The Relationship Between Musical Sophistication and Rhythmic Entrainment to Musical Beat: an EEG Study

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Abstract

Past research in the field of music cognition has tended to use musicianship status as a method to classify individuals according to their musical ability; however, there is a distinct problem with this approach (Bigand & Poulin-Charronnat, 2006; Doelling & Poeppel, 2015; Grahn & Rowe, 2009; Matthews et al., 2016; Repp & Doggett, 2007). It leaves those with untraditional music experiences or untapped natural abilities inappropriately grouped or ignored altogether. For this reason, the present study has chosen to investigate music sophistication—a more comprehensive classification that assesses musical ability on dimensions beyond a simple history of music training—as it relates to rhythmic entrainment. This study examined whether greater musical sophistication was related to better behavioural and neural entrainment task performance. Participants completed the *Gold-MSI* and the *Mini-PROMS* to assess musical sophistication, and a Sustained Beat Task (SBT) to assess entrainment via tapping responses and Steady State Evoked Potential (SSEP) strength. Higher musical sophistication scores were related to more consistent and in-time taps with the beat; however, contrary to our expectations, musical sophistication was negatively related to SSEP amplitudes. These findings demonstrate the importance of using a comprehensive measure of musical ability while also highlighting the need for future research to further investigate the relationship between SSEP power and beat perception.

Acknowledgements

I would like to express my sincerest gratitude to my wonderful supervisors Dr. Jessica Grahn, Dr. Karli Nave, and Riya Sidhu for their invaluable mentorship and guidance throughout this project. From the creation of the project and showing me the ropes of neuroimaging and music cognition research, to data collection and analysis, I can't imagine working with anyone else. Secondly, I would like to thank the members of the Grahn lab for their feedback and support on my presentations throughout the year, it has been a privilege and an amazing learning experience being a part of this team. Additionally, I would like to thank my research partner Caitlynn van Kralingen, I am eternally grateful to have had such an amazing partner-in-crime throughout this past year. Finally, I would like to thank all my friends and family for supporting me this past year. I couldn't have done it without all your continued love and support.

Statement of Contribution

I developed the research question for this project under the guidance of Dr. Karli Nave and her larger individual differences project. Between October 2024 and March 2025, I completed data collection jointly with Caitlynn van Kralingen, an honours thesis student from the Grahn Lab. Dr. Nave created stimuli for the Sustained Beat Task and coding scripts. Together, we analyzed tap and neural data using JASP. I completed the final written report under the guidance and feedback of Dr. Nave and Riya Sidhu.

The Relationship Between Musical Sophistication and Rhythmic Entrainment to Musical Beat: an EEG Study

From watching the Rolling Stones live to listening to Beethoven's Moonlight Sonata from the comfort of your own home, music has the universal ability to make people want to move along with it (Honing, 2012). For some, a near-automatic response when hearing music is to dance or move along with the beat. However, even for those who do not make an effort to move to the music, listeners often remain attuned to the underlying musical structure of the piece. The question many researchers have attempted to answer is; What is responsible for an individual's ability to isolate and recognize the rhythmic elements of music? Before introducing our study and exploring this question ourselves, we will review the literature on beat perception, then discuss ways to classify musical skills, and finally, review the relevance of entrainment as it relates to musical abilities.

What is Beat?

Beats are a fundamental component of musicality and are involved in the construction and perception of music as we know it. In essence, a musical beat is a repetitive pulse-like pattern that structures the rhythm of a piece (Parncutt, 1994). Individuals are usually synchronizing with this pulsing pattern when tapping along to a song. While these behaviours often appear effortless, the intricacies behind beat perception are far from simple. *Beat perception* is a complex cognitive task requiring coordination from the brain's auditory and motor areas (Grahn & Rowe, 2009). These two regions communicate back and forth to process and predict the beat. When a beat is perceived, the auditory region sends signals to supplementary motor regions, triggering responses to the stimulus through increased brain activity. This complex process is believed to conclude when the stimulus-response sends a signal back to the auditory cortex, where the information may then be used to predict the arrival/timing of future beats' arrival (Iversen & Patel, 2014). To add to the complexity of musical structure is the hierarchical nature of beat, where multiple levels of nested beats can be embedded in a song (Bigand & Poulin-Charronnat, 2006). This layered pattern, also known as the beat pattern, is responsible for the distinction between strong beats and weak beats. It is evident that beat perception is a complex task, leaving room for immense variability in performance, but what makes some individuals a better beat perceiver than another?

Musical Classification

In the past, many have compared data from musicians against non-musicians to explain the individual differences in performance on beat-based perception tasks and neural entrainment measures (Bigand & Poulin-Charronnat, 2006; Doelling & Poeppel, 2015; Grahn & Rowe, 2009; Matthews et al., 2016; Repp & Doggett, 2007). In an effort, to measure the differences in neural entrainment—synchrony of cortical activity to external stimuli—to rhythmic structure, researchers have found that metrical complexity can account for some of the variation in performance. Notably, they found that when the detailed rhythmic structure of their stimuli was broken down by multiple levels of subdivided beats, musicians showed a consistent advantage in their tapping and neural responses over the non-musician group on all conditions except the binary beat pattern where both groups performed similarly (Celma-Miralles et al., 2021). The consensus from these studies is that formally trained musicians tend to perform better on beat tasks; however, this grouping choice fails to consider the abilities of those with unconventional music experience (Franěk et al., 1991; Matthews et al., 2016).

In contrast to the above findings, when Brigand and Poulin-Charronnat (2016), excluded technical musical terms in their study, non-musicians performed similarly to the musical group.

Although the musically trained group performed better overall, their findings indicate that some musical abilities must develop through music exposure rather than training (Bigand & Poulin-Charronnat, 2006). These findings provide evidence that formal music education may not be the most effective way to assess competence in tasks of musical structure.

Another problem with using musicianship as a grouping variable is that there is no common consensus on what classifies an individual as a "formally trained musician." A recent meta-analysis found that, typically, "musicians" were those who had an average of six years of formal training. This discounts anyone who is self-taught or has less formal experience but a natural capacity to be musical (Zhang et al., 2020). Instead of viewing musicianship as a binary, choosing a new way to classify musical competence might be more advantageous.

What is the Alternative?

Musical sophistication is a term designed to do just this. It is a new classification method that bases musical abilities on various musical and environmental influences such as age, occupation, gender, and wealth (Morrison et al., 2024). The most commonly used self-report measure of musical sophistication is the *Goldsmiths Musical Sophistication Index* (*Gold-MSI*). This measure identifies individuals who reach the threshold to be classified as musically sophisticated using the total scores from five subscales: active engagement, perceptual ability, music training, singing ability, and emotional engagement (Müllensiefen et al., 2014).

Alternatively, researchers Law and Zentner (2012) have developed an objective measure to assess musical sophistication. The pair developed a new test battery to measure musical skills regardless of formal training history. Their measure, the *Profile of Music Perception Skills* (*PROMS*), provides an empirically validated way to assess musical sophistication that can be compared to the *Gold-MSI* (Kunert et al., 2016). A significant finding from the development of the *PROMS* was a phenomenon called *musical sleepers*. Musical sleepers demonstrate proficiency on music structure tasks despite a lack of formal training. It is a term that provides unique insight into the intricacies of musical sophistication (Law & Zentner, 2012). Furthermore, *musical sleepers* are a phenomenon that provides further evidence that musicianship is not the most accurate way to categorize musical capabilities.

Another strength of using the *PROMS* as a measure of musical sophistication is that it is designed to assess the elementary structures of music, such as melody, rhythm, and tempo, allowing for greater cultural sensitivity than the previous measures (Kunert et al., 2016). This is essential as past research has found that humans have an innate predisposition to pick up on the structure of music (Honing, 2012). By assessing proficiency in music structure tasks, participants respond to the universal aspects of musicality rather than any culturally defined music skills.

Measuring Entrainment

Entrainment—the synchronization of neural or behavioural activity to an external stimulus—is considered to be a measure of beat perception. This term offers insight into one's ability to predict, synchronize, and reproduce beat patterns from external stimuli (McAuley & Fromboluti, 2014). Concerning music cognition research, synchronizing one's movement to music is a form of behavioural entrainment. A standard method of measuring behavioural entrainment is to track the asynchrony and variability of tapping responses to a presented stimulus. Although beat perception is argued to be an innate human function, there is a wide variance in performance on beat-based tasks within the population (Iversen & Patel, 2008; Fiveash et al., 2022). These differences in rhythmic competence, although supposedly an inherent ability, indicate that other factors may account for the diversity in performance on musical structure tasks.

One factor that has the potential to influence performance on entrainment tasks is beat pattern/metre (Nave et al., 2022). Music structure in a Western context is generally made up of a beat pattern that involves one strong prominent beat that repeats at a regular interval and weaker beats that are nested within the primary beat pattern. In a study that sought to test participants' ability to adapt to fluctuating tempi of music, Rankin and Large (2009) found that participants could predict tempo changes accurately and were anticipating this change rather than reacting to it. They found that the nested pattern of sub-divided beats in their stimuli, also referred to as fractal scaling, enabled individuals to predict and anticipate the arrival of the principal beat pattern. Anticipating the temporal structure of a piece goes beyond simple behavioural entrainment. These kinds of complex temporal frameworks involve not just the synchronization of neural activity to external stimuli but also integrating information from subdivided beat patterns to predict the arrival of the principal beat. The additional cues provided by hierarchical beat patterns provide an alternative explanation as to why there is such variance in performance on musical structure tasks, regardless of musical training.

To further investigate what leads to the development of beat-perception skills, it is essential to define what it means to be "rhythmically competent." A group of researchers collected data from nine established rhythm tasks with the goal of understanding what makes up rhythmic competence. Supporting the hypothesis of the divergence of rhythmic skills, their results established three distinct dimensions that make up this idea: tapping precision and beat alignment, beat-based rhythm perception, and sequence memory-based rhythm perception (Fiveash et al., 2022). Establishing these dimensions is particularly relevant to the field of music cognition research as these findings support the separation of beat perception and beat production tasks. As some individuals may excel in one of these dimensions but not another, to gather a comprehensive understanding of rhythmic competency, one must ensure to collect information across these dimensions. Examining behavioural entrainment through tapping responses will address the beat production dimension, while analyzing neural entrainment will provide insight into beat perception.

Although musicianship may be an ineffective predictor of musical ability, as there are a multitude of influences that can contribute to beat-induction and reproduction skills, much remains unknown about how musical beat is processed within the brain. Examining beat-related neural entrainment while considering its connection to beat production and perception provides an avenue to investigate this relationship. The term neural entrainment describes the synchronization of oscillatory fluctuations in neural activity with external stimulus rhythms (Nave et al., 2022). Beat-related neural entrainment describes how the brain responds to and synchronizes with musical stimuli. A popular approach to measuring this type of entrainment is to use an electroencephalogram (EEG) to examine beat-related steady state-evoked potentials (SSEPs). Also known as frequency-tagging, this type of brain data reflects repeated fluctuations in neural activity due to corresponding rhythmic changes. An additional component of frequency tagging that makes it an effective way to measure neural entrainment is that SSEPs are relatively consistent over time, allowing researchers to analyze the data in the frequency domain where they can be directly contrasted against the stimuli's beat pattern (Nozaradan, 2014). This is essential to measuring neural entrainment as it enables the comparison of neural oscillations to corresponding rhythmic components of the stimuli.

Conscious beat perception can be affected by a range of external factors; however, whether it is directed by stimulus-driven activity or participants' rhythmic perception abilities remains understudied. Finding evidence that SSEPs reflect the conscious perception of beat rather than simply the external stimulus features, Nave and colleagues (2022) propose that neural entrainment is modulated by tempo and beat pattern (e.g. binary vs ternary). However, their exploratory findings suggest a need for future studies to closely measure beat behaviour in relation to behavioural and neural entrainment (Nave et al., 2022). While this paper provides context for the relationship between behavioural and neural entrainment, a great deal remains unknown about how exactly entrainment is connected to musical behaviours.

While there is still much to discover about the intricacies of neural entrainment, many have sought to explain the underlying neural processes that are responsible for beat processing. Dynamic Attending Theory (DAT) is one framework that considers the temporal structure of a stimuli in relation to attention and perception (Jones, 1976). In respect to beat induction and reproduction, dynamic attending explains how individuals anticipate a beat's arrival based on the stimulus's temporal regularity (Henry & Herrmann, 2014). Proponents of this theory posit that attention mirrors the timing of external stimuli. In other words, internal attentional rhythms synchronize with external rhythms, such as musical beat (McAuley & Fromboluti, 2014). According to this framework, a regular, periodic beat pattern is expected to facilitate the prediction of the following beat as it is easier for internal attentional rhythms to synchronize to a consistent beat pattern. When a musical beat pattern does not follow a periodic pattern, predicting the next beat onset becomes significantly more challenging (Henry & Herrmann, 2014). Ultimately, DAT attempts to explain how attentional rhythms can contribute to one's ability to rhythmically entrain to a beat pattern.

Building on this concept, research by Nozaradan and colleagues (2016) has sought to examine the relationship between neural and behavioural entrainment by exploring temporal precision in participants with a range of musical abilities. By analyzing SSEPs, this paper established a link between neural and behavioural entrainment measures, finding that greater precision on behavioural tasks, such as tapping, is associated with greater neural entrainment; however, they were unable to establish a relationship between music training and performance on this task (Nozaradan et al., 2016). Establishing a direct link between the two types of entrainment suggests that neural entrainment should be able to predict accuracy on behavioural beat entrainment tasks, although further research is necessary to confirm this relationship. It is important to note that tapping accuracy and precision data were gathered separately from SSEP data in the aforementioned study. Although they aimed to establish a relationship between sensorimotor synchronization and beat-related neural entrainment, caution must be taken when interpreting these results as brain activity and behavioural data were not collected simultaneously.

Much of the existing literature on the relationship between beat-related neural entrainment and behavioural measures is limited by similar procedures. In widely cited paper by Tal and colleagues (2017), examining NRT related to neural entrainment, the authors also made correlative conclusions about this relationship. Although their findings support the idea that SSEPs indicate sustained neural entrainment, behavioural and neural data were once again collected separately. To move beyond simple correlations and better understand this relationship, it is essential to gather data concurrently to minimize the influence of external factors.

Contrasting the work of Tal et al. (2017), Stupacher and colleagues (2016), collected EEG data simultaneously with their behavioural measures. They found neural entrainment to the beat both when a musical stimulus had a simple beat pattern and when it had a complex beat pattern where the beat was more challenging to infer. They found no beat-related SSEPs when participants passively attended to the stimuli by implementing silent breaks between drum clips.

However, when participants were instructed to continue tapping the beat through these silent periods, beat-related SSEPs persisted (Stupacher et al., 2016). By collecting this data concurrently, the experimenters were able to suggest that internal processes are involved in sustained neural entrainment, even in the temporary absence of external stimuli.

The Present Study

Considering that most music cognition research classifies participants based on formal training, our study aims to gain insight into how music sophistication and non-traditional music experience influence achievement on beat-related entrainment tasks. Given that previous research has found a limited relationship between formal training and beat-perception skills, focusing on this new measure of musical ability will give greater weight to informal experiences and latent abilities that can influence rhythm perception skills (Macnamara et al., 2014). Studying music sophistication with two different measures will help researchers discern what types of music influences, if any, reliably predict performance on behavioural and neural entrainment tasks.

Using the *Gold-MSI* as a self-report measure of music sophistication and the *Mini-PROMS* as an objective task measure, we investigated the effect of musical sophistication on neural and behavioural measures of entrainment to beat. Participants completed both measures independently from EEG data collection. While attached to the EEG, the study team assessed beat perception proficiency through a SSEP task. We hypothesize that greater musical sophistication will be related to better performance on neural and behavioural entrainment tasks and that weaker musical sophistication will be related to decreased performance. Specifically, we expect higher scores on the *Mini-PROMS* and the *Gold-MSI* to be related to lower variability in tapping responses and tapping asynchrony. We also anticipate that higher SSEP amplitudes at the expected beat frequencies to be related to higher scores on the *Mini-PROMS* and the *Gold-MSI.*

Methods

Participants

Forty participants between 17 and 45 (*M* = 22.5*, SD* = 4.39; 31 female, 9 male*)* were recruited from Western University and the surrounding community of London, Ontario. Inclusion criteria included self-reported normal hearing and no known neurological disorders. Two participants were excluded from data analysis as they had too many missing trials after filtering for a minimum number of taps (less than six per trial). Participants received course credit (0.5 credits per half hour) or financial compensation ($5 per half hour) for their participation. Procedures were approved by the Western University Non-Medical Research Ethics Board (see Appendix A).

Materials

Goldsmiths Musical Sophistication Index

To assess for different types of musical sophistication, we administered the *Goldsmith's Musical Sophistication Index* (*Gold-MSI*; Müllensiefen et al., 2014) to provide a comprehensive and reliable self-reported measure of musical sophistication (see Appendix B; Baker et al., 2020). The internal consistency of the general score of this measure, assessed via Cronbach's alpha was very high, demonstrating good reliability (α = .93). The *Gold-MSI* is a 39-item self-reported measure designed to assess musicality on five dimensions: active engagement (α = .87), perceptual abilities (α = .87), musical training (α = .90), singing abilities (α = .87), and emotion (α = .79; Baker et al., 2020). It is intended to evaluate how individuals perceive their musical abilities (e.g., pitch discrimination) and music's role in their day-to-day lives, such as how much time an individual spends listening to music.

Mini Profile of Music Perception Skills

The *Mini-Profile of Music Perception Skills* (*Mini-PROMS*) is an empirically validated, objective measure that can be used to assess musical sophistication. This online test battery was constructed to provide a reliable and validated way to assess musical ability through a brief discrimination task. In this task, participants listen to two identical audio clips and are asked to determine if a third clip is the same or different from the initial two excerpts they heard (Law & Zentner, 2012). Internal consistency of the general score of the *Mini-PROMS* evaluated by McDonald’s omega was acceptable ($\omega = .87$). The *Mini-PROMS* evaluates musical abilities in four dimensions: melody ($\omega = .75$), tuning ($\omega = .73$), accent ($\omega = .52$), and tempo ($\omega = .54$; Vázquez-Fragua et al., 2024).

Procedure

Participants were first presented with the Letter of Information (see Appendix C). After the experimenter obtained informed consent, they completed the *Gold-MSI* and a demographics survey on a laptop while the experimenters set up the EEG equipment. Once the EEG setup and surveys were completed, the participants were brought to a sound booth to complete the SBT task while EEG data were collected.

Participants completed the SBT task on a desktop computer in a sound-attenuated booth. Before the test blocks began, participants were presented with two demonstrations of the task, where a drummer attended to the first two phases of the trial and then began tapping along to the perceived beat of the stimuli in the final tapping phase, followed by a short practice block. The participant completed four practice trials under the supervision of the experimenter. The experimenter listened to the trial to ensure participant comprehension of the task. Participants were given corrective feedback by the study team and were given the option to repeat practice if deemed necessary by the experimenter. After the practice trials, the experimenter left the sound booth, and the participant completed four blocks. Each block was comprised of 16 trials, eight of which consisted of a binary beat pattern and the other eight reflecting a ternary beat pattern. We expected participants to sustain the inferred beat and beat pattern from the context phase through the ambiguous rhythm they heard in this second phase of our trials. Taps were recorded via the "M" key on the desktop keyboard. RadioEar IP30 insert earphones were used during the experiment. Participants were asked to refrain from moving during the task and to keep their eyes open. The experimenter gave reminders when necessary to ensure the participants followed the instructions. Trials were participant-paced, and the experimenter offered breaks for rest in between test blocks. Blocks were approximately 15 minutes, and participants spent a total of approximately 60 minutes in the sound booth completing the SBT task. After completion of the experiment, participants were debriefed (see Appendix D) and thanked for their participation.

Sustained Beat Task

Each trial in the Sustained Beat Task (SBT) consisted of three phases: (1) the context phase, (2) the maintenance phase, and (3) the tapping phase. In the first phase, participants listened to a rich musical excerpt for 8 measures that contained multiple musical cues that clearly support the beat pattern as either binary or ternary. In the maintenance (second) phase of the task, these additional cues were removed, and the participant listened to a beat-ambiguous isochronous rhythm, in which they could perceive a binary or ternary beat pattern. This forced the participants to rely on their beat induction abilities, as the beat pattern was not explicit like in the trial's first phase. In the final tapping phase, participants were asked to tap along to the beat for 8 measures.

Additional precautions were taken to control for the potential influence of tempo bias. We included a fast tempo and slow tempo condition for both beat patterns. Previous literature has found that adults show a preference towards inter-beat intervals (IBIs) around 600 ms, including both fast and slow conditions (McAuley et al., 2006). We aimed to control this, ensuring it would affect the binary and ternary conditions uniformly if present.

Stimuli for SBT Task

Musical stimuli were adapted from Nave et al., (2022) and created using MIDI-sequencing in the Logic X Program for Apple computer systems. The demonstration trials and context phase musical excerpts were computer-generated and created with the Steinway Grand Piano and Snare Drum (Apple Inc., 2015). Stimuli for the maintenance and tapping phases were adapted to be isochronous. This set of stimuli is publicly available as part of the Open Science Framework and is available at www.osf.io/hwun9.

All musical excerpts created for the context phase consisted solely of piano music and six eighth-note positions per measure (see Figure 1a). In the binary condition, the pattern of beats demonstrates the subdivision of the strong beat by two eighth notes (SW-SW-SW). Meanwhile, in the ternary condition, the strong beat is subdivided by three eighth notes (SWW-SWW). Stimuli were constructed so there were no significant differences in the total number of onsets, average pitch, average pitch range, or average pitch interval for the binary or ternary condition (Nave et a., 2022). This helped ensure that participants were inferring the beat and not relying on other cues to execute the task.

Figure 1

Trial Structure

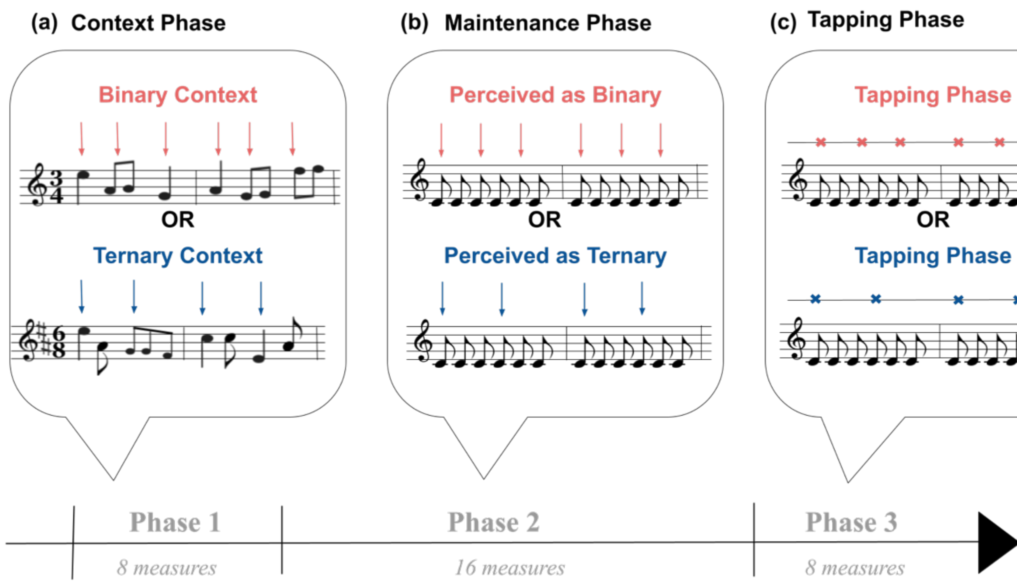

Figure 1. Trial structure. (a) Phase 1: context. Each arrow is an indication of where a strong beat is perceived. Examples of the binary (pink) and ternary (blue) beat pattern are shown. (b) Phase 2: maintenance. Arrows indicate where strong beats could be perceived when the rhythm becomes ambiguous. (c) Phase 3: tapping. Pink x's represent how a participant could tap to ambiguous rhythm following a binary pattern. Blue x's represent how a participant could tap to the ambiguous rhythm following a ternary beat pattern.

During the maintenance phase of the task, the stimuli rhythm consisted of six eighth notes per measure, and lasted 16 measures (see Figure 1b). Contrary to the context phase, the stimuli in the maintenance phase of the task did not consist of any additional cues provided by changes in pitch, rhythm, or contour. Therefore, during the maintenance phase, fast trials were 19.2 seconds, and slow trials were 28.8 seconds to ensure we could precisely estimate the frequency of the participants' neural activity. In the final tapping phase of the trial, the stimuli remained identical to the maintenance phase, lasting eight measures (see Figure 1c).

EEG Recording

EEG data were collected using a 64-channel Biosemi ActiView system with six eternal electrodes placed on the participants' right and left mastoids, the outer canthus of each eye, and the inferior and superior areas of the left orbit. These externals were positioned to monitor eye and movement artifacts. Electrode placement was established according to the 10/20 international system. Signals were recorded using a low-pass filter at 500 Hz and a 1024 Hz sampling frequency.

EEG Pre-Processing

Several processing steps were used to refine the EEG data, filtering out unwanted data, such as artifacts and electrical noise, that could interfere with data analysis. All pre-processing was done in Matlab. EEG data were filtered to remove drift from the recording using a 0.1 Hz high-pass Butterworth zero-phase filter and to remove beta and gamma waves (The Mathworks, Inc., 2022). After cleaning, EEG data was also refined to the maintenance phase of the SBT trials. Fast-trial epochs lasted 19.2 seconds (16 measures; 1 measure =1.2 s), while slow-trial epochs lasted 28.8 seconds (16 measures; 1 measure = 1.8 s).

EEG data across conditions and trials were averaged to minimize extra noise unrelated to the beat-based stimuli. To analyze the periodic neural activity corresponding to our stimuli, we used a Discrete Fourier Transform (DFT) to convert the time-based neural activity data into a frequency-based format, allowing us to investigate the participant's subjective beat perception through their neural responses to the rhythmic stimuli (Frigo & Johnson, 1998). Previous studies have followed similar procedures, therefore supporting our choice to use a frequency resolution of 0.052 Hz in the fast condition and 0.035 Hz in the slow condition (Bach & Meigen, 1999; Celma-Miralles et al., 2016; Cirelli et al., 2015; Nave et al., 2022; Nozaradan et al., 2011, 2012).

We calculated the averages of neighbouring frequency bins just above and below our frequencies of interest (0.052 Hz and 0.035 Hz). By subtracting this average, we could remove background noise unrelated to our stimuli and ensure our SSEP measurements were not contaminated by non-task-related neural activity. If the expected response was absent at beat-based frequency, the amplitude of any SSEP peak after subtracting background noise should be close to zero. Previous studies have found that this subtraction method effectively removes background noise regardless of the number of bins; therefore, we chose the range of 3-5 bins to ensure that we did not remove activity relevant to the SSEP signal (Srinivasan et al., 1999). This peak was expected to be prominent if the stimuli elicit a strong response at the desired frequency.

In the fast tempo condition, the stimulus frequency is 5.00 Hz, with binary beats at 2.50 Hz and ternary beats at 1.67 Hz. Alternatively, the stimulus is 3.33 Hz in the slow tempo condition, with binary beats at 1.67 Hz and ternary beats at 1.11 Hz. In line with prior research, SSEP magnitudes were averaged across all scalp electrodes for each participant and condition (Nave et al., 2022; Nozaradan et al., 2011, 2012).

Results

The current study explored the relationship between musical sophistication and measures of behavioural and neural entrainment. Participants showed a wide range in their scores of musical sophistication with scores from the *Mini-PROMS* ranging between 10.5 and 31.0 M = 22.569, SD = 4.338), and scores from the *Gold-MSI* in-between 39.0 and 127.0 (M = 80.135, SD = 24.780; see Table 1). To determine if our measures of rhythmic entrainment differed across beat context or tempo, four separate 2 (beat pattern type: binary vs ternary) x 2 (tempo: fast vs slow) repeated measures Analysis of Variance (ANOVAs) were conducted on tapping asynchrony, the Coefficient of Variance (CoV), SSEP amplitudes at the beat frequency, and SSEP amplitudes at the stimulus frequency.

Table 1

Descriptive Statistics

	Age	Mini-PROMS	Gold-MSI	Asynchrony	CoV	Beat SSEP	Stim SSEP
Mean	22.568	21.908	80.135	0.111	0.157	0.122	0.173
SD	4.388	4.575	24.780	0.066	0.132	0.210	0.141

Note. Averages calculated across all participants and trials.

Analysis of Tapping Across Conditions

Our first two ANOVAs examined mean differences in beat pattern and tempo on behavioural entrainment (see Figure 2). There was a significant main effect of beat pattern on tapping asynchrony ($F = 19.711$, $p < .001$, $n^2_p = 0.117$). Post-hoc pairwise tests using the Bonferroni Correction confirmed that tapping asynchrony scores were higher in the binary condition ($M = 0.076$, $SD = 0.036$) than the ternary beat pattern condition ($M = 0.074$, $SD = 0.074$), $t = 4.440$, $P_{bonf} < .001$, *Cohen's d* = 0.321. These analyses did not find any significant effects of tempo ($F = 0.115$, $p = .738$, $n^2_p = 0.002$), nor any significant interaction between beat and tempo ($F = 1.592$, $p = .218$, $n^2_p = 0.011$).

Figure 2

Asynchrony Across Conditions

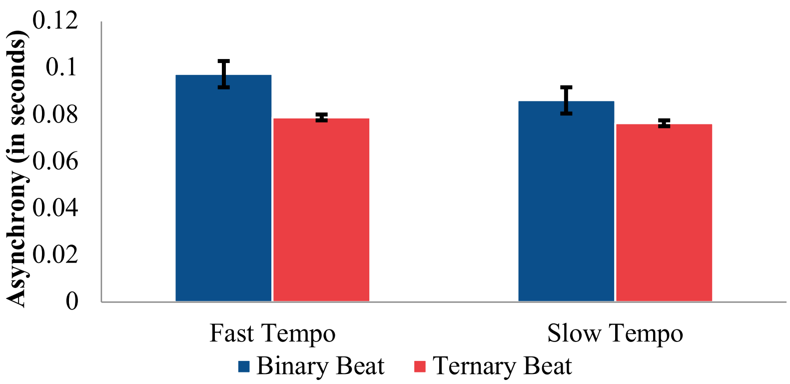

Figure 2. Tapping results are displayed across tempo and beat pattern. Conditions are represented on the x-axis, where binary trials are represented by blue, ternary trials are represented by red. Absolute asynchrony in seconds is represented on the y-axis. Results were averaged across all participants and trials. Error bars represent standard error of the mean.

The following ANOVA conducted on variability in tapping responses across conditions (see Figure 3) did not reveal a main effect of beat ($F = 1.015$, $p = .323$, $n^2_p = 0.015$) nor tempo ($F = 9.718\text{x}10^{-5}$, $p = .992$, $n^2_p = 1.015\text{x}10^{-6}$). There was no interaction between beat and tempo ($F = 2.636$, $p = .116$, $n^2_p = 0.026$).

Figure 3

CoV Across Conditions

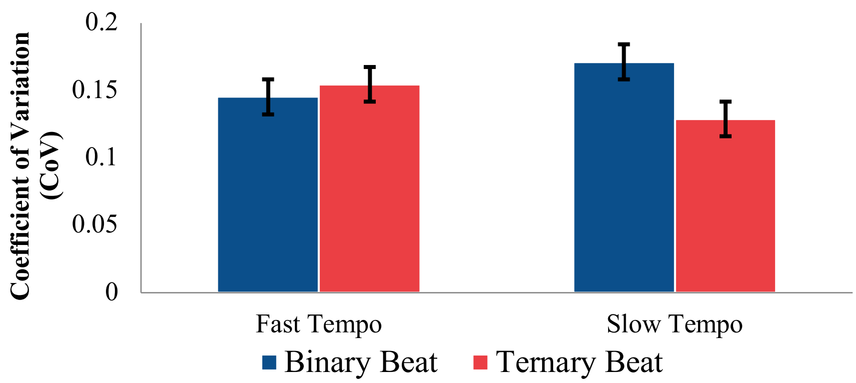

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Figure 3. Tapping on the Coefficient of Variation results are displayed across tempo and beat pattern. Conditions are represented on the x-axis, where binary trials are represented by blue, ternary trials are represented by red. Variability in trapping responses in seconds is represented on the y-axis. Results were averaged across all participants and trials. Error bars represent standard error of the mean.

Analysis of SSEPs Across Conditions

To examine the effect of beat pattern and tempo on neural entrainment we analyzed ANOVAs on SSEP amplitudes at beat-pattern frequencies, and the stimulus frequency. Based on our ANOVA on beat-SSEPs (see Figure 4), we were able to establish a main effect of tempo ($F = 72.469$, $p < .001$, $n^2_p = 0.544$). Pairwise comparisons confirmed that SSEP amplitudes were significantly higher in the fast tempo condition ($M = 0.018$, $SD = 0.194$) than the slow tempo condition (*M* = 0.033, *SD* = 0.272), $t = 4.727$, $P_{bonf} < .001$, *Cohen's d* = 0.956. No significant effects were found for beat-pattern type, nor was an interaction found between beat-pattern type and tempo ($F = 0.402$, $p = .531$, $n^2_p = .001$).

Figure 4

Beat Frequency SSEPs Across Conditions

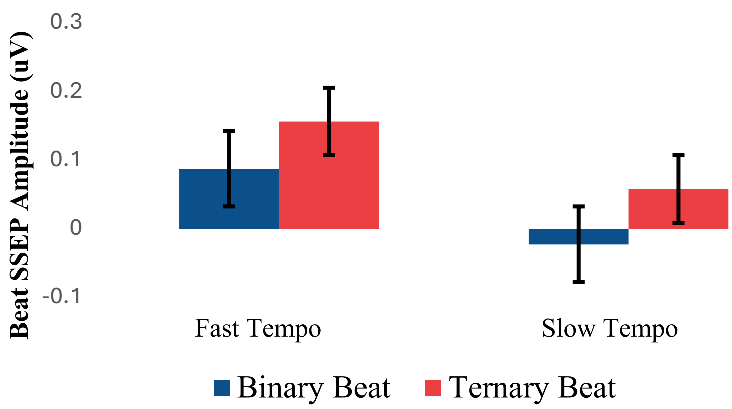


Figure 4. SSEP amplitudes at the expected beat frequency are displayed across tempo and beat pattern. Conditions are represented on the x-axis, where binary trials are represented by blue, ternary trials are represented by red. SSEP amplitudes is represented on the y-axis. Results were averaged across all participants and trials. Error bars represent standard error of the mean.

Finally, we conducted an ANOVA to examine any potential interactions with SSEP amplitudes at the stimulus frequency itself. Similarly to the ANOVAs on behavioural entrainment measures, we established a significant main effect of tempo on stimulus SSEP amplitudes ($F = 22.345$, $p < .001$, $n^2_p = 0.401$). Follow-up post-hoc tests indicated that SSEP amplitudes at the stimulus frequency were higher in the fast tempo condition (*M* = 0.097, *SD* = 0.060), as opposed to the slow tempo (*M* = 0.124, *SD* = 0.112), $t = -5.563$, $P_{bonf} < .001$, *Cohen's d* = -0.860. No significant effect of beat pattern was found ($F = 3.258$, $p = .081$, $n^2_p = 0.004$). There were also no significant interactions between beat and tempo ($F = 0.001$, $p = .975$, $n^2_p < 0.001$).

Figure 5

Stimulus Frequency SSEPs Across Conditions

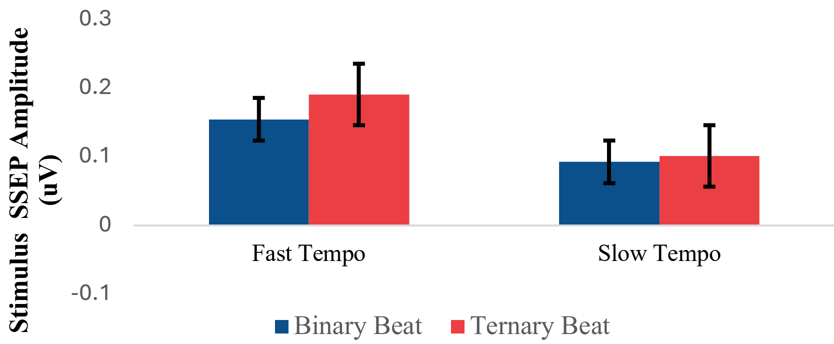


Figure 5. SSEP amplitudes at the stimulus frequency are displayed across tempo and beat pattern. Conditions are represented on the x-axis, where binary trials are represented by blue, ternary trials are represented by red. SSEP amplitudes is represented on the y-axis. Results were averaged across all participants and trials. Error bars represent standard error of the mean.

Table 2
Correlation Matrix

	Async-Bin	Async - Tern	CoV - All	SSEP Beat-Fast	SSEP Beat-Slow	SSEP Stim-Fast	SSEP Stim-Slow	Mini-PROMS	Gold-MSI GM	Gold-MSI MT	Gold-MSI EM	Gold-MSI SA	Gold-MSI AE	Gold MSI PA
Async – Bin	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Async - Tern	.857***	-	-	-	-	-	-	-	-	-	-	-	-	-
CoV – ALL	.627***	.454**	-	-	-	-	-	-	-	-	-	-	-	-
SSEP Beat-Fast	.083	.161	.105	-	-	-	-	-	-	-	-	-	-	-
SSEP Beat-Slow	.060	.020	.135	-.051	-	-	-	-	-	-	-	-	-	-
SSEP Stim-Fast	.383*	.349	.244	.583***	.120	-	-	-	-	-	-	-	-	-
SSEP Stim-Slow	.310	.244	-.301	.134	.327	.356*	-	-	-	-	-	-	-	-
Mini-PROMS	-.535**	-.301	-.392*	-.234	-.411*	-.408*	-.107	-	-	-	-	-	-	-
Gold-MSI GM	-.077	-.054	.076	-.093	-.080	-.301	-.106	.339*	-	-	-	-	-	-
Gold-MSI MT	-.307	-.226	-.203	-.249	-.214	-.510**	-.101	.485**	.820***	-	-	-	-	-
Gold-MSI EM	.304	.221	.577***	.050	-.090	-.015	-.146	-.030	.698***	.346*	-	-	-	-
Gold-MSI SA	.081	.127	.222	.033	.097	-.173	.028	.097	.839***	.533***	.717***	-	-	-
Gold-MSI AE	.081	.098	.361*	.049	-.084	.005	-.036	.103	.772***	.487**	.839***	.624***	-	-
Gold-MSI PA	.211	.109	.280	-.028	.017	-.134	-.075	.112	.837***	.584***	.823***	.773***	.759***	-

Note. Correlation matrix for variables of musical sophistication, behavioural, and neural entrainment.

Relation between Music Sophistication and Behavioural Entrainment

Based on the results from our four ANOVAs, we collapsed across beat and/or tempo (when non-significant) for all measures of entrainment. These variables were then entered into a Pearson correlation along with our measures of music sophistication (see Table 2). CoV was negatively corelated with scores on the *Mini-PROMS* (r = -.392, p = .018). Asynchrony in the binary condition was additionally related to performance on the *Mini-PROMS* (r = -.535, p = .002). We also found relationships between CoV and two *Gold-MSI* subscales, emotional engagement (r = .577, p <.001), and active engagement (r = .361, p = .033), though the general musical sophistication score did not demonstrate a significant relationship.

Relation between Music Sophistication and Neural Entrainment

For our measures of neural entrainment, there was a negative correlation between SSEP amplitudes at beat frequencies in slow conditions (1.11 & 1.67 Hz) and participant scores on the *Mini-PROMS* (r = -.411, p = .020), where higher scores on the *Mini-PROMS* were related to lower SSEP amplitudes. No such relationship was found between either of our measures of music sophistication and SSEP amplitudes at fast-beat frequencies. On the other hand, SSEP amplitudes at stimulus frequencies (5 Hz) in the fast condition were negatively correlated to performance on the *Mini-PROMS* (r = -.408, p = .021). Fast tempo trials at the stimulus frequency were also related to the music training subscale of the G*old-MSI* (r = -.510, p = .003). No such relationships were found with the slow stimulus frequency (3.33 Hz). Performance on the *Mini-PROMS* was also moderately related to scores on the *Gold-MSI* (r = .339, p = .040) and the music training subscale (r = .485, p = .002).

Discussion

This study sought to investigate the relationship between levels of music sophistication and measures of entrainment. Music sophistication was measured using the *Mini-PROMS* as an objective discrimination task measure and the *Gold-MSI* as a validated self-reported measure. For the measures of behavioural entrainment, we analysed performance on the SBT task across two dimensions: asynchrony and tapping variability. Regarding the measures of neural entrainment, we examined the amplitude of SSEPs at the beat and stimulus frequency. This study provides evidence of a relationship between musical sophistication and rhythmic entrainment.

The study findings establish a significant relationship between the *Mini-PROMS* and the *Gold-MSI*. However, it is relevant to mention that this relationship appears to be driven by the *Gold-MSI's* Music Training subscale. This finding supports the decision to use both measures, while theoretically measure the same underlying construct of musical sophistication; the *Gold-MSI* and the *Mini-PROMS* appear not to be perfectly interchangeable in their assessment of musical abilities.

Findings from Behavioural Responses

On the first behavioural entrainment measure, CoV, participants with higher scores of musical sophistication tended to show more consistent tapping responses, thus indicating a possible relationship between musical sophistication and behavioural entrainment abilities. This was true for our objective measure of musical sophistication, the *Mini-PROMS* and our self-reported measure, the *Gold-MSI*. Our other measure of behavioural entrainment, how far off the beat participants responded, showed an effect of beat pattern; therefore, we chose to analyze absolute asynchrony results from the binary and ternary beat-pattern conditions separately. Absolute asynchrony was significantly related to the *Mini-PROMS* in the binary condition, where those demonstrated musical sophistication had lower scores for tapping asynchrony. This once again provides supports for the idea that music sophistication may be related to more significant behavioural entrainment. While the relationship between performance on the *Mini-PROMS* and asynchrony in the ternary condition did not reach statistical significance, this relationship may have been affected by missing behavioural data in our sample, likely contributing to the diminished statistical power. The *Gold-MSI* showed no significant relationship with tapping asynchrony on either beat pattern condition.

Findings from Neural Responses

Expected SSEP Findings

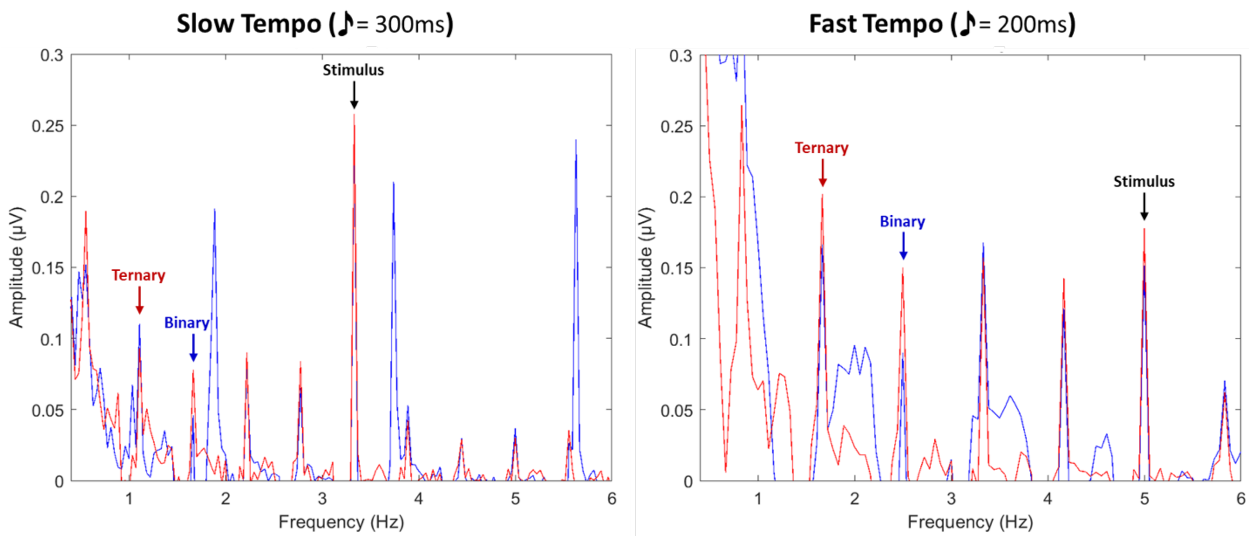
We expected the SSEPs to align with the beat frequencies from the context phase. Specifically, when the context phase followed a binary beat pattern, we anticipated that we would find stronger SSEPs at 1.67 Hz in the slow-tempo condition and 2.50 Hz in the fast-tempo condition. In contrast, we expected that when the context phase had a ternary beat pattern, we expected to find stronger SSEPs at 1.11 Hz in the slow tempo condition and 1.67 Hz in the fast tempo condition.

Actual SSEP Findings

Findings from our ANOVAs on neural entrainment informed our decision to analyze SSEP data separately for the slow-tempo and fast-tempo conditions (see Figure 6). Interestingly, we found a negative relationship between performance on the *Mini-PROMS* and SSEPs in the slow tempo condition at the beat frequency, where those who had higher levels of musical sophistication interestingly had smaller peaks at expected SSEP frequencies. No relationship was found between this measure and SSEPs in the fast-tempo condition at the beat frequency. Additionally, at our stimulus frequency in the fast condition, a negative relationship was also established with performance on the *Mini-PROMS*, where higher SSEP amplitudes were related to lower scores on the *Mini-PROMS*.

Figure 6

EEG Results



Note. SSEP results. Trials in which participants heard a binary beat pattern in the context phase are plotted in blue. Trials where participants heard a ternary beat pattern in the context phase are plotted in red. The x-axis reflects frequency (in Hertz). The y-axis represents SNR-corrected amplitude (in microvolts) where 0 reflects the absence of neural activity after filtering out background noise.

The only significant relationship between the *Gold-MSI* and SSEP amplitudes occurred with the Music Training subscale and SSEPs at the stimulus frequency in the fast condition. Again, no corresponding relationship was found with the alternative, slow-tempo stimulus frequency condition on either of our measures of music sophistication.

These unexpected negative relationships between measures of music sophistication and SSEPs highlight the exploratory nature of using SSEPs to measure neural entrainment and the need to investigate this relationship further. To date, there have only been a handful of studies that have examined SSEPs as a measure of neural entrainment, which informed our expectation to find a positive relationship between SSEPs and scores of musical sophistication (Nave et al., 2022; Nozaradan et al., 2016; Tal et al., 2017). One explanation that supports these unexpected findings focuses on attentional changes for fast and slow trials. According to Dynamic Attending Theory (DAT), there are differences in how attention dynamically adapts and adjusts according to the timing of external events (fast vs slow tempo; Large & Jones, 1999). Therefore, during our task, participants' attentional focus could have been influenced by stimuli tempo, thereby influencing our SSEP results. Similarly, Stupacher et al. (2016) found that SSEPs were absent when listeners passively attended to the stimuli. As incorrect trials were not filtered out, SSEP amplitudes could be influenced by a number of factors, such as boredom and fatigue, leading to the absence or diminished appearance of SSEPs at the expected frequencies. Our findings highlight the need for further research to investigate the relationship between SSEP amplitudes and how it relates to neural entrainment on beat-based perception tasks.

Implications

This study contributes to the growing evidence that differences in musical ability are related to performance on rhythmic entrainment tasks. Participants with higher musical sophistication scores—mainly as measured via the *Mini-PROMS*—demonstrated greater performance on our measures of behavioural entrainment, with more consistent and on-the-beat tapping responses. Consistent with previous research, musical ability seems to be related to one's ability to physically synchronize with musical stimuli (Bigand & Poulin-Charronnat, 2006). By using musical sophistication as our measure of musical competence, we investigated how individual differences in musical ability can influence beat perception and synchronization.

These findings—that behavioural entrainment was more consistently related to the *Mini-PROMS* as opposed to the *Gold-MSI*—underscore the importance of using objective and task-based measures to assess musical ability. Although the *Gold-MSI* provided valuable insights into participants' music habits and experiences, the measure's self-report nature could have allowed participants to over- or under-state their abilities and experiences. Using the *Mini-PROMS* allowed us to capture perceptual skills likely relevant to our beat-perception task.

Contrary to our hypothesis, participants with greater musical sophistication revealed smaller SSEPs in response to the beat-based stimuli. While these findings were unexpected, in that we expected greater musical sophistication to be related to stronger SSEPs, several possibilities may help explain the observed result. Firstly, those with greater musical abilities may have less neural activation when attending and responding to a musical stimulus. Although past research has used SSEPs to examine the relationship between neural and behavioural entrainment, researchers have yet to establish any significant relationship between neural entrainment and music training history (Nozaradan et al., 2016; Stupacheer et al., 2016). This raises further questions about how SSEPs capture individual differences in musical abilities. Future research must continue to investigate the use of SSEPs to investigate neural entrainment to gain a more comprehensive understanding of how musical ability influences neural responses to musical stimuli. Secondly, it is also important to consider that neural data was transformed using averages across all participants and trials, regardless of whether they performed well on the task. Some participants who struggled could disproportionately affect the averaged SSEP results. Finally, the is still much to discover about how the amplitude of SSEPs relates to the strength or quality of individual entrainment. Findings on SSEPs as a measure of neural entrainment are still very much exploratory, and more must be done to understand how individual factors, such as musical abilities, can influence the strength of SSEPs as a response to external stimuli.

Limitations

Several relevant limitations to this study are essential to address. First, some participants could not complete the *Mini-PROMS* at the experiment session due to server connectivity issues. These participants were asked to complete this task from home at a later time and were instructed to use their best-quality headphones (wired headphones are preferred) and to be in a place with minimal distractions. This issue was shortly resolved, but it is relevant to address as we could not control experiment conditions for this task with these participants. A second limitation of this study is that some participants may not have followed instructions on the SBT task when asked to refrain from moving. We intended for participants to keep the beat solely in their head during the maintenance phase, but they could have relied on external strategies to keep the beat pattern, such as moving a toe or blinking along to the beat. Finally, it was evident that some participants had a more challenging time with the SBT task than others. Trials with less than six taps were excluded, however, trials where participants were tapping to something other than the binary or ternary beat pattern could have been left in and skewed behavioural results.

Conclusion

The current study provides evidence of the relationship between musical sophistication and behavioural entrainment on a sustained beat task. Those with lower scores of music sophistication typically had more inconsistent taps to the stimulus beat pattern and more off-beat tapping. On the other hand, those with higher scores of music sophistication tended to have better consistency in their taps and had increased accuracy when tapping in time with the beat. Although we expected greater music sophistication to relate to stronger SSEP responses, our findings reported the opposite relationship. While we failed to reject this null hypothesis, using

SSEPs as a measure of neural entrainment is still exploratory. Thus, our findings highlight the need for further research to explore SSEP in response to rhythmic stimuli.

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Appendix A

Ethics Approval Letter

Date: 19 March 2024

To: Dr. Jessica Grahn

Project ID: 106385

Study Title: Behavioral studies of rhythm and music perception

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Date Approval Issued: 19/Mar/2024 15:53

REB Approval Expiry Date: 30/Mar/2025

Dear Dr. Jessica Grahn,

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

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

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.

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

Electronically signed by:

Mr. Joshua Hatherley, Ethics Coordinator on behalf of Dr. Isha DeCoito, NMREB Chair 19/Mar/2024 15:53

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

Goldsmiths Musical Sophistication Index (Müllensiefen et al., 2014)

Level of Agreement	Completely Disagree	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Completely Agree
I have never been complemented for my talents as a musical performer	☐	☐	☐	☐	☐	☐	☐
I would not consider myself a musician	☐	☐	☐	☐	☐	☐	☐
I can sing or play music from memory	☐	☐	☐	☐	☐	☐	☐
I am able to hit the right notes when I sing along with a recording	☐	☐	☐	☐	☐	☐	☐
I spend a lot of my free time doing music related activities	☐	☐	☐	☐	☐	☐	☐
Music is kind of an addiction for me- I couldn't live without it	☐	☐	☐	☐	☐	☐	☐
I don't like singing in public because I'm afraid I would sing wrong notes	☐	☐	☐	☐	☐	☐	☐
When I sing I have no idea whether I'm in tune or not	☐	☐	☐	☐	☐	☐	☐
After hearing a new song two or three times, I can usually sing it by myself	☐	☐	☐	☐	☐	☐	☐
I only need to hear a new tune once and I can sing it back hours later	☐	☐	☐	☐	☐	☐	☐
I often read or search the internet for things related to music	☐	☐	☐	☐	☐	☐	☐
I am able to identify what is special about a given musical piece	☐	☐	☐	☐	☐	☐	☐
I am not able to sing in harmony when somebody is singing a familiar tune	☐	☐	☐	☐	☐	☐	☐
I enjoy writing about music for example on blogs and forums	☐	☐	☐	☐	☐	☐	☐
I can compare and discuss differences between two performances or version of the same piece of music	☐	☐	☐	☐	☐	☐	☐
I sometimes choose music that can trigger shivers down my spine	☐	☐	☐	☐	☐	☐	☐
If somebody starts singing a song I don't know, I can usually join in	☐	☐	☐	☐	☐	☐	☐
I am able to judge whether someone is a new singer or not	☐	☐	☐	☐	☐	☐	☐
I usually know when I'm hearing a song for the first time	☐	☐	☐	☐	☐	☐	☐

I'm intrigued by musical styles I'm not familiar with and want to find out more	☐	☐	☐	☐	☐	☐	☐
Pieces of music rarely evoke emotions for me	☐	☐	☐	☐	☐	☐	☐
I find it difficult to spot mistakes in a performance of a song even if I know the tune	☐	☐	☐	☐	☐	☐	☐
I have trouble recognizing a familiar song when played in a different way or by a different performer	☐	☐	☐	☐	☐	☐	☐
I often pick certain music to motivate or excite me	☐	☐	☐	☐	☐	☐	☐
I can tell when people sing or play out of time with the beat	☐	☐	☐	☐	☐	☐	☐
I am able to talk about the emotions a piece of music evokes for me	☐	☐	☐	☐	☐	☐	☐
I don't spend much of my disposable income on music	☐	☐	☐	☐	☐	☐	☐
I can tell when people sing or play out of tune	☐	☐	☐	☐	☐	☐	☐
When I hear a piece of music I can usually identify its genre	☐	☐	☐	☐	☐	☐	☐
I keep track of new music that I come across (e.g. new artists or recordings)	☐	☐	☐	☐	☐	☐	☐
Music can evoke my memories of past people and places	☐	☐	☐	☐	☐	☐	☐

I have attended __ live music events as an audience member in the past twelve months:
☐ 0
☐ 1
☐ 2
☐ 3
☐ 4 to 6
☐ 7 to 10
☐ 10+

I listen attentively to music for __ per day:
☐ 0 to 15 min
☐ 15 to 30 min
☐ 30 to 60 min
☐ 60 to 90 min
☐ 2 hrs
☐ 2 to 3 hrs
☐ 4+ hrs

I engaged in regular, daily practice of a musical instrument (including voice) for __ years:
☐ 0
☐ 1
☐ 2
☐ 3
☐ 4 to 5
☐ 6 to 9
☐ 10+

At the peak of my interest, I practiced __ hours per day on my primary instrument
☐ 0

☐ 0.5
☐ 1
☐ 1.5
☐ 2
☐ 3 to 4
☐ 5+

I have had formal music training in music theory for __ years
☐ 0
☐ 0.5
☐ 1
☐ 2
☐ 3
☐ 4 to 6
☐ 7+

I have had __ years of formal training on a musical instrument (including voice) during my lifetime
☐ 0
☐ 0.5
☐ 1
☐ 2
☐ 3 to 5
☐ 6 to 9
☐ 10+

I can play __ musical instruments
☐ 0
☐ 1
☐ 2
☐ 3
☐ 4
☐ 5
☐ 6+

Appendix C

Letter of Information

Behavioral studies of rhythm and music perception

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

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 stimuli or see visual rhythms. Auditory stimuli may vary in complexity (ranging from simple tone sequences to real music and speech). If you agree to participate, you will be asked to listen to or watch 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. If you are participating in an in-person study, 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 tasks will take no more than 3 hours. In-person task(s) will be conducted in the Brain and Mind in the Western Interdisciplinary Research Building or the Robarts Research Institute on the University of Western Ontario campus.

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 from the study.

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, music or motor therapy) for disorders like Parkinson's disease.

Compensation

You will receive course credit (1 credit per hour) or monetary compensation for your participation ($5 per half hour for an in-person study or $2.50 per half hour for an online study). If you do not complete the entire study you will still be compensated the full amount (e.g. 10 minutes of participation for a 1/2 hour study will gain $5).

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. Online survey responses will be collected anonymously through secure online survey platforms such as Qualtrics, Pavlovia, Prolific, Gorilla, or Mturk. These online platforms use encryption technology and restricted access authorizations to protect all data collected. Western's Qualtrics servers are in Ireland, where privacy standards are maintained under the European Union safe harbour framework. Gorilla and Prolific are regulated by the UK General Data Protection Regulation (GDPR). Pavlovia server is in the United Kingdom and servers have a high level of security whereby, encryption is maintained to a level suitable for HIPAA. Lastly, Mturk adheres to the Privacy Shield Framework and Principles. The data will then be exported from the online platforms and securely stored on Western University's server. 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.

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:
Your contact and demographic information, will be stored in a secure, password-protected 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 enrol 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.

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.

Consent Form (2 pages)

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: ______________________________

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 □

Audio Recording:

I agree to have my audio recorded for the purposes of this research study. These recordings will be used for research purposes only which include analyzing the recordings along with using anonymous audio recordings to play to future participants or to use as examples for research conferences.

Yes □

No □

Appendix D

Debriefing Form

Debriefing Form

Title of research: Behavioral studies of rhythm and music perception

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

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 <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.

Version date: 01/05/2015

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

Version date: 01/05/2015

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.