

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

Investigators:
<Name and contact information for co-investigator acting as contact person>

Dr. Jessica Grahn (Principal Investigator)
Department of Psychology, The University of Western Ontario, London, ON
Telephone: (519) 661-2111: Email: jgrahn@uwo.ca

Neuroimaging and neuropsychological studies have shown the involvement of areas of the brain involved in movement when passively listening to auditory stimuli that evoke a sense of the "beat" in musical rhythms (Grahn & Brett, 2007; Kung, Chen, Zatorre, & Penhune, 2013). The "beat" in music is the perceived pulse in rhythms that marks equally spaced intervals in time. Functional neuroimaging studies have shown activation of the supplementary motor area, the premotor cortex, and the cerebellum in motor performance, motor timing, and in perceiving the beat in music (Grahn & Brett, 2007; Kung, Chen, Zatorre, & Penhune, 2013). Although, these brain areas are known to be involved in motor planning, sequencing, and time perception, the functional role of these brain areas in beat perception remain unclear.

The aim of this project is to evaluate the neural mechanisms for beat perception and motor performance, by modulating excitability of brain areas thought to be involved in beat perception and motor performance using transcranial direct current stimulation (tDCS). By participating in this study, you have provided data that will help us to meet this goal. Your participation and responses are much appreciated.

If you have any further questions about this study please contact <Name and contact information for co-investigator acting as contact person> or Dr. Jessica Grahn (email: jgrahn@uwo.ca, office: NSC 229, number: 519 661 2111 ext. 84804).

If you have questions about your rights as a research participant, you should contact the Director of the Office of Research Ethics at ethics@uwo.ca or 519 661 3036.

For further information on this topic, you may wish to consult the following articles:

Relation between fMRI activation and rhythm perception:

J.A. Grahn, M. Brett. (2007). **Rhythm and beat perception in motor areas of the brain**. Journal of Cognitive Neuroscience, 19, 893-906.

J.A. Grahn, J.D. McAuley. (2009) **Neural bases of individual differences in beat perception**. NeuroImage, 47, 1894-1903.

J.A. Grahn, J.B. Rowe. (2009). **Feeling the beat: premotor and striatal interactions in musicians and non-musicians during beat perception**. Journal of Neuroscience, 29, 7540-7548.

Kung, S.J., Chen, J.L., Zatorre, R.J. & Penhune, V.B. (2013) **Interacting cortical and basal ganglia networks underlying finding and tapping to the musical beat**. Journal of Cognitive Neuroscience, 25, 401-420.