The Association between Musical Reward and Entrainment to Beat: ***an EEG study***

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Abstract

Humans enjoy entraining their responses to the periodic pulse, or the beat, in music. However, individual differences exist in how well people can entrain to beat. Similarly, music is almost universally rewarding to engage with, though there are individual differences in how individuals experience musical reward. In this study, we aimed to understand the extent to which individual differences in the musical reward experience can explain individual differences in entrainment to beat. We did this using factor scores on the Barcelona Music Reward Questionnaire to measure musical reward sensitivity, and examined participants' beat-related and stimulus-related steady state evoked potentials (SSEPs) as measures of neural entrainment, and measured behavioural entrainment using a tapping paradigm. In the first phase participants heard a musical context with a salient beat. In the second phase, they heard isochronous eighth notes with no salient beat cues. In the third phase, they were asked to tap the beat they originally heard. Participants who scored higher on the Social Reward subfactor of the BMRQ exhibited better behavioural entrainment to beat. In contrast, there was no relationship between SSEP amplitudes and scores on the BMRQ. These findings provide evidence that individual differences in musical reward are associated with the individual differences observed in entrainment to beat.

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Statement of Contribution

The research question was developed by C.V.K. with guidance by K.M.N. and R.S. Data was collected with the help of Kira Nourse, and research assistant Kaite Winsor. The SBT was developed by Nave et al. (2022) and adapted for the present study by K.M.N. EEG data was cleaned and compiled by K.M.N. Tapping data was cleaned and compiled by C.V.K., K.M.N., and Kira Nourse. All tables and figures were made by C.V.K. The manuscript was written by C.V.K. and edited by K.M.N. and R.S.

The effect of musical reward on entrainment to beat: *an EEG study*

Music is an intrinsically human phenomenon to which people have an innate and universal urge to move and tap to the beat. Music permeates almost every aspect of our lives from childhood to old age. However, individual differences exist in how people experience music, from the levels of reward and enjoyment experienced in relation to musical experiences, to the amount of neural activation elicited while listening to music. The way we interact with music varies greatly; Some people may spend hundreds of dollars on concert tickets simply for the experience whereas others may not be willing to attend one at all. At that concert, some people love to move their bodies and engage with the music, whereas others prefer to stand and simply listen. People also find it inherently rewarding to entrain their responses to the beat in music. However, there are individual differences how people entrain to beat. The question regarding how these individual differences in musical reward interact to affect neural responses to music and beat perception remains. Before discussing the current study, I will first examine the individual differences in how musical reward is experienced, then briefly review musical structure. Finally, we will discuss the concepts of dynamic attending theory and entrainment as they relate to music and beat perception before discussing the present study.

Variability in Music Processing

Individual differences in musical reward

Listening to music, while pleasurable and rewarding for most, does not elicit the same reward experience across all individuals. The Barcelona Music Reward Questionnaire (BMRQ) has been designed and implemented to measure individual differences across the five facets of music-associated reward experiences (Mas-Herrero et al., 2013). The five facets of musical reward include (a) The *Musical-seeking* facet, which measures how people seek out information about the music they enjoy; (b) The *Sensory-Motor* facet, which measures in general, how people move to music; (c) *Emotion Evocation*, which is the facet looking at emotional and empathetic responses to music; (d) *Mood Regulation*, a facet examining how well music may calm an individual; (e) The *Social Reward* facet which looks at how engaging with music facilitates an individual's social connection (Mas-Herrero et al., 2013). Zatorre et al. (2015) utilized the BMRQ to capture these individual differences in musical reward and found that while most people do experience reward from music across each subfactor to varying degrees, this is not true for all people. In fact, about 5% of individuals experience negligible levels of reward when listening to "globally pleasing" music, which is music that large samples of individuals have deemed to have pleasing qualities (Zatorre, 2015). According to the authors, these individuals who do not experience music-associated reward exhibit no differences in general reward system responding in the brain, and similarly, the lack of reward is not accounted for by general perceptual disorders of music or depression and anhedonia. There were even differences in physiological responding, such that some individuals experienced chills to a piece of music, and others did not, indicating further individual differences in how people experience music and reward. These individual differences in the music-reward experience suggest inherent differences in how the brain experiences and processes music. While we know that these individual differences exist, it is not clear what the implications are on how people engage and synchronize with music as a result.

The pleasure one derives from engaging with music through movement is well captured through the Sensory-Motor subfactor of the BMRQ. The sensation of groove has been widely studied and has been defined as a behavioural urge to move and dance to certain types of music as a result of the underlying musical structure (Witek et al., 2014). Music that elicits the groove response tends to contain more complex rhythms and beat patterns, and is often rated as more pleasurable to listeners than music that does not elicit the groove response. Similarly, the ability to make predictions about the music you are listening to may make it more enjoyable and enhance this urge to move and synchronize (Matthews et al., 2020).

Further research has been conducted to examine how musical reward can motivate behaviours such as learning. Gold et al. (2019) utilized the BMRQ to measure individual differences in musical reward, and examined how the brain's reward pathway is activated when listening to music with unpredictable endings. Participants were asked to press a button indicating whether they predicted the song they were listening to would end with a consonant or dissonant melody, before the song finished. The authors measured learning as a change in accuracy of correct predictions of song endings over time. Their study showed a relationship between the individual differences in the levels of reward people experienced as measured by the BMRQ, and more reliable and robust neural activation in the reward pathway, especially in the Nucleus Accumbens, and the ability to learn and predict the endings of the song excerpts. Ultimately, these findings suggest music-associated reward experienced by individuals can be linked to neural activation and correlated to learning outcomes within the music domain (Gold et al., 2019). The ability to make predictions in music tends to be highly pleasurable, or rewarding, in the context of listening to groove music, which consists of moderately complex rhythms and beats (Matthews et al., 2020; Witek et al., 2014), and in the context of waiting for the beat to drop as music builds and you successfully predict the climax of the piece.

When considering each of these findings in conjunction, it is clear that individual differences in music reward exist, and that music reward is capable of driving behaviours. The behavioural urge to move to music and the beat is considered rewarding. It is known to be related to and motivated by the beat patterns extracted from the music (Matthews et al., 2020; Witek et al., 2014). It is unclear how individual differences in these behaviours and facets of music reward might affect how people perceive the underlying structure of music, or how readily an individual can entrain to beat.

Underlying Musical Structure

Music is generally a highly pleasurable human phenomenon. Every musical piece follows a unique structure consisting of recurring probabilistic structural cues which must be processed by listeners to understand and follow the story being told (Hannon et al., 2004). These structural cues can be combined within the brain to help listeners perceive a specified beat and metre. At times, these patterns and induced beat perceptions are physically present in the music through accented notes and sounds, however this is not always the case, and listeners must infer the beat and metre using previous structural input (Hannon et al., 2004; Mcauley, 2010). Musical beat can be defined as a pattern of prominent pulses which occur quasi-periodically with a regular pattern of alternating acoustic events. Differences in terms of how saliently or accented the beats are perceived, such as strong (S) and weak (W) beats, leads to metre, or the pattern of strong and weak beats (Nave et al., 2022). More specifically, the metre is referred to as the organization of beats within a specified hierarchy (Mcauley, 2010). The metre is used to subdivide one measure, or bar of music, into a specified number of equally spaced and predictable beats, which follow a regular accent pattern. For example, a 3/4 time signature, which would be considered a ternary metre, is subdivided into three distinct beats, following a SWW beat accent pattern. In contrast, 4/4 time would be split into four equal sections, following a SWSW beat pattern, and would be considered a binary metre (Mcauley, 2010). Ideally, an individual should attend to music and perceive the metre with the intended metrical pattern through attending to the important, recurring probabilistic events related to the beat (Hannon et al., 2004; Mcauley, 2010), which draw listeners in. Beat and metre are unique temporal and acoustic patterns which combine to form a rhythmical structure in music, aiding in the dynamic attentional shifts and synchrony of listeners and players (Hannon et al., 2004).

How an individual engages with a beat is related to how clearly the beat is presented. With prominent beat patterns driving the sensation of groove, groove music is known to be highly rewarding, and activates brain regions involved in beat perception and pleasure (Matthews et al., 2020). The research on groove has identified the involvement of a multitude of regions of activation within the reward pathway and areas thought to be responsible for beat perception (Matthews et al., 2020). Groove research has examined how the complexity of a beat affects this pleasurable urge to move, such that different levels of syncopation elicit different levels of groove behaviour (Witek et al., 2014). Syncopation can be defined as a beat pattern where the notes fall outside of the regular position of the strong beat, thus violating listener expectations of the stable beat pattern (Matthews et al., 2020). A beat with no syncopation would be highly predictable, with beats falling exactly where expected, whereas highly syncopated beats would be complex and unpredictable, violating listener expectations (Matthews et al., 2020). When the beat is either too complex or too elementary, people tend experience less reward, which may be associated with how well listeners can predict the musical pattern (Matthews et al., 2020; Witek et al., 2014). Similarly, the movements expressed to groove music exhibits clear synchrony to the musical beat across different beat saliency conditions, such that medium beat clarity conditions with moderate degrees of syncopation may drive the sensation of groove and the urge to synchronize one's movement (Matthews et al., 2020; Witek et al., 2014). Musical structure is a fundamental part of what makes the experience enjoyable. The saliency of the structure, or the beat, has a significant relationship to the pleasurable urge to move, and in turn, the reward experience is enhanced as individuals synchronize their movements to the beat.

Entrainment to External Rhythms

Entrainment of attention: Dynamic Attending Theory

Music consists of various complex beat patterns and rhythms which humans attend to, and even synchronize with through listening. To do so, the brain must be capable of first identifying the beat, then deem it as important, before filtering out irrelevant information (Jones, 2019). The way humans attend to important and salient stimuli, such as the musical beat, is dynamic and oscillatory, constantly alternating over time based on regularly timed environmental stimuli (Henry & Herrmann, 2014). It has been suggested that this ability to synchronize is inherently rewarding and reinforcing (Jones, 2019) which is, in part, what may motivate individuals to engage in these behaviours. This phenomenon is known as dynamic attending (Henry & Herrmann, 2014). Dynamic attending theory posits that natural silences, such as a pause in dyadic conversation signalling it is time to respond, or time intervals such as those heard between beats in music, may serve as a crucial signal of a larger rhythm within their contexts (Jones, 2019). Given the dynamic nature of attending, certain criteria must be met for the perception of stimuli to occur. That is, an individual's attention must co-occur, at the right moment or time, with the intended stimuli. This brings up the idea of synchronization between attention and external stimuli (Jones, 2019). Dynamic attending is a rhythmic attentional entrainment, underlying a variety of contexts (Clayton, 2012), and can be translated to how we attend and entrain to music. Dynamic attending theory posits that a rhythmic, oscillatory nature of attention and perception underlies attentional entrainment. Within the context of music, entrainment to a beat can be defined as the synchronization of responses or the oscillatory phase alignment of two simultaneous events, such as physical tapping, to external, perceived rhythms (Clayton, 2012; Tal et al., 2017), or through the synchronization of neural responses (Jones, 2019; Nave et al., 2022; Tal et al., 2017). Thus, as the quasi-periodic nature of beat aligns with an individual's oscillating attentional shifts, beat may be perceived, and responses can be entrained.

Behavioural Entrainment to Beat

When an individual has entrained to external musical rhythms, it can be readily observed through behaviours such as tapping or swaying with the beat. Some music, such as groove music, elicits these behaviours more readily as the beat may be more clear (Matthews et al., 2020; Witek et al., 2014). Previous research has examined the ability to entrain a behaviour, such as tapping, to the beat of music. Tal et al. (2017) used tapping as a measure of behavioural entrainment to a beat. In their task, participants were instructed to tap out the beat as soon as possible following the onset of listening. Findings indicated that individuals were capable of entraining their tapping once the beat was perceived, as observed through consistent tapping behaviours. There were individual differences exhibited in how fast people started tapping, which was thought to be because of individual differences in beat perception (Tal et al., 2017). This study provides evidence that tapping behaviours can be entrained to a beat, and readily observed, although there may be some individual differences in how fast behavioural entrainment can occur as a result of differences in beat perception. For this reason, it is important to also look at neural entrainment to beat, to capture a more holistic understanding of the mechanisms of entrainment to beat.

Neural Entrainment to Beat

While entrainment to beat can be studied through behaviours, it may also be observed in the synchronization of neural responses to the beat. Previous works have used Electroencephalography (EEG), a non-invasive tool used to measure neural activity through the scalp. From this data, analyses can be conducted to calculate the average waveform, and examine amplitudes across trials to estimate what is called the steady-state evoked potentials (SSEPs) (Kidmose et al., 2013; Nave et al., 2022). Amplitude changes are expected to be observed at the same frequency as a presented stimulus, such as the prominent beat in music (Kidmose et al., 2013; Nave et al., 2022). SSEPs with higher amplitudes (power) provide evidence of better neural recognition of the stimulus, relative to an SSEP with lower amplitude power (Nave et al., 2022), which is consistent with better neural entrainment.

In addition to examining behavioural entrainment, Tal et al. (2017) also examined neural entrainment to a beat. Of particular interest was the phenomenon of the missing pulse, such that even in the absence of a physical beat stimuli, individuals are still capable of perceiving a beat. Participants were tasked with listening to a basic drum beat for eight passive listening rounds, with the final trial omitting one of the strong beats. Participants' neural activation was recorded throughout the duration of this task. Results showed consistent SSEP activation at the frequency of the missing pulse, indicating that the brain still shows evidence of neural entrainment to the beat even when a physical stimulus is not present. Participants with the greatest estimated SSEP amplitude were also those who had faster tapping onset times in the behavioural entrainment task, showing some relationship between behavioural and neural entrainment to the beat. However, the accuracy of tapping was not related to neural SSEP recordings.

Nave and colleagues (2022) investigated how SSEPs reflect music listeners' subjective perception of musical beat using EEG. Participants were tasked with a three-phase listening paradigm, where they had to maintain the beat in their heads without any behavioural strategies. The context phase was presented first with a rich musical excerpt following either a binary or ternary-beat pattern. Next, there was a beat ambiguous phase which had no identifying metrical structure. Participants were thought to maintain the beat subjectively, in their heads, throughout this phase. Then, the third phase was the probe phase consisting of a snare drum, which would either match the original pattern heard in the context phase or not. Their study found evidence of SSEPs occurring at the frequency of the beat throughout the ambiguous phase, into the probe phase, which provides further evidence of the SSEP as a signal of neural entrainment to the beat, which can persist in the absence of continued explicit beat and metre cues. This allowed participants to correctly indicate beat matching status at above chance levels through subjective beat maintenance. However, a limitation to this study is that no behavioural entrainment tasks were performed, thus no conclusions can be formed regarding the relationship between neural and behavioural entrainment. This study provides evidence of the brain's capacity to faithfully track and entrain to beat stimuli for extended periods of time, with SSEPs as a neural correlate for beat perception.

In summary, existing research has examined how reward and music activate the brain and prompt neural responding. The brain is known to be capable of faithfully tracking and entraining beat stimuli, even when no physical beat is present. There is a wide body of literature discussing the way musical reward motivates behaviours, such as in groove research and moving to music when stimuli are appropriately complex and engaging, and music reward motivating individuals to learn within the music domain. Research has also found that there are individual differences in the way reward is experienced in relation to music, which can reliably be measured using the BMRQ. Similarly, there are differences in how fast individuals exhibit entrainment of behavioural responding to beat. Nevertheless, it remains unclear how these differences affect neural and behavioural entrainment to beat, as there has yet to be any research which looks at the relationship between musical reward experiences and the ability to entrain responses to a beat.

The Present Study

The current study aims to understand how individual differences in musical reward might interact with an individual's ability to entrain to the beat of music either behaviourally or neurally. The current study will utilize a paradigm similar to the one implemented by Nave and colleagues (2022). While in an EEG cap to measure SSEP activation, participants will be tasked with a combination of listening and tapping tasks. Trials will consist of three listening phases: (1) a context phase with a rich musical excerpt following a clear beat and metre, (2) an ambiguous phase with no explicit beat patterns, (3) and a probe phase. However, this will differ from the previous study by Nave et al. (2022). Rather than simply listening to determine whether the probe matches the context phase, participants will be prompted to reproduce the beat behaviourally in the probe phase through tapping on a keyboard. It is expected that participants should be able to subjectively maintain the beat in their heads once they have perceived it in the context phase, throughout the duration of the ambiguous phase and into the probe phase to successfully complete this task. We expect participants who exhibit higher levels of music reward, as measured by the BMRQ, especially in the sensory motor and musical seeking facets, to exhibit SSEPs with more power associated with the frequency of the beat, indicating better entrainment of neural responding to the beat. Similarly, we expect to observe more synchronous and consistent tapping behaviours, indicative of behavioural entrainment to the beat, relative to participants with lower reward scores.

Methods

Participants

Forty participants were recruited from the University of Western Ontario using SONA, the Western University undergraduate participant recruitment tool, mass email recruitment methods, and the London community through word of mouth. Each participant met the inclusion criteria of being between 17-45 years of age (*M = 22.568, SD = 4.388),* having self-reported normal hearing, and having no known neurological conditions. One participant was excluded due to technical recording errors. Another was excluded due to having insufficient taps, and insufficient trial data. The final sample consisted of thirty-eight participants (9 = male, 29 = female), for whom all subsequent data analyses were conducted. All participants were compensated for their time with either $10 per hour (prorated to the half hour) or with research credits (0.5 per half hour of participation). Ethics approval was obtained by the Western University Research Ethics Board (See Appendix A).

Experimental Design

Measures

Participants filled out a basic demographics survey asking questions about age, sex, handedness, language, music reading abilities, and education experience, as well as questions regarding the exclusion criteria.

The Barcelona Music Reward Questionnaire (BMRQ) was used to assess individual differences in musical reward. The BMRQ measures five factors of music reward: emotion evocation, mood regulation, social reward, sensory-motor experience, and social reward (Mas-Herrero et al., 2013). Participants are asked to rate how much they agree or disagree with 20 statements measuring composite musical reward. Each subfactor was measured by four out of 20 questions. Participants had to select one of five options, ranging from “Completely disagree” to “Completely agree” (see Table B1). It has been suggested that the composite score is useful for estimating music reward sensitivity for individuals overall, but that specificity in individual differences in music reward can also be obtained based on the total score for each individual facet (Mas-Herrero et al., 2013).

Sustained Beat Task

To obtain measures of both neural and behavioural entrainment, we used the Sustained Beat Task (SBT), adapted from Nave et al. (2022) to include a behavioural measure of entrainment. Each trial in the SBT consists of three phases (See Figure 1). The context phase (phase 1) consists of a real musical excerpt played on a piano for 8 measures, where participants were instructed to listen to the music in this phase and extract the steady pulse, or the beat. The ambiguous or maintenance phase immediately follows the context phase, transitioning to a series of six isochronous eighth notes for 16 measures, during which participants are expected to subjectively maintain the beat within their minds throughout the duration (phase 2). Finally, the tapping phase consists of 8 additional measures of the beat-ambiguous rhythm, during which participants are asked to tap to the beat of the rhythm which they extracted from the context phase (phase 3). Participants completed the experiment on a desktop computer in a sound booth, tapping a key on the keyboard. This task was self-paced by participants, such that the next trial would not commence until they pressed the space bar.

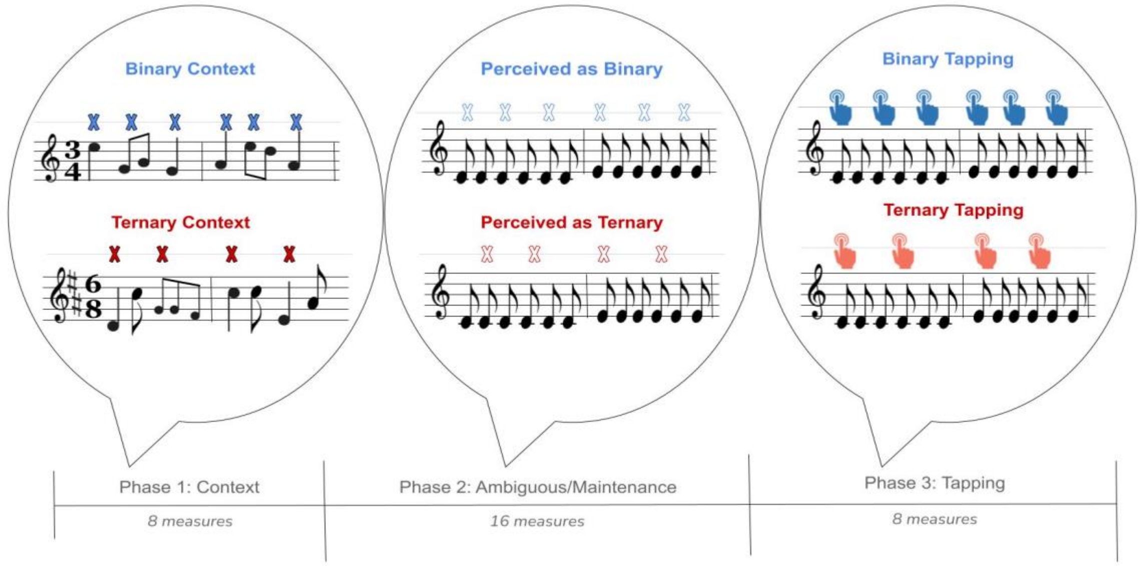


FIGURE 1. Trial structure for the Sustained Beat Task (SBT). In Phase 1, each solid “X” indicates where a beat should be perceived in the context phase, with Blue indicating binary beat, and red indicating ternary beat. In Phase 2, each outlined “X” indicates where an individual would maintain the induced beat percept in their head throughout the ambiguous phase, with blue “X” outlines indicating a binary beat percept, and red “X” outlines indicating a ternary beat percept. In Phase 3, the tapping phase, each blue hand indicates when participants should tap if they perceived a binary beat pattern, and each red hand indicates where the participants should tap is they perceived a ternary beat pattern. Phase 1 repeats for 8 measures. Phase 2 repeats for 16 measures. Phase 3 repeats for 8 measures.

Participants experienced four blocks, consisting of 16 trials each, of which eight trials had a binary beat, and eight had a ternary beat in the context phase. The total duration of each block is approximately 15 minutes, with an experimenter checking on the participant between each block and giving rest breaks where needed. The total duration of the SBT was approximately 60 minutes.

Stimuli for Entrainment Task

The SBT stimuli consist of 22 musical excerpts for the context phase, each one lasting for eight measures. Two are used as demonstration stimuli, four are practice stimuli, and the remaining 16 are experimental stimuli, each heard during the context phase of their respective blocks. All musical stimuli were adopted from Nave et al. (2022) and were MIDI generated with grand piano sampling. The music is available online through the Open Science Framework at www.osf.io/hwun9. Each musical excerpt has six eighth note positions per measure, differing in terms of the strong (S) and weak (W) accent placements to induce the perception of binary or ternary beat patterns. Melodic cues, such as changes in pitch contour and rhythm, were manipulated throughout the arrangement of each stimulus as important factors for inferring beat as a listener (Hannon et al., 2004; Nave et al., 2022). These manipulations ensured a salient beat was present in the stimulus. To ensure participants were only reliant upon the inferred beat pattern rather than other stimulus attributes, binary and ternary beat patterns were matched, such that no significant differences were present in the number of onsets, average pitch range, average pitch, and average pitch interval. The trials varied across beat and tempo conditions, such that participants were presented with half binary trials (half ternary) and half fast trials (half slow).

The ambiguous phase consists of six isochronous eighth notes, presented without specific beat cues or changes in pitch contour and rhythm to form a melody. This differs from the previous version of the SBT by Nave et al. (2022), which contained a rhythmic pattern. This allowed participants to perceive the beat pattern as either binary or ternary for the duration of this phase without extra influence. After each set of six eighth notes, a pitch change occurred to indicate a new measure and keep participants on track. The beat ambiguous condition continues for 16 measures. This allows for better frequency resolution estimates of the neural activity during this phase using Fast-Fourier transforms (FFTs) for analysis. Fast trials last 19.2 seconds, whereas slow trials last 28.8 seconds for the best results.

The tapping phase has been modified from the previous version of the SBT task by Nave et al. (2022), which included a pre-recorded example of a snare drum matching the binary or ternary beat pattern, to allow for the collection of behavioural entrainment data. Rather than hearing a pre-recorded drum snare, as in the demonstration and the previous SBT task, with the modifications, participants saw white text appear on the computer screen prompting them to "get ready to start tapping," then "tap the "m" key until the sound ends," after 16 measures of the maintenance phase. Throughout the duration of the tapping phase, participants continued to hear the same isochronous eighth notes from the ambiguous phase for eight measures, where the previous version only continued for two.

All stimuli were presented at both a fast tempo, with inter onset intervals (IOI) of 200ms per eighth note, and a slow tempo, with IOIs of 300ms per eighth note. The target beats of the fast tempo thus occur at 400ms for the binary beat pattern and 600ms for the ternary beat pattern. The target beats of the slow tempo stimuli thus occur at 600ms for binary beat patterns, and 900ms for ternary beat patterns. Adult humans tend to prefer 600ms inter beat intervals (IBIs; McAuley et al., 2006; van Noorden & Moelants, 1999), so this manipulation prevents any bias towards binary or ternary beat patterns based on IBI, as both binary and ternary have a condition where the IBI is set to 600ms.

Tasks and Procedure

Upon arrival, participants were brought to the EEG prep room, where they provided informed consent (see Appendix C). Here, they were fitted for the correct size EEG cap, and the EEG electrodes were fitted to their scalp and face. While this occurred, participants completed the demographics questionnaire and then the BMRQ, administered through Qualtrics on a laptop. EEG application and survey completion takes approximately 20 minutes in total.

Once both the EEG setup was complete and participants submitted all surveys, they were moved to a separate room equipped with a sound-attenuated booth and a desktop computer for participants to complete the SBT task. Using Radioear air tube headphones, participants completed the SBT task. The first block consisted of two demonstration trials, presented as though a piano teacher was teaching her student drummer, who was trying to match the beat of the music she played. Then, in the practice block, it was the participant's turn to practice matching the beat for four trials. An experimenter was present and listening to the audio in the sound booth through a second pair of headphones to aid participants in training and ensure they understood the task. If participants struggled with the task, either tapping to the rhythm or tapping the eighth notes in the ambiguous phase rather than beat, experimenters re-explained the task – if need be, the experimenter could also repeat the practice block for another four trials. Participants then continued to complete the four experimental blocks, consisting of 16 test trials each, taking approximately 15 minutes per block.

Participants were instructed to keep their feet flat on the floor, restrict their movement throughout each trial (i.e., no tapping extremities, no swaying etc.), and ensure their eyes stayed open and fixed on the screen for the duration of the task. The experimenter monitored the EEG data during the test blocks to ensure the cleanest EEG recordings as possible. Once participants finished all four experimental blocks, the EEG cap was removed, and participants were debriefed (see Appendix D) and compensated for their time.

EEG recording

All EEG data was recorded using a 64 channel Biosemi system, placed using the 10/20 international coordinate system. Six external electrodes were placed on participants at the outer canthus and the inferior orbit of each eye, as well as on each mastoid to control for eye movement and other muscle tension in the EEG data. EEG signals were recorded using an average reference, amplified, low-pass filtered at 500 Hz with a 1024 Hz sampling rate.

EEG Data Preprocessing

EEG preprocessing was conducted on all EEG data using Matlab (The MathWorks Inc., 2022). Data for all trials were trimmed (-1s to +1s) from the start and end to remove any excess data from continuous recording. To remove drift from EEG recordings, data were filtered through a 0.1 Hz high pass Butterworth zero phase filter. Bad channels were identified, and the bad channels were interpolated using surrounding data. Manual independent component analysis (ICA) rejection was then performed to remove any artifact in the EEG recordings such as eye blinks or muscle activity. To reduce the impact of any one channel and enhance signal clarity, re-referencing was performed across all electrodes. All epochs extracted lasted the exact length of the ambiguous or maintenance phase (phase 2) in each trial, such that fast trial epochs were 19.2 seconds and slow trial epochs were 28.8 seconds, removing both the probe and context phase. Each participant's EEG epochs were calculated as average waveforms across trials of all conditions. This was done to reduce the signal-to-noise ratio, removing excess activity not explicitly related to the stimulus, and leaving behind only stimulus-related activity. To investigate the periodic neural activity occurring during subjective beat perception in the ambiguous phase, the average waveforms were transformed into the frequency domain using a discrete Fourier transformation, with a frequency resolution of 0.052 Hz in the fast condition and

0.035 Hz in the slow condition. This allows for comparisons to be made between amplitude data at the same frequency in the stimuli and EEG data.

To extract valid amplitude estimates at the frequencies of interest, activity which was irrelevant to the task was removed by subtracting the average amplitude of signals at neighbouring frequency bins equal in size to the frequency resolution, allowing us to isolate only activity directly related to the SSEP. Waveforms without SSEPs are expected to approximate zero. Each subtracted average consisted of the activity from 3 to 5 bins on either side of the peak of interest (i.e. -3, -5, 0r +3, +5). Then, the amplitudes were extracted for the frequencies of interest at 1.11, 1.67, 2.50, 3.33, and 5.0 Hz. These frequencies do fall neatly into single frequency bins. As a result, max amplitudes of the peak from the three closest bins to the frequency of interest were extracted. This was done for comparison purposes between the SSEPs at the frequencies of interest throughout the beat ambiguous phase, where it was expected that SSEP activity would match the pattern of the induced beat from the context phase. The eighth note occurred at a 5.00 Hz frequency for the fast tempo, and 3.33 Hz frequency for the slow tempo stimuli. Thus, the resulting beat pattern for the binary condition had a beat pattern of 2.50 Hz in the fast condition, and 1.67 in the slow condition. The ternary condition had a beat pattern of 1.67 Hz in the fast condition, and 1.11 in the slow condition. SSEP magnitudes were averaged across all scalp electrodes for each participant in both conditions. Higher SSEP amplitudes are expected to be found at binary frequencies (2.5 Hz, 1.67 Hz), when the context phase preceding the ambiguous phase is binary, and higher SSEP peak amplitudes at ternary frequencies (1.67 Hz, 1.11 Hz), when the preceding context phase was ternary.

Data were subsequently categorized based on whether the participants “accurately” tapped to the induced beat presented in the context phase, rather than the rhythm or with every event (eighth note). Trials where participants did not tap accurately were removed from all subsequent analyses, including EEG analyses.

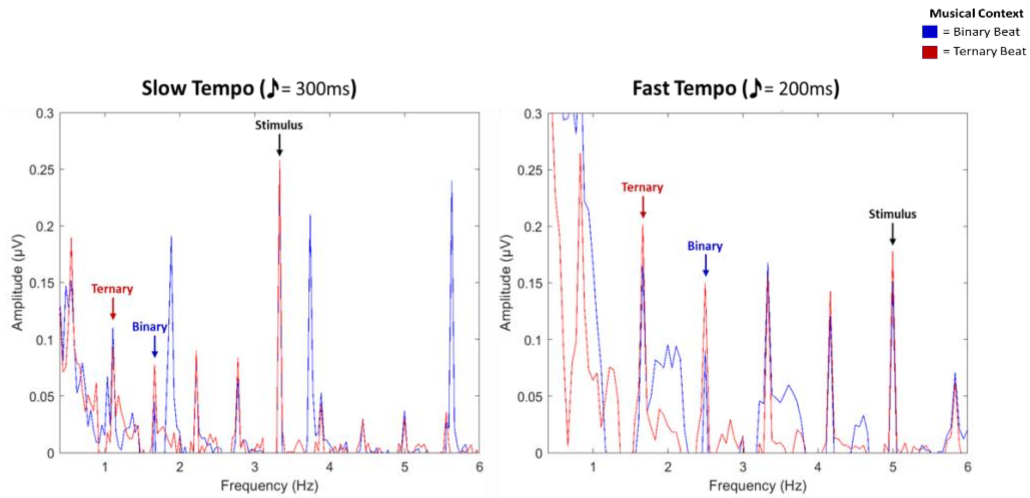
Data analysis

This study aimed to analyze the relationship between individual differences in musical reward and rhythmic entrainment as measured both behaviourally and neurally. To analyze the relationship between musical reward and behavioural entrainment. Pearson's correlations were conducted on all BMRQ subfactor scores and the composite score, as well as measures of behavioural and neural entrainment.

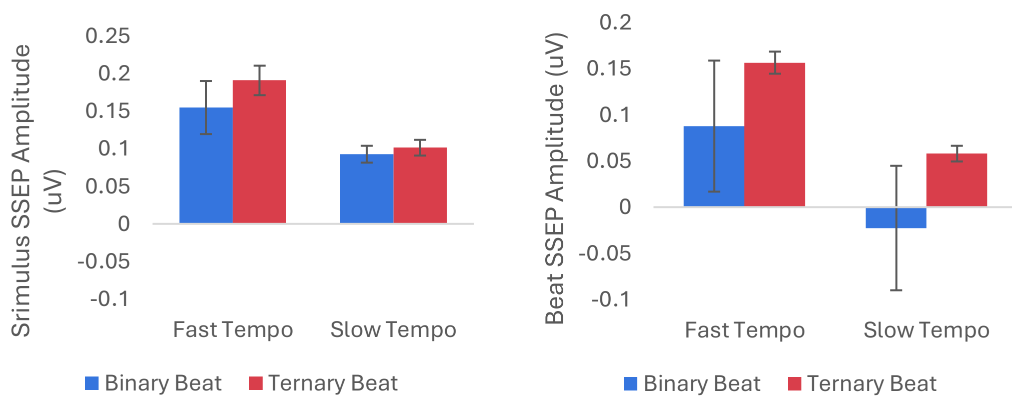
Using participant inter tap intervals and inter beat intervals, we examined participant average tapping asynchrony and tapping coefficient of variation (CoV). CoV can be defined as a measure of the consistency in an individual's taps, whereas asynchrony was calculated as a measure of absolute differences (ie., how early or late) participants tapped relative to the event, or the beat across all trials (Cameron & Grahn, 2014). To measure neural entrainment, we investigated average amplitudes of beat-related SSEPs, as well as the average amplitudes of stimulus-related SSEPs across all participants (Binary Fast: 2.5Hz, Binary Slow: 1.67Hz, Ternary Fast: 1.67Hz, Ternary Slow: 1.11Hz). All trials where participants tapped outside of the beat rate from the context phase were filtered out. To determine if entrainment differs within participants, across conditions, we conducted four separate 2x2 Tempo [fast, slow] x Beat [binary, ternary] repeated measures Analysis of Variance (ANOVAs) to determine whether there were any significant main effects or interactions for our within-subjects variables for each measure of entrainment (see Figure 2). All significant effects were corrected for multiple comparisons.

Analysis of Variance (ANOVAs) across conditions

a)



b)



c)

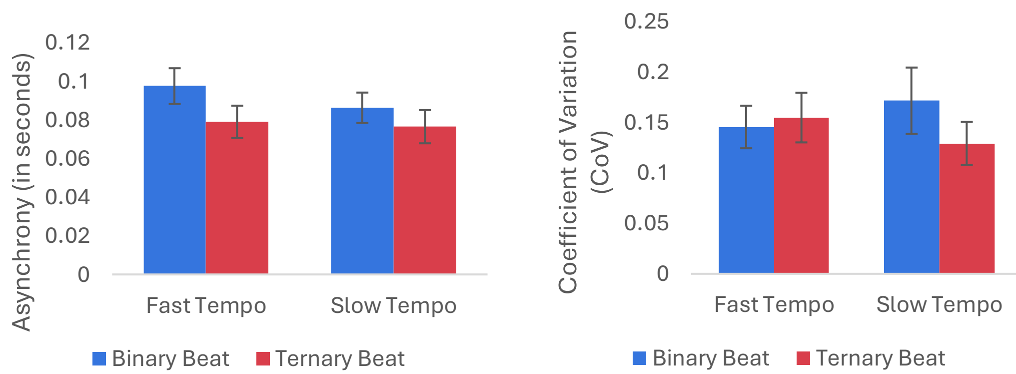


FIGURE 2. a) Fast Fourier Transform showing SSEPs at fast and slow, binary and ternary frequencies. b) Amplitude of Stimulus and Beat SSEPs for all participants across trial conditions. c) Asynchrony and CoV for participants across all trial conditions.

ANOVAs on Behavioural Measures of Entrainment

There was a significant main effect of beat on asynchrony (F = 19.711, p<.001, η^2_p = 0.117), but not tempo (F = 0.115, p=.738, η^2_p = 0.002) and no significant interaction (F = 1.592, p =.218, η^2_p = 0.011). There were no significant main effects of beat (F = 1.015, p = .323, η^2_p = 0.015) or tempo (F = 9.718 x 10^{-7}, p = .992, η^2_p = 1.015 x 10^{-6}), nor interaction for CoV. For all subsequent analyses, we collapsed across tempo for asynchrony and across tempo and beat for CoV.

ANOVAs on Neural Measures of Entrainment

The results from the ANOVA on beat SSEPs revealed a significant main effect of tempo (F = 0.429, p=.518, η^2_p = 0.002), but not beat pattern (F = 72.469, p<.001, η^2_p= 0.544) on SSEP amplitude at the beat frequency and no significant interaction effect between beat and tempo, for beat-related SSEPs. For stimulus SSEPs, we found a significant main effect of tempo (F = 22.342, p<.001, η^2_p = 0.401), but no main effect of beat (F = 3.258, p=.081, η^2_p = 0.004) and no significant interaction. As a result, we collapsed beat-related and stimulus-related SSEPs across beat, but not tempo (fast, slow) for all subsequent analyses.

Results

Musical Reward and Behavioural Entrainment

The results of the Pearson's correlation for the BMRQ scores and measures of entrainment provide some evidence of a relationship between only the Social Reward subfactor scores and ternary tapping asynchrony, but not with binary tapping asynchrony. The Social Reward subfactor of the BMRQ was significantly negatively correlated with average asynchrony on ternary trials (*r* = -.355*, p* = .037), such that lower asynchrony was associated with higher social reward sensitivity. While asynchrony on binary trials was not significantly correlated with scores on the Social Reward subfactor (*r* = -.325*, p* = .079), there was some evidence of a trend towards significance. No significant relationship was found between Social Reward and CoV. The remaining four subfactors of the BMRQ showed no evidence of a relationship to either average tapping asynchrony across beat conditions or CoV. We also found that composite Musical Reward scores were not significantly correlated with either average tapping asynchrony, or CoV (see Table 1).

Musical Reward and Neural Entrainment

We performed a Pearson's correlation analysis for BMRQ scores and measures of neural entrainment, which revealed no significant results (see Table 1). The average SSEP amplitudes at the stimulus frequency (Fast: 5Hz, Slow: 3.33 Hz), were not significantly related to BMRQ composite scores nor the five subfactor scores. SSEP amplitudes at the beat frequency were also not significantly related to the BMRQ subscale scores or composite, however there was evidence of Sensory of a trend towards significance (*r =.311, p* = .088), for Sensory-Motor reward scores and fast beat-SSEPs.

Discussion

This study's findings provide evidence of an association between individual differences in musical reward, and individual differences in behavioural entrainment to beat. The results of this research provide support for our hypothesis that individual differences in musical reward are associated with individual differences in entrainment, for behavioural entrainment but not neural entrainment to the beat. However, in contrast to our hypothesis, there was no evidence that Sensory Motor reward or Musical Seeking subfactors of musical reward are associated with

Table 1.
Correlation matrix: Entrainment Measures & Barcelona Music Reward Scores

Variables		*Async. Binary Trials*	*Async. Ternary Trials*	*CoV All Cond.*	*SSEP Beat Fast*	*SSEP Beat Slow*	*SSEP Stim Fast*	*SSEP stim slow*
1. *Composite Music Reward*	Pearson's r	-0.241	-0.215	-0.115	0.223	-0.060	0.189	-0.031
	p-value	0.200	0.214	0.510	0.229	0.748	0.310	0.870
2. *Emotional Evocation*	Pearson's r	-0.219	-0.184	-0.052	0.216	-0.013	0.192	-0.151
	p-value	0.244	0.291	0.767	0.243	0.946	0.302	0.418
3. *Musical Seeking*	Pearson's r	0.049	0.035	0.006	-0.059	0.033	0.069	0.063
	p-value	0.795	0.841	0.972	0.753	0.860	0.711	0.738
4. *Social Reward*	Pearson's r	-0.325^{t}	-0.355*	-0.262	-0.068	-0.102	0.018	0.075
	p-value	0.079	0.037	0.128	0.717	0.586	0.912	0.687
5. *Mood Regulation*	Pearson's r	0.079	0.114	0.229	0.119	-0.089	0.119	-0.074
	p-value	0.678	0.513	0.186	0.524	0.633	0.524	0.693
6. *Sensory Motor*	Pearson's r	-0.229	-0.190	-0.247	0.311^{t}	0.001	0.116	0.035
	p-value	0.223	0.273	0.153	0.088	0.995	0.535	0.850

Note: All measures of entrainment calculated as participant averages across all trials
P<0.05, p<0.01**, p<0.001***,* x^{t}*=trending*

either type of entrainment to beat. The relationship between Sensory-Motor reward and fast tempo SSEPs should be explored further.

The relationship between Social Reward and entrainment to beat is in line with dynamic attending theory, which posits that attentional shifting and entrainment to external stimuli occurs across contexts which allows humans to engage with their environments (Clayton, 2012), such that entrainment in musical contexts acts as a facilitator of social connection and engaging with others. This finding highlights the psychological basis and motivation for engaging with music, such that better entrainment to the periodic pulse in music facilitates reward through social connection.

Implications

Social connectedness is a fundamental need for all humans, with positive impacts on overall health and wellbeing (Delgado et al., 2023). Future research should examine the practical implications of entraining to music as a social facilitator. Music is a commonly used treatment for a variety of neurodegenerative disorders and can be used as a form of therapy to improve quality of life (Sharma et al., 2022). Future research should examine the role of entrainment on such positive outcomes, and how social reward through music may play a role in these positive treatment outcomes. Similarly, research should aim to examine whether social reward and entrainment scores are related to treatment outcomes across a variety of therapies.

Limitations

While the study was well designed, there were some limitations. The sample consisted largely of women, with 66% of the sample self-identifying as women (see Table 2), and participant ages closely hover around the mean age of 22.5 years. Due to the relatively homogenous sample, it is difficult to make conclusions regarding individual differences across sex or age. It is also possible that some participants struggled, as the SBT task was complex and required a participant's full sustained attention. Some participants reported not understanding what the "beat" was or asked experimenters to repeat the task instructions multiple times due to a lack of understanding. As a result, it is possible that some participants did not perform well because of their lack of task comprehension, rather than due to poor beat perception and entrainment. Similarly, despite being instructed to remain still with their eyes open and fixated on the screen for the duration of the trials to ensure the beat was maintained internally, it is possible that participants were maintaining the beat from the context phase using external strategies, such as tapping, blinking, singing or otherwise not mentioned strategies. This would likely have the effect of inflating behavioural entrainment scores (ie., lower asynchrony, lower CoV) for people who perceived the correct beat, and may cause noise on the EEG readings, making it difficult to measure neural entrainment.

Table 2.
Descriptive statistics

	Musical Reward		*Emotional Evocation*		*Musical Seeking*		*Social Reward*		*Mood Regulation*		*Sensory Motor*	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
n = valid	9	28	9	28	9	28	9	28	9	28	9	28
n=missing	0	0	0	0	0	0	0	0	0	0	0	0
Mean	50.000	54.536	46.000	53.214	54.556	55.571	49.222	56.393	56.222	55.214	43.889	46.536
Std Dev.	8.246	6.686	12.600	8.346	7.178	8.194	13.113	8.434	7.138	7.218	6.214	10.105
Minimum	37.000	43.000	25.000	33.000	46.000	35.000	30.000	30.000	46.000	37.000	34.000	21.000
Maximum	62.000	67.000	63.000	63.000	69.000	68.000	67.000	70.000	66.000	65.000	51.000	61.000

Conclusion

The present study aimed to understand how individual differences in musical reward relate to individual differences in entrainment to beat. We established a relationship between behavioural entrainment to a beat in ternary beat conditions, as measured by tapping asynchrony and CoV, and the Social Reward subfactor of musical reward, as measured by the BMRQ. No relationship was found between measures of neural entrainment and musical reward, as measured by the BMRQ. Further research should be conducted to understand why we see this relationship between Social Reward and behavioural entrainment, but not neural entrainment, and to understand how it develops.

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Appendix A

Research Ethics Status Form

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

Table B1.

Barcelona Music Reward Questionnaire (Mas-Herrero et al., 2013)

Instructions: Each item of this questionnaire is a statement that a person may either agree with or disagree with. For each item, indicate how much you agree or disagree with what the item says. Please respond to all the items; do not leave any blank. Choose only one response to each statement. Please be as accurate and honest as you can be. Respond to each item as if it were the only item. That is, don't worry about being consistent in your responses. Choose from completely disagree (left) to completely agree (right) one of the five options.

	Completely disagree	Disagree	Neutral	Agree	Completely Agree
When I share music with someone, I feel a special connection with that person.	☐	☐	☐	☐	☐
In my free time, I hardly ever listen to music.	☐	☐	☐	☐	☐
I like music that contains emotion.	☐	☐	☐	☐	☐
Music keeps me company when I'm alone.	☐	☐	☐	☐	☐
I don't like to dance, not even with music I like.	☐	☐	☐	☐	☐
I sometimes feel like I am "one" with music.	☐	☐	☐	☐	☐

Music makes me bond with other people.	☐	☐	☐	☐	☐
I inform myself about music I like.	☐	☐	☐	☐	☐
I get emotional listening to certain pieces of music.	☐	☐	☐	☐	☐
Music calms and relaxes me.	☐	☐	☐	☐	☐
Music often makes me dance.	☐	☐	☐	☐	☐
While listening to music, I may become so involved that I forget about myself and my surroundings.	☐	☐	☐	☐	☐
I am always looking for new music.	☐	☐	☐	☐	☐
I can become tearful or cry when I listen to a melody that I like very much.	☐	☐	☐	☐	☐
I like to sing or play an instrument with other people.	☐	☐	☐	☐	☐
Music helps me chill out.	☐	☐	☐	☐	☐

I can't help humming or singing along to the music that I like.	☐	☐	☐	☐	☐
It is sometimes possible for me to become completely immersed in music and feel as if my consciousness has been temporarily altered.	☐	☐	☐	☐	☐
At a concert, I feel connected to the performers and audience.	☐	☐	☐	☐	☐
I spend quite a lot of money on music and related items.	☐	☐	☐	☐	☐
I sometimes feel chills when I hear a melody that I like.	☐	☐	☐	☐	☐
Music comforts me.	☐	☐	☐	☐	☐
When I hear a tune I like a lot, I can't help tapping to the beat.	☐	☐	☐	☐	☐
When listening to great music, I sometimes feel as if I am being lifted into the air.	☐	☐	☐	☐	☐

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