Re-Evaluating the Beat Alignment Test (BAT) and Proposing New Models

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Abstract

This thesis investigated the efficacy of the Perception subtest of The Beat Alignment Test (BAT) and created prototype models of an alternative test. The BAT is a commonly used test of beat perception in non-musicians. According to the model of Auditory Scene Analysis (ASA), the current version of the BAT is incompatible with the principles of Sequential Integration and may therefore be invalid and ineffective. The Perception Subtest consists of several song clips played simultaneously with a superimposed metronome. The metronome is shifted in some clips, which include ‘on beat,’ ‘phase shift,’ and ‘period shift’ conditions. For the purposes of this experiment, the degree of phase shift was increased by 25%. Four metronome conditions were tested: 1000Hz, 2000Hz, broadband, and custom frequency. A modified perceptual BAT consisting of 68 trials was administered to 20 participants of normal hearing. Contrary to prediction, the mean accuracy of the metronome conditions did not significantly differ. This experiment successfully altered the ‘phase shift’ percentage to achieve approximately equal accuracy to the ‘period shift’ trials. Future experiments containing modifications to the metronome frequency of the BAT may be beneficial in order to obtain valid and accurate measures of beat perception.

Keywords: beat alignment test, beat perception, auditory scene analysis, sequential integration

Acknowledgements and Dedication

I would like to dedicate this thesis to my grandmother, Mary Borntrager Reesor, who passed away just days before I completed this project (April 18th, 2017). She always encouraged me to pursue my dreams. Despite having the equivalent of an eighth grade education herself, she encouraged each of her children and grandchildren to obtain a university education. I know she was proud that I've nearly completed mine. I would also like to thank my supervisors Molly Henry and Jessica Grahn, and the rest of the Grahn Lab in the Brain and Mind Institute. Without their assistance and leadership this experiment would not have been possible. I'd like to give special thanks to Daniel Cameron for his help; Dan was instrumental regarding the coding and creation of audio files for this experiment. I'd like to thank Christina Vanden Bosch der Nederlanden for all of her editing and statistical help. She was prepared to answer any question, even at the very last minute. Lastly, I would like to thank Jana Celina Everling for her assistance with all things administrative.

Re-Evaluating the Beat Alignment Test (BAT) and Proposing New Models

Beat perception is the ability to perceive a periodic pulse or beat within a rhythm (Leow, Parrott, & Grahn, 2014). The majority of people are readily able to recognize a beat and nod their head, tap their feet, or clap their hands to the music. The ability to perceive rhythm or beat is nearly universal, but substantial differences exist in both individual beat perception and brain activation (Grahn & McAuley, 2009). The basal ganglia, cerebellum, premotor and supplementary motor areas are implicated in beat perception in all individuals (Grahn & Brett, 2009), and strong and weak beat perceivers differ in their neural activity when perceiving a beat. Beat perception extends to many areas of the brain, and measuring deficits in beat perception could provide information about potential neural dysfunction (Grahn & McAuley, 2009).

The motor cortex also plays a large role in auditory and beat perception. The auditory cortex and the motor cortex are so closely interlinked that the motor cortex is activated when listening to music, even in the absence of movement. Much of the current research on beat perception has been directed toward the therapeutic use of music for individuals with Parkinson's disease, who suffer from extremely diminished motor coordination and walking ability (Leow et al., 2014; Nombela et al., 2013).

The current research aims to re-evaluate the current procedures of the Beat Alignment Test (BAT), a widely used test battery designed to measure beat perception in non-musicians. The Beat Alignment Test (BAT) was one of the first of its kind. Since its implementation, other tests building on the original BAT have been created. Examples of these include the Harvard Beat Assessment Test (H-BAT), and the Battery for the Assessment of Auditory Sensorimotor Timing Abilities (BAASTA; Fujii & Schlaug, (2013). As the study of beat perception and rhythm processing is relatively new, the original BAT has not undergone many changes since its implementation (Iverson & Patel, 2008). A commonly used version of the original test is an adaptation by Goldsmiths University of London; it was modified to include song clips that are accessible in a copyright-free music library (Müllensiefen, Gingras, Stewart, & Musil, 2014). The present experiment will identify any necessary modifications of the Goldsmiths BAT and implement them by creating prototype models. It is important to measure beat perception accurately in order to learn more about its processes and its relation to neural dysfunction (Tranchant & Vuvan, 2015).

The Beat Alignment Test (BAT)

The Beat Alignment Test was developed by Iverson and Patel in 2008. It is a three-part test battery designed to measure beat perception in non-musicians. Its development was intended to create a norm of beat perception for the general population and to identify irregularities in beat perception. This experiment focuses on the third section of the BAT, which consists of the Production and Perception subtests. The Production subtest was designed as a traditional measure of beat perception: a song clip is played and a participant is asked to tap a keyboard key in order to produce their perception of the beat in time to the music. Each key tap is recorded and compared to the actual song beat, with high accuracy indicating high beat perception and low accuracy indicating low beat perception. This method of testing requires both accurate beat perception and accurate synchronization of keyboard tapping, therefore implicating both the auditory and motor cortices. The Perception subtest was designed to measure beat perception independent of motor synchronization. In this test, participants listen to a song clip over which a metronome has been superimposed. The metronome either aligns with the beat, is phase shifted with respect to the beat (meaning it is too early or too late), or is period shifted with respect to the beat (meaning it is too fast or too slow). After listening to each clip, participants are asked to indicate whether the metronome was ‘on’ or ‘off’ the beat of the music by pressing keyboard keys. With the use of this subtest, beat perception can be quantified while bypassing motor synchronization, therefore measuring beat perception only (Iversen & Patel, 2008).

The BAT was the first beat perception test to separate beat perception from motor synchronization. This has proven especially useful in research concerning individuals with motor irregularities (Iversen & Patel, 2008; Leow et al., 2014). For example, Parkinson’s disease results in degradation of the basal ganglia. This results in severely diminished motor coordination and walking ability, including a distinctly shuffled, jerky gait. It was thought that the involvement of the motor cortex caused individuals with Parkinson’s disease to perform poorly on previous tests of beat perception. Following the implementation of the BAT it was found that individuals with Parkinson’s disease have trouble identifying the beat even without motor involvement, indicating deficiencies in other rhythm processing capabilities. It was also found that variability in beat perception exists between individuals with Parkinson’s disease, indicating the existence of strong and weak beat-perceivers. This variability is important in the use of musical therapy as a form of gait rehabilitation for individuals with Parkinson’s disease. Leow et al. (2014) found that strong beat-perceivers tend to respond well to music as a form of gait rehabilitation. Weak beat-perceivers do not respond well to any music, particularly “low-groove” music, which has a non-obvious beat. Weak beat-perceivers had worsened gait when music was played, likely because their attempts to perceive the beat were distracting. The BAT is therefore an asset in music therapy, as therapy sessions can be tailored to individual beat perception capabilities.

Auditory Scene Analysis (ASA)

Sequential integration is a component of Auditory Scene Analysis, a model for the basis of auditory perception. Bregman’s model of Auditory Scene Analysis describes the perception of environmental sounds by the auditory system. In the environment, there are many sounds which occur at different frequencies, arise from different sources, and are emitted at different times. Humans hear all of these sounds mixed together, as a single pressure wave. In order to perceive sounds as distinct from one another they must be partitioned into different groups of sound, each one arising from a different source. Using this process, humans are able to distinguish individual sources and form distinct auditory streams or objects.

Auditory Scene Analysis consists of both Sequential Integration and Simultaneous Integration. Sequential Integration allows frequencies to be connected over time and recognized as the same or distinct streams. Simultaneous Integration allows frequencies emitted at the same time to be identified as one or more streams. Both principles are frequently described using the 'Cocktail Party' effect, the phenomenon which describes the ability to follow a single conversation when many are being conducted at the same time. In terms of auditory scene analysis, each person's voice would be considered to be a different stream. Simultaneous integration allows for distinction of different voices as belonging to different people. Sequential integration allows for the connection of words spoken by an individual and recognition of the words as a sentence spoken by said individual (Bee & Micheyl, 2008; Bregman, 1990; Bregman, 2008).

Sequential Integration

Sequential integration can be illustrated by the laboratory phenomenon of stream segregation. In stream segregation, a stimulus of two tones (high frequency and low frequency) is played in repeating triplets. At slow rates the triplets are heard as the same rhythm. If the rate increases and the frequencies are significantly different, the high and low frequencies are perceived as separate sequences or streams. With similar frequencies the triplets are perceived as the same stream, even with a high rate. It can be concluded that sounds are best perceived as coming from the same stream if they have similar frequencies and are heard at a slow rate (Bregman, 1990, Bregman, 2008). This concept can be directly applied to the Perception subtest of the BAT. It is proposed that the frequency of the metronome tone is too high compared to the songs played, resulting separate stream perception of the metronome and the song over which it is superimposed.

The Present Experiment

In accordance with the principles of Sequential Integration, it is postulated that the frequency of the metronome in the current version of the Perception subtest is too high compared to the music over which it is superimposed. As such, the metronome may be perceived as a different auditory stream than the song clip. If the two beats are perceived as different streams this test does not measure beat perception as intended, instead measuring the ability to hear and incorporate a high frequency tone into a song clip. This is an indication of low test validity.

In addition, it is proposed that the Perception subtest of the BAT is ineffective. The subtest consists of three conditions: ‘on beat’, ‘phase shift’, and ‘period shift’, or ‘stretch’. In raw data it has been observed that participants consistently perform much worse on the ‘phase shift’ trials compared to the ‘on beat’ or ‘period shift’ trials. Based on the available information, it is posited that the shift trials are too difficult compared to the other trials, making the perception subtest of the BAT an inaccurate test of beat perception.

This thesis aimed to create an alternative prototype of the BAT. The degree of phase shift was modified in order to make it more obvious. It was intended that participants’ accuracy of the ‘phase shift’ trials would approximate that of the ‘period shift’ trials (~70%). In addition, the frequency of the metronome was altered to encourage single-stream perception. Four alternative metronomes were tested: 1000Hz, 2000Hz, broadband sound, and a custom frequency metronome. The first independent variable was “Metronome Alterations” (within-subjects), the second independent variable was “Metronome Type” (within-subjects), and the dependent variable was the accuracy, or the proportion of correct answers for each condition. It was hypothesized that the mean accuracy of each metronome condition would significantly differ. The null hypothesis of this experiment was that the accuracy would not significantly differ across conditions, and the alternative hypothesis was that the accuracy would significantly differ between conditions, within each subject. It was also proposed that the mean accuracy of each manipulation condition would significantly differ. The second null hypothesis was that the accuracy would not significantly differ across conditions, and the alternative hypothesis was that the accuracy would significantly differ between conditions, within each subject.

Validating and improving the Beat Alignment Test is crucial in order to accurately test beat perception in both healthy individuals and those with motor processing deficits, such as individuals with Parkinson’s disease. Beat perceptual ability has also been correlated with childhood grammar ability, dyslexia, and even memory recall (Gordon et al., 2015; Muneaux, Ziegler, Truc, Thomson, & Goswami, 2004; Wallace, 1994). Accurate measurement of beat perception is instrumental regarding the identification and treatment of related deficits and advancement of the study of auditory processing as a whole. This study aimed to identify the areas of the BAT which require improvement, and the resultant prototype models may be used in future research. To date, no published data has compared the difficulty between trials within the Perception subtest. Tranchant and Vuvan (2015) emphasized the necessity of effective and specific assessment of rhythm perception, and described the BAT as “particularly promising.” In order to measure beat perception accurately and effectively, modifications to the Beat Alignment Test are necessary.

Method

Participants

Twenty University of Western Ontario undergraduate students (16 males, 4 females) ranging in age from 18 to 24 years (M = 18.7, SD = 1.49) participated in this experiment. Students registered in a first year introductory psychology course were selected via the Western University Department of Psychology Research Participation Pool. Students received course credit for their participation. All participants were required to have self-reported normal hearing. Participants completed this study individually. No participants were excluded from final analyses.

Of the twenty participants, 18 reported right-handedness and two reported left-handedness. Participants were asked how many years they had played a played a musical instrument (if any); responses ranged from zero to 14 years (M = 4.52, SD = 3.89). Participants were also asked to rate their musical skills/experiences on 6-point Likert scale ranging from 1 (*not skilled/experienced*) to 6 (*very skilled/experienced*). Participants' self-reported abilities ranged from 1 to 6 (M= 3.65, SD =1.60) (refer to Demographic Questionnaire, Appendix B).

This study was approved by the Western University Non-Medical Science Research Ethics Board (NMREB) on October 20th, 2016, under the name "Behavioural studies of rhythm and music perception" (refer to Appendix D). All participants provided written informed consent. Data collection was completed March 28th, 2017.

Materials and Procedure

The Modified Perception Alignment Test was adapted from v1.0 of the Beat Alignment Perception Task from the Goldsmiths Music Sophistication Index (Müllensiefen et al., 2014). There were 68 clips of nine songs, consisting of four metronome conditions (1000Hz, 2000Hz, broadband 'click,' custom frequency) and three metronome alteration conditions ('on beat,' 'phase shift,' 'period shift'). Each metronome condition was present over 17 song clips, in which four clips contained an 'on beat' condition, five clips contained a 'phase shift' condition, and eight clips contained a 'period shift' condition (16 total 'on beat,' 20 total 'phase shift,' 32 total 'period shift'; refer to Appendix C, Table 2).

The song clips consisted of 11 instrumental excerpts from three distinct genres (rock, jazz, pop orchestral) chosen from a copyright-free music library (refer to Appendix C, Table 3). For purposes of comparison, these song clips were the same as those used in v1.0 of the Beat Alignment Perception Task from the Goldsmiths Musical Sophistication Index. Each song clip was presented with a superimposed metronome tone of varying frequency. The present experiment consisted of four metronome conditions: 1000Hz sine-tone, 2000Hz sine-tone, a broadband 'click' (white noise), or custom frequency sine-tone. The original BAT as well as the Goldsmiths Beat Alignment Perception Task used 1000Hz as the metronome frequency; this was selected as a condition in the present experiment for purposes of comparison (Iverson & Patel, 2008; Müllensiefen et al., 2014). The 2000Hz sine-tone metronome was selected as a 'higher' frequency metronome, hypothesized to result in lower accuracy by the participants (fewer correct answers) as compared to the other metronome conditions. The broadband 'click' (white noise) was selected as it contains all frequencies; this intended to eliminate any issues of sequential integration thought to be present. The custom frequency metronome was created by averaging the frequency of all notes within each individual song; this metronome was selected on a 'per song basis' as the average frequency of all notes in each individual song.

The metronome alteration condition referred to the difference in timing between the metronome 'beeps' and the perceptual beat of each song. In the 'on beat' condition, the metronome beep was objectively the same as the perceptual beat of the song over which it was superimposed (the beep was created by a human and therefore cannot be said to be entirely without error). In the 'period shift' condition, the metronome beeps were 2% faster or slower than the song over which they were superimposed. In the 'phase shift' condition, the metronome beeps were ahead of the actual beat by either 12.5% or 21.9% of the actual beat. The phase shift percentages were generated via modification of the 10% and 17.5% shifts present in v1.0 of the Beat Alignment Perception Task from the Goldsmiths Music Sophistication Index (Müllensiefen et al., 2014). In previous experiments using this test, participants' accuracy (number of correct answers) in the 'phase shift' trials was consistently lower than that of the 'period shift' trials. Using a small pre-experimental group, the Goldsmiths phase shift percentage was increased by 1.1x, 1.2x, and 1.3x with the intention of achieving an accuracy of ~70%. The most effective variant of the original phase shift in obtaining a mean accuracy of ~70% was selected as 1.25x (or 25%), resulting in the experimental shift percentages of 12.5% and 21.9% of the metronome beat. Each of the 68 stimuli was created by modifying the original songs using MATLAB (matrix laboratory) software.

At the test's onset, two practice trials (one aligned, one tempo error) were presented, followed by 68 test trials. Immediately after the presentation of each song clip, participants were asked to evaluate whether the metronome beeps were "on" or "off" the beat of the music by pressing the "y" keyboard key to indicate yes and the "n" keyboard key to indicate no. Feedback was given for both practice trials, indicating if the correct answer was selected ("on" for the 'on beat' trial, "off" for the 'period shift' trial). Feedback was not given for the 68 test trials. Each stimulus was presented once, and stimulus order was randomly varied for each participant.

Participants were tested individually. After reading over a letter of information and signing an informed consent form (refer to Appendix A), participants were outfitted with Sennheiser over the ear noise-cancelling headphones connected to a Dell laptop. E-Run program of the E-Prime experimental software application suite was implemented for stimulus delivery and response collection. Participants were instructed to follow the on-screen prompts, and avoid moving or tapping their hands, feet or other body parts while completing the experiment (other than when necessary to complete the experiment). Upon completion of the study, participants completed a post-experiment questionnaire in addition to a demographic questionnaire, and were given a debriefing form (refer to Appendix B). The experiment took approximately 40 min.

Results

The null hypothesis of this experiment was that the accuracy would be the same across all conditions, and the alternative hypothesis was that the accuracy would differ between conditions. The independent variables included metronome type (within-subjects; four levels: 1000Hz, 2000Hz, broadband, custom frequency) and metronome alteration (within-subjects; three levels: on beat, phase shifted, period shifted). The dependent variable was the accuracy, or percentage of correct answers for each song. The proportion of correct responses for all participants was submitted to a 4 metronome (1000Hz, 2000Hz, broadband, custom frequency) x 3 manipulation type ('on beat,' 'phase shift,' 'period shift') within-subjects analysis of variance (ANOVA).

This ANOVA revealed only a significant main effect of manipulation type on accuracy, $F(2, 38) = 19.53$, $p < .001$, $\eta_p^2 = 0.51$. Manipulation type influenced how well participants were able to notice whether the metronome was on or off the perceptual beat (see Figure 1). There was no significant main effect of metronome type on accuracy, $F(3, 57) = 1.04$, $p = 0.38$, $\eta_p^2 = 0.05$. Metronome type did not influence how well participants were able to notice whether the metronome was on or off the perceptual beat (see Figure 2).

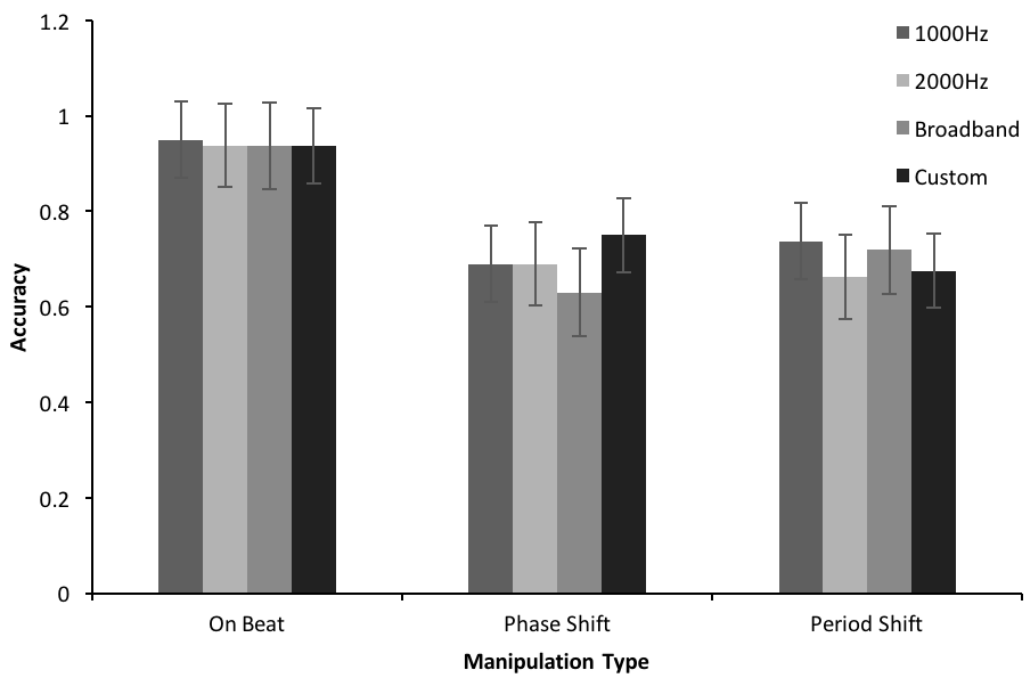

Figure 1. Mean accuracy (percentage) of correct answers as a function of metronome type and manipulation type. Error bars represent standard error.

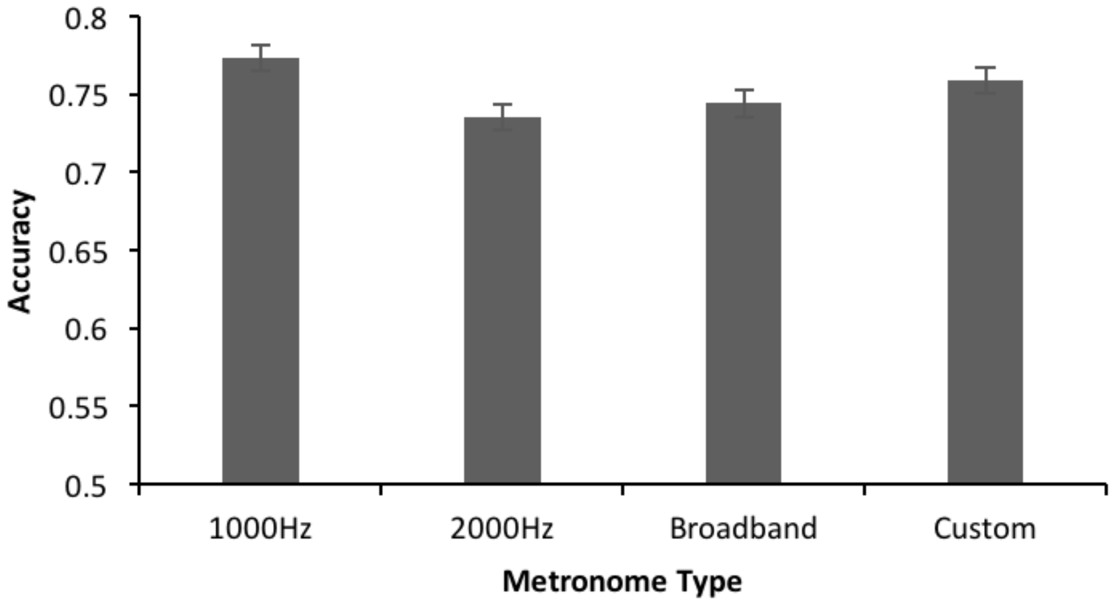

Figure 2. Mean accuracy (percentage) of correct answers as a function of metronome type. Error bars represent standard error.

There was no significant interaction between metronome type and manipulation type, $F(6, 114) = 1.549$, $p = .169$, $\eta_p^2 = 0.08$, which suggests that the effects of metronome type do not depend on the type of manipulation, and the effects of manipulation do not depend on metronome type. Since there was no interaction between metronome and manipulation type, a Tukey's honest significance difference (HSD) post hoc analysis was performed to examine the effect of manipulation type across all metronome conditions. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the on beat condition ($M = 0.94$, $SD = 0.13$) was significantly different ($p < .001$) than the phase shift condition ($M = 0.69$, $SD = 0.30$) and the period shift condition ($M = 0.70$, $SD = 0.25$) (see Table 1). However, the phase shift condition did not significantly differ ($p = .98$) from the period shift condition (see Figure 1). Participants' accuracy was similar for the 'phase shift' and 'period shift' conditions, but accuracy in both conditions was much lower as compared to the 'on beat' condition.

Table 1

Means and Standard Deviations of Accuracy on the Modified Perceptual BAT as a Function of Both Metronome Type and Manipulation Type

	Metronome Type									
	1000Hz		2000Hz		Broadband		Custom		Overall	
Manipulation	M	SD	M	SD	M	SD	M	SD	M	SD
On Beat	0.95	0.13	0.94	0.11	0.94	0.14	0.94	0.14	0.94*	0.13
Phase Shift	0.69	0.31	0.69	0.29	0.63	0.33	0.75	0.25	0.69	0.30
Period Shift	0.74	0.24	0.66	0.27	0.72	0.27	0.68	0.25	0.70	0.25
Overall	0.79	0.30	0.76	0.27	0.76	0.28	0.79	0.24	0.75	0.19

Note. Accuracy is a percentage of correct answers.

*$p < .01$. Indicates ‘on beat’ and ‘phase shift’ significantly differ, and ‘on beat’ and ‘period shift’ significantly differ.

Discussion

The main hypothesis of this experiment predicted that the mean participants’ accuracy would differ between metronome conditions. There was no main effect of metronome condition on accuracy, and thus this hypothesis was disproved. The secondary hypothesis of this experiment predicted that the mean participants’ accuracy would differ between manipulation conditions. There was a main effect of manipulation condition on accuracy, but this was to be expected. When the Perception subtest of the BAT was used in previous experiments, participants generally performed much better on the ‘on beat’ conditions as compared to the ‘phase shift’ and ‘period shift’ conditions. Despite finding no main effect of metronome condition, one objective of this thesis was satisfied: participants’ accuracy in the ‘phase shift’ conditions did not differ significantly from participants’ accuracy in the ‘period shift’ conditions. In prior use of the BAT, participants performed much more poorly on the ‘phase shift’ condition as compared to the other conditions. This experiment intended to modify the degree of metronome shift in order to reach comparable accuracies for the ‘phase shift’ and ‘period shift’ conditions, of ~70%. In Figure 2, it can be seen that the mean accuracy for all ‘phase shift’ conditions was 69%, and the mean accuracy for all ‘period shift’ conditions was 70%.

Although well-reasoned and consistent with ASA and sequential integration, none of the metronome tones proved to result in significantly different accuracy. The 2000Hz metronome was selected specifically to demonstrate the accordance of sequential integration; if the frequency of the metronome was very different from the music over which it was superimposed, it would make it more difficult to perceive them as coming from the same source and thus reduce participants’ accuracy.

The broadband sound in this experiment was selected because it contains all frequencies, posited to thereby eliminate the problem of sequential integration. In theory this would have been a solution, but the actual metronome sound was muffled and not very clear. Future experiments could attempt to generate a broadband metronome using a different medium, and potentially increase the volume to encourage clarity of sound. Some participants reported that they found this condition to be the most difficult, which was not the intention of this experiment. As the metronome accuracies were not significantly different, it is evident that this metronome was not more effective than the original 1000Hz metronome tone.

Although the custom metronome tone was hypothesized to be more effective, participants’ accuracy did not significantly differ from the other metronomes. The custom frequency tone was created by calculating the mean frequency of all tones within each song. This was theorized to reduce the difference in frequency between the metronome and song, encouraging single-stream perception. A decrease in volume was not controlled for in this condition, and participants reported that they perceived the metronome tone as quieter than the music, making it more difficult to perceive the beat.

Future experiments should make use of metronomes with slightly lower frequency than 1000Hz, in addition to controlling for volume loss if a custom frequency metronome is used. In addition, a broadband tone generated in a different context may be more effective, emphasizing a clear beat. Lastly, a metronome with even higher frequency than 2000Hz should be used in order to exemplify the drop in accuracy proportional to the frequency difference of the metronome and song. Although not statistically significant, the 2000Hz metronome did have slightly lower accuracy than the 1000Hz metronome (Figure 2), indicating that a reduction in the metronome frequency may help increase accuracy.

Measuring beat perception accurately and effectively is crucial to understanding the areas of the brain that are implicated in certain neural dysfunctions, and for determining the most viable form of treatment in conditions such as Parkinson’s disease. Future research should be directed towards creating a valid and more effective BAT.

References

Bee, M. A., & Micheyl, C. (2008). The "Cocktail Party Problem": What is it? How can it be solved? And why should animal behaviourists study it? *Journal of Comparative Psychology, 122*(3), 235-251. doi:10.1037/0735-7036.122.3.235

Bregman, A. S. (2008). Auditory scene analysis. *Encyclopedia of Neuroscience,* 729-736. Oxford, UK: Academic Press.

Bregman, A. S. (1990). *Auditory scene analysis: The perceptual organization of sound*. Cambridge, MA: MIT Press.

Fujii, S., & Schlaug, G. (2013). The Harvard Beat Assessment Test (H-BAT): a battery for assessing beat perception and production and their dissociation. *Frontiers in Human Neuroscience, 8*(771). doi:10.3389/fnhum.2013.00771

Gordon, R. L., Shivers, C. M., Wieland, E. A., Kotz, S. A., Yoder, P. J., McAuley, J. D. (2015). Musical rhythm discrimination explains individual differences in grammar skills in children. *Developmental Science, 18*(4), 635-644. doi: 10.1111/desc.12230

Grahn, J. A., & Brett, M. (2008). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex, 45*(1), 54-61. doi:10.1016/j.cortex.2008.01.005

Grahn, J. A., & Mcauley, J. D. (2009). Neural bases of individual differences in beat perception. *NeuroImage, 47*(4), 1894-1903. doi:10.1016/j.neuroimage.2009.04.039

Iverson, J. R., & Patel, A. D. (2008). The Beat Alignment Test (BAT): Surveying beat processing abilities in the general population. *Proceedings of the 10th International Conference on Music Perception and Cognition (ICMPC10)*.

Leow, L., Parrott, T., & Grahn, J. A. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Müllensiefen, D., Gingras, B., Stewart, L., & Musil, J. (2014). The Goldsmiths Musical Sophistication Index (Gold-MSI): Technical Report and Documentation v1.0. London: Goldsmiths, University of London.

Muneaux, M., Ziegler, J. C., Truc, C., Thomson, J., Goswami, U. (2004). Deficits in beat perception and dyslexia: Evidence from French. *Neuroreport, 15*(8), 1255-1259. doi: 10.1097/01.wnr.0000127459.31232.c4

Nombela, C., Hughes, L. E., Owen, A. M., & Grahn, J. A. (2013). Into the groove: Can rhythm influence Parkinson's disease? *Neuroscience and Biobehavioural Reviews.* doi:10.1016/j.neubiorev.2013.08.003

Tranchant, P., & Vuvan, D. T. (2015). Current conceptual challenges in the study of rhythm processing deficits. *Frontiers in Neuroscience, 9*. doi:10.3389/fnins.2015.00197

Wallace, W. T (1994). Memory for music: Effect of melody on recall of text. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(6), 1471-1485. doi: 10.1037/0278-7393.20.6.1471

Appendix A

Letter of Information & Informed Consent

Behavioral studies of rhythm and music perception

Principal Investigator: Dr. Jessica Grahn

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Introduction

You are being invited to participate in a research study about human perception of music and rhythm. The purpose of this study is to investigate how humans perceive rhythm and music, and how rhythm and music might change our experience of or memory for other sights and sounds.

The purpose of this letter is to provide you with information required for you to make an informed decision regarding participation in this research. It is important for you to understand why the study is being conducted and what it will involve. Please take the time to read this carefully, and feel free to ask questions if anything is unclear or if there are words or phrases you do not understand.

Research Procedures

The experiments conducted as part of this study will test how humans hear, see, remember, and move when they listen to auditory rhythms (including music) or see visual rhythms. If you agree to participate, you will be asked to listen to or watch rhythmic stimuli. You may be asked to make simple responses about whether you detect the presence of or differences between stimuli, to tap, bounce, or walk in time with the stimuli, and/or to make ratings about your impressions of the stimuli. You might also be asked to perform a task testing your memory or attention while you are listening to music. Finally, your brain activity might be recorded using a technique called electroencephalography (EEG), where electrodes placed on the scalp measure electrical signals that brain cells use to communicate. It is anticipated that the entire task will take no more than 3 hours. The task(s) will be conducted in the Brain and Mind Institute in the Natural Sciences building, the Social Sciences Building, or the Robarts Research Institute on the University of Western Ontario campus. There will be a total of 750 participants.

Inclusion and Exclusion Criteria

Individuals who are at least 17 years of age having hearing and vision adequate to perform the task are eligible to participate in this study. Individuals who are younger than 17 years of age or who have hearing damage or vision problems too severe to complete the task will be excluded.

Risks and Benefits

There are no known or anticipated risks or discomforts associated with participating in this study. Although you may not directly benefit from participating in this study, the information gathered may provide benefits to society as a whole which include enhancing our scientific understanding of music perception and leading to advancements in medical care (for example, disorders like Parkinson’s disease).

Compensation

You will receive course credit (1 credit per hour) or monetary compensation ($5 per half-hour) for your participation in this study. If you do not complete the entire study you will still be compensated a pro-rated amount.

Voluntary Participation

Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect on your future academic status.

Confidentiality

Any information obtained from this study will be kept confidential and will be accessible only to the investigators of this study. In the event of publication, any data resulting from your participation will be identified only by case number, without any reference to your name or personal information. The data will be stored on a secure computer in a locked room. Both the computer and the room will be accessible only to the investigators. After completion of the experiment, data will be archived on storage disks and stored in a locked room. Any documents identifying you by name will be kept separately from your data, and will be destroyed after 5 years.

Representatives of the University of Western Ontario Health Sciences Research Ethics Board may require access to your study-related records or may follow up with you to monitor the conduct of the study.

Contacts for Further 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.

If you have any questions about your rights as a research participant or the conduct of the study you may contact:

The Office of Research Ethics

The University of Western Ontario

519-661-3036

E-mail: ethics@uwo.ca

This letter is yours to keep for future reference.

<u>Consent Form</u>

Project Title: Behavioral studies of rhythm and music perception

Study Investigator's Name: Dr. Jessica Grahn

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.

Participant's Name (please print): ______________________________

Participant's Signature: ______________________________

Date: ______________________________

Person Obtaining Informed Consent (please print): ______________________________

Signature: ______________________________

Date: ______________________________

Debriefing Form

Title of research: Behavioral studies of rhythm and music perception

Investigators:

Stephanie Reesor

Email: sreesor3@uwo.ca

Dr. Jessica Grahn (Principal Investigator)

Department of Psychology, The University of Western Ontario, London, ON

Telephone: (519) 661-2111 ext. 84804

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Perception of rhythms is fundamental to normal hearing, speech, motor control, and music. However, sensitivities to certain patterns depend both on physical characteristics of the rhythm like modality (auditory, visual; Grahn, Henry, & McAuley, 2011; Grahn, 2012) and event timing (Grahn & Brett, 2007) as well as on individual differences such as musical expertise/training and exposure (Cameron & Grahn, 2014; Grahn & Rowe, 2009), auditory short-term memory (Grahn & Schuit, 2012), and activation (as measured by fMRI) in specific brain areas thought to underlie beat perception (Grahn & McAuley, 2009). Differences timing/rhythm abilities translate to differences in the ability to perceive, synchronize with, remember, or reproduce rhythmic stimuli (Grahn & Brett, 2007; Leow et al., 2014) or potentially even to the ability to understand spoken and written language (Gordon et al., 2014; Muneaux et al., 2004). Moreover, physical and subjective characteristics of music can affect specific cognitive functions like working memory and attention (Wallace, 1994).

The purpose of this large-scale project is to understand the reciprocal interactions between music, timing and rhythm abilities, movement, perception/cognition, and brain activity. 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 Stephanie Reesor (email: sreesor3@uwo.ca) 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 modality (auditory vs. visual) and rhythm perception:

J.A. Grahn, M. J. Henry, J.D. McAuley. *FMRI investigations of cross-modal interactions in beat perception: Audition primes vision, but not vice versa* (2011). NeuroImage 54:1231-43.

J.A. Grahn. *See what I hear? Beat perception in auditory and visual rhythms* (2012). Experimental Brain Research, 220:51-61.

Relation between event timing and rhythm perception:

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

Relation between musical training/expertise and rhythm perception:

D.J. Cameron, J.A. Grahn. *Enhanced timing abilities in percussionists generalize to rhythms without a musical beat* (2014). Frontiers in Human Neuroscience, 8:1003, doi: 10.3389/fnhum.2014.01003

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

Relation between auditory short-term memory, musical training, and rhythm perception:

J.A. Grahn, D. Schuit. *Individual differences in rhythmic abilities: behavioural and fMRI investigations* (2012). Psychomusicology: Music, Mind, & Brain 22:105-121.

Relation between fMRI activation and rhythm perception:

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

Relation between individual differences and synchronization abilities:

L.-A. Leow, T. Parrot, J. A. Grahn**.** *Individual differences in beat perception affect gait responses to low- and high-groove music* (2014). Frontiers in Human Neuroscience, 8:811. doi: 10.3389/fnhum.2014.00811

Relation between rhythm perception abilities and spoken language understanding:

R.L. Gordon, C.M. Shivers, E.A. Wieland, S.A. Kotz, P.J. Yoder, J.D. McAuley. *Musical rhythm discrimination explains individual differences in grammar skills in children* (2014). Developmental Science. doi: 10.1111/desc.12230

M. Muneaux, J.C. Ziegler, C. Truc, J. Thomson, U. Goswami. *Deficits in beat perception and dyslexia: Evidence from French* (2004). NeuroReport, 15:1255-1259.

Relation between music and memory performance:

W.T. Wallace. *Memory for music: Effect of melody on recall of text* (1994). Journal of Experimental Psychology: Learning, Memory, & Cognition, 20: 1471-1485.

Appendix B

Post-Experiment Questionnaire

Questionnaire

(Please circle the number you select)

Important: You are free to leave any question blank

1. How well did you understand the task?

1 2 3 4 5 6

(1 = I understood very well what the task was. 6 = I did not understand the task.)

2. How difficult did you find the task?

1 2 3 4 5 6

(1 = The task was very easy. 6 = The task was very difficult.)

3. How strongly did you concentrate on the task?

1 2 3 4 5 6

(1 = I was highly concentrated. 6 = I was not concentrated.)

4. Did your concentration on the task changed throughout the experiment?

1 2 3 4 5 6

(1 = My concentration did not change. 6 = My concentration strongly changed.)

4b. If your concentration changed, in which direction did it change?

1 2 3 4 5 6

(1 = My ability to concentrate improved throughout the experiment.

6 = My ability to concentrate declined throughout the experiment.)

5. Were there occasions where you guessed when responding?

1 2 3 4 5 6

(1 = I almost never guessed. 6 = I almost always guessed.)

6. How motivated were you for the experiment?

1 2 3 4 5 6

(1 = I was not motivated. 6 = I was highly motivated.)

7. Did you use/develop any specific strategies during the experiment to solve the task?

□ Yes □ No

If yes, please describe briefly:

____

____

____

10. Do you have additional comments regarding the experiment?

Post-Experiment Demographic Questionnaire

Demographic information

Important: You are free to leave any question blank

Are you (circle one): Male Female

Age: ____________________

Which hand do you write with (circle one): Right Left

What level did you attain in school (please check one):

□ Elementary School

□ Less than Grade 12

□ High school diploma

□ Some university undergraduate schooling

□ College Degree (2 years)

□ Bachelor's degree

□ Postgraduate degree

□ Other (please specify): ____

What is your first language? _____________________________________

What other languages do you know?

Please also rank the degree of fluency (1 – very fluent, 6 – Slightly).

____

____

How would you describe your musical skills/experiences (please cycle one number)?

(not skilled/experienced) 1 2 3 4 5 6 (very skilled/experienced)

Have you ever played a musical instrument? Yes No

If yes, which instrument(s)?

____

For how many years did/have you played? _______________________

What type of training did you receive? (ex. conservatory, private lessons, self-taught)?

____

Are you currently practicing music? Yes No

If yes, how many hours per week do you practice? ____

How important is music to your identity?

(not important) 1 2 3 4 5 6 (very important)

Do you wear a hearing aid? No Right Left Both

Do you have ringing in your ears? Sometimes Always Never

If YES, which ear(s)? Both Left Right

How would you describe your general hearing abilities (please circle one number)?

(bad) 1 2 3 4 5 6 (good)

When you talk with someone at a place that strongly reverberates/echoes (e.g., in a church or train station), can you understand what the person says?

(not at all) 0 … 1 … 2 … 3 … 4 … 5 … 6 … 7 … 8 … 9 … 10 (perfectly)

When you are with a group (~5 people) in a lively restaurant, can you follow the group's conversation?

(not at all) 0 … 1 … 2 … 3 … 4 … 5 … 6 … 7 … 8 … 9 … 10 (perfectly)

Based on the sound of a bus or truck, can you tell whether it is moving towards or away from you?

(not at all) 0 … 1 … 2 … 3 … 4 … 5 … 6 … 7 … 8 … 9 … 10 (perfectly)

When you are in an unknown environment, can you tell from which direction a brief sound originates?

(not at all) 0 … 1 … 2 … 3 … 4 … 5 … 6 … 7 … 8 … 9 … 10 (perfectly)

Are you able to ignore distracting sound when you concentrate on a specific aspect of your acoustic surrounding?

(not at all) 0 … 1 … 2 … 3 … 4 … 5 … 6 … 7 … 8 … 9 … 10 (perfectly)

Appendix C

Table 2

Experimental BAT Stimuli

Stimulus No.	Song No.	Name (abbr.)	Genre	Tempo	Metronome Type	Alteration	Shift Direction	Shift %
1	1	Crazy	Jazz	165	1000Hz	Tempo	Faster	2
2	5	Lord	Pop/Orch	165	1000Hz	Tempo	Faster	2
3	4	King	Pop/Orch	85	1000Hz	Tempo	Slower	2
4	2	Freedom	Pop/Orch	132	1000Hz	Phase	Ahead	21.9
5	2	Freedom	Pop/Orch	132	1000Hz	Tempo	Slower	2
6	2	Freedom	Pop/Orch	132	1000Hz	None	-	-
7	3	Hedgehog	Jazz	142	1000Hz	Phase	Ahead	21.9
8	3	Hedgehog	Jazz	142	1000Hz	Tempo	Slower	2
9	3	Hedgehog	Jazz	142	1000Hz	None	-	-
10	8	Sassy	Jazz	115	1000Hz	Phase	Ahead	12.5
11	8	Sassy	Jazz	115	1000Hz	Tempo	Slower	2
12	7	Psyched	Rock	143	1000Hz	Tempo	Faster	2
13	7	Psyched	Rock	143	1000Hz	None	-	-
14	9	Switch	Rock	159	1000Hz	Phase	Ahead	21.9
15	6	Prime	Rock	104	1000Hz	Phase	Ahead	12.5
16	6	Prime	Rock	104	1000Hz	Tempo	Faster	2
17	6	Prime	Rock	104	1000Hz	None	-	-
18	1	Crazy	Jazz	165	2000Hz	Tempo	Faster	2
19	5	Lord	Pop/Orch	165	2000Hz	Tempo	Faster	2
20	4	King	Pop/Orch	85	2000Hz	Tempo	Slower	2
21	2	Freedom	Pop/Orch	132	2000Hz	Phase	Ahead	21.9
22	2	Freedom	Pop/Orch	132	2000Hz	Tempo	Slower	2
23	2	Freedom	Pop/Orch	132	2000Hz	None	-	-
24	3	Hedgehog	Jazz	142	2000Hz	Phase	Ahead	21.9
25	3	Hedgehog	Jazz	142	2000Hz	Tempo	Slower	2
26	3	Hedgehog	Jazz	142	2000Hz	None	-	-

27	8	Sassy	Jazz	115	2000Hz	Phase	Ahead	12.5
28	8	Sassy	Jazz	115	2000Hz	Tempo	Slower	2
29	7	Psyched	Rock	143	2000Hz	Tempo	Faster	2
30	7	Psyched	Rock	143	2000Hz	None	-	-
31	9	Switch	Rock	159	2000Hz	Phase	Ahead	21.9
32	6	Prime	Rock	104	2000Hz	Phase	Ahead	12.5
33	6	Prime	Rock	104	2000Hz	Tempo	Faster	2
34	6	Prime	Rock	104	2000Hz	None	-	-
35	1	Crazy	Jazz	165	Broadband	Tempo	Faster	2
36	5	Lord	Pop/Orch	165	Broadband	Tempo	Faster	2
37	4	King	Pop/Orch	85	Broadband	Tempo	Slower	2
38	2	Freedom	Pop/Orch	132	Broadband	Phase	Ahead	21.9
39	2	Freedom	Pop/Orch	132	Broadband	Tempo	Slower	2
40	2	Freedom	Pop/Orch	132	Broadband	None	-	-
41	3	Hedgehog	Jazz	142	Broadband	Phase	Ahead	21.9
42	3	Hedgehog	Jazz	142	Broadband	Tempo	Slower	2
43	3	Hedgehog	Jazz	142	Broadband	None	-	-
44	8	Sassy	Jazz	115	Broadband	Phase	Ahead	12.5
45	8	Sassy	Jazz	115	Broadband	Tempo	Slower	2
46	7	Psyched	Rock	143	Broadband	Tempo	Faster	2
47	7	Psyched	Rock	143	Broadband	None	-	-
48	9	Switch	Rock	159	Broadband	Phase	Ahead	21.9
49	6	Prime	Rock	104	Broadband	Phase	Ahead	12.5
50	6	Prime	Rock	104	Broadband	Tempo	Faster	2
51	6	Prime	Rock	104	Broadband	None	-	-
52	1	Crazy	Jazz	165	Custom	Tempo	Faster	2
53	5	Lord	Pop/Orch	165	Custom	Tempo	Faster	2
54	4	King	Pop/Orch	85	Custom	Tempo	Slower	2
55	2	Freedom	Pop/Orch	132	Custom	Phase	Ahead	21.9
56	2	Freedom	Pop/Orch	132	Custom	Tempo	Slower	2
57	2	Freedom	Pop/Orch	132	Custom	None	-	-

58	3	Hedgehog	Jazz	142	Custom	Phase	Ahead	21.9
59	3	Hedgehog	Jazz	142	Custom	Tempo	Slower	2
60	3	Hedgehog	Jazz	142	Custom	None	-	-
61	8	Sassy	Jazz	115	Custom	Phase	Ahead	12.5
62	8	Sassy	Jazz	115	Custom	Tempo	Slower	2
63	7	Psyched	Rock	143	Custom	Tempo	Faster	2
64	7	Psyched	Rock	143	Custom	None	-	-
65	9	Switch	Rock	159	Custom	Phase	Ahead	21.9
66	6	Prime	Rock	104	Custom	Phase	Ahead	12.5
67	6	Prime	Rock	104	Custom	Tempo	Faster	2
68	6	Prime	Rock	104	Custom	None	-	-

Table 3

Original Song List

Song No.	Style	Piece	Artist	Link to Original Sound File
1	Jazz	Crazy	Tim Garland	https://www.audionetwork.com/browse/m/track/crazy_5197
2	Pop Orchestral	Freedom of the City	Ray Davies	https://www.audionetwork.com/browse/m/track/freedom-of-the-city_35540
3	Jazz	Four Handed Hedgehog	Chris Egan	https://www.audionetwork.com/browse/m/track/four-handed-hedgehog_33902
4	Pop Orchestral	For King and Country	Terry Devine-King	https://www.audionetwork.com/browse/m/track/for-king-and-country_29632
5	Pop Orchestral	Lord Arbinger Waltz	Debbie Wiseman	https://www.audionetwork.com/browse/m/track/lord-abinger-waltz_19351
6	Rock	Prime Rib	Adam Drake/Neil Williams	https://www.audionetwork.com/browse/m/track/prime-rib_15643
7	Rock	Psychedelic Space	Igor Dvorkin/ Duncan Pittock	https://www.audionetwork.com/browse/m/track/psychedelic-space_9831
8	Jazz	Sassy Stomp	Terry Devine-King	https://www.audionetwork.com/browse/m/track/sassy-stomp_26241
9	Rock	Switchblade	Barrie Gledden	https://www.audionetwork.com/browse/m/track/switchblade-2_14006
10	Pop Orchestral	One Jump Ahead (example)	Ray Davies	https://www.audionetwork.com/browse/m/track/one-jump-ahead_35559
11	Jazz	Roaring Twenties (example)	Terry Devine-King	https://www.audionetwork.com/browse/m/track/roaring-twenties_26259
12	Rock	Never Going Back Again (example, omitted)	Chris Norton	https://www.audionetwork.com/browse/m/track/never-going-back-again_17255

Appendix D

Research Ethics

Western University Non-Medical Research Ethics Board
NMREB Amendment Approval Notice

Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,Western University

NMREB File Number: 106385
Study Title: Behavioral studies of rhythm and music perception
Sponsor: Natural Sciences and Engineering Research Council

NMREB Revision Approval Date: October 20, 2016
NMREB Expiry Date: March 30, 2017

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Revised Letter of Information & Consent		2016/07/27
Recruitment Items	SONA recruitment text	2016/07/27
Revised Western University Protocol	Submitted Oct 11, 2016	
Recruitment Items	email recruitment text	2016/07/27
Recruitment Items	flyer	2016/07/27

The Western University Non-Medical Science Research Ethics Board (NMREB) has reviewed and approved the amendment to the above named study, as of the NMREB Amendment Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Ethics Officer, on behalf of Dr. Riley Hinson, NMREB Chair

Ethics Officer: Erika Basile ___ Katelyn Harris___ Nicole Kaniki ___ Grace Kelly___ Vikki Tran ___ Karen Gopaul ___

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