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How attention and beat perception modulate neural entrainment to rhythm

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A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

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HOW ATTENTION AND BEAT PERCEPTION MODULATE NEURAL ENTRAINMENT TO RHYTHM

(Thesis format: Monograph)

by

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Graduate Program in Psychology

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of the requirements for the degree of
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Abstract

Recently, steady-state evoked potentials (SS-EPs) at the frequency of the beat have been observed in electroencephalograms (EEG; Nozaradan et al., 2011, 2012). Previous studies involved participants actively attending to isochronous sequences and repeating rhythms. Here we assessed whether neural enhancement of SS-EPs at beat-related frequencies occurred when (1) participants did not attend to the rhythms, and (2) the rhythm was novel and did not repeat.

When participants listened to rhythms that contained a beat SS-EP enhancement was larger during attended rhythms than when participants were distracted by another task, although SS-EPs were still present in all conditions. SS-EP enhancement therefore occurs in non-repeating rhythms, providing further evidence of SS-EPs as a marker of beat perception. Greater response in attended conditions suggests that attention may be a necessary component of beat perception.

Keywords:

Electroencephalography (EEG); Steady-State Evoked Potentials (SS-EP); Entrainment; Beat Perception; Rhythm; Attention; Sensorimotor Synchronization (SMS); Rapid Serial Visual Presentation task (RSVP)

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Chapter 1: Introduction

1.1 Beat and Meter

Music is ubiquitous. It pervades all cultures and regions. Rhythm and feeling the beat is fundamental to experiencing music. Rhythm refers to a series of auditory events in a temporal sequence. For example, if a bag of marbles is thrown in the air, they will make a rhythm when they hit the floor. This is not the kind of rhythm that is present in music. That is because rhythms in music are more temporally structured. When rhythms are structured so that they contain regularity, the temporal structure alone can give rise to perceptual accents (Essens, 1995; Povel & Essens, 1985). Perceptually accented events in a rhythm are events that are perceived as more salient than events that are not perceptually accented. When perceptually accented tones occur at regular intervals, the effect is the feeling of the beat, or a steady pulse that you can tap your foot to. Not all beats are perceived as equally salient; there are strong and weak beats. This pattern of strong and weak beats is referred to as meter. Meter happens on a number of different timescales, called metrical levels (Iversen, Repp, & Patel, 2009; Patel, Iversen, Chen, & Repp, 2005). In general, people are very good at finding the beat. Although most people do so spontaneously (Carolyn Drake, Jones, & Baruch, 2000; Sowiński & Dalla Bella, 2013) little is known about how we perceive a beat. For example, does beat perception arise spontaneously, even when we are not explicitly attending to the rhythm?

1.2 Advantages of electrophysiological techniques

Although beat perception has traditionally been studied using behavioural techniques, neuroscientific methodologies are becoming more popular in the field. Neuroscientific techniques have some undisputable advantages over behavioural techniques. For example, neuroscientific approaches provide another dependent variable to test; the brain's response can provide valuable information when an overt behavioural response cannot be measured. A study by Winkler, Haden, Ladinig, Sziller, and Honing (2009) illustrates this advantage. The researchers investigated whether the ability to feel the beat was present in newborns. Obviously, the researchers could not ask infants to make a behavioural response, so the infants (2-3 days old) listened to rhythms while their brain activity was recorded using EEG. Occasionally a tone in the rhythm was omitted; sometimes this omission was on a beat, other times it was off the beat. In this study, a clear difference in the EEG responses to omissions on and off the beat was detected, suggesting that beat perception may be present at birth, an exciting finding that behavioural research could not have shown.

A direct measure of the brain's response is also needed when studying the response to a stimulus that is not being attended to. It is difficult to have someone not pay attention to something, but still make responses. It would be like asking participants to indicate when they were not thinking about a specific animal; either they are thinking about not thinking about the animal (in which case they are thinking about it), or they are not able to make a response because they are not aware that they are not thinking about the animal. In any case, it is difficult to get an accurate assessment of the effect of attention from behavioural measures alone. A traditional behavioural response requires attention, but to find out what happens when attention is being diverted, another type of dependent measure is needed. Electrophysiological techniques like EEG are useful in this regard.

1.3 Is attention required for beat perception?

There is debate about whether or not the process of beat perception requires attention; could beat perception be automatic and pre-attentive? In the past, researchers have used event related potentials (ERPs) to try to answer this question, but the results were conflicting. Two EEG studies used evoked responses to test whether the neural components related to rhythm were distinguishable from those related to meter. In the first, Geiser, Ziegler, Jäncke, and Meyer (2009) measured changes in ERP responses to alterations of metrical organization (changes to the pattern of strong and weak beats in a rhythm) and responses to alterations of rhythmic organization (changes in the rhythm that did not affect the meter). To alter the metrical structure, one tone was added to or omitted from the rhythmic pattern. The original metrical organization of the rhythms was in groups of three beats. This means that every third beat was perceived as stronger relative to the other two in the group (e.g., **1** 2 3, **1** 2 3, etc.). The addition of a tone changed the grouping of three long beats to 3.5 beats, or seven beats that were half the original beat length. The omission of a tone changed the grouping to 2.5 beats, or five beats that were half the original beat length (in musical terms, the alterations shifted the metric structure from 3/4 time to 7/8 or 5/8 time). To make alterations to rhythm, without changing meter, the patterns were altered by replacing one long note with two faster ones. Participants either attended to the rhythm and meter directly (pressing a key when rhythmic or metrical changes were detected) or attended and responded to pitch changes in the stimuli that were unrelated to the rhythm and meter. In line with previous work, Geiser and colleagues (2009) found that changes to the rhythm elicited a negative ERP component between 100 to 150 ms after the perturbation, regardless of attention (Jongsma et al., 2005; Vuust et al., 2005). Perturbations to the metric structure, however, only elicited a negative ERP when attended. The fact that negative ERPs were observed for rhythmic violations regardless of attention, but to metrical violations only when attended, suggests that processing of meter is a more complex, attention-demanding process than processing of rhythm. One caveat, however, is that the metrical violations used in these study were more difficult to detect behaviourally than the rhythmic violations. Therefore, the lack of negative deflection to metrical changes in the pitch-detection condition may indicate that these particular metric violations were difficult, and required attention to detect, rather than indicating that *all* metrical encoding requires attention.

Other findings suggest attention may not be necessary to encode metrical structure (Ladinig, Honing, Haden, & Winkler, 2009). Ladinig et al. (2009) presented participants with repeating rhythms, but rather than changing the rhythms by adding or subtracting notes (as in Geiser et al, 2009), certain notes in the rhythm were omitted entirely, and there was silence where the note should have been. The omissions occurred on notes that were either metrically strong (e.g., downbeats), or metrically weak. By comparing omissions on strong and weak metric positions, both omissions are acoustically identical (silence is silence), but if participants had a metrical representation of the rhythm then omission of metrically strong notes should produce a greater response than omissions of metrically weak notes. To manipulate attention, participants were either asked to monitor the rhythm and indicate when an omission occurred, or to monitor a stream of white noise presented at the same time as the rhythms and indicate when the noise intensity changed. Metrically strong omissions elicited a larger brain response compared to metrically weak omissions, as measured by an ERP component called the mismatch negativity (MMN). The MMN was also larger for strong omissions in the white noise condition, when participants were not attending to the rhythm but rather to the white noise stream, suggesting that encoding of metrical structure does not require attention.

Thus, the ERP findings remain unclear about whether attention is required to perceive changes in meter or rhythm. Geiser and colleagues (2009) concluded that although rhythm perception was pre-attentive, metrical interpretation was not. However, Ladinig and colleagues (2009) showed a greater MMN to metrically strong omissions than to metrically weak omissions even when participants were distracted, suggesting that that at least some aspects of metrical structure are encoded pre-attentively. Given the contradictory nature of these findings others have tried to use different methodologies to answer the question of whether beat perception requires attention, or if it is an automatic response. The current study employs one of these methodologies, and will be discussed in more detail shortly.

1.4 Resonance Theory

The question of how one builds these metrical representations (regardless of whether the process is pre-attentive or not) is still unknown. One theory that has been gaining popularity is neural resonance theory (Large, 2008) which proposes that beat and meter perception arises from subpopulations of neurons entraining to, and resonating with, the beat frequency of the incoming stimulus. There is evidence that neural oscillations in primary sensory cortices entrain to attended rhythmic stimuli (Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008; Schroeder & Lakatos, 2009). In fact, resonance theory complements the ERP findings discussed earlier. Periodic oscillation of increasing and decreasing excitability in populations of neurons to beat and meter would suggest a mechanism for the modulation of the transient ERP response (Iversen et al., 2009). Notes occurring in more excitatory or ideal phases of the oscillation are enhanced, while notes occurring in inhibitory phases of the oscillation are not enhanced, or may even be suppressed (Lakatos et al., 2005). As more neurons fire in synchrony with the rhythm, the notes of the rhythm that occur at the times of peak firing evoke a greater response and are perceived as more salient. The increased neural firing in synchrony with the incoming stimuli also entrains the phase of lower frequency oscillations (Lakatos et al., 2005). This phase locking of low frequency oscillations (e.g., delta band <4Hz) gives rise to higher order sub-harmonics of the beat frequency. These sub-harmonics, in turn, are thought to give rise to metrical interpretation/perception (Nozaradan, Peretz, & Mouraux, 2012).

1.5 Steady-State Evoked Potentials

To measure neural entrainment to beat and meter directly, recent studies (Nozaradan, Peretz, Missal, & Mouraux, 2011; Nozaradan et al., 2012) have investigated the electrical activity generated by neural populations resonating with periodic stimuli in the form of steady-state evoked potentials (SS-EPs). As the name implies, SS-EPs are a series of individual evoked potentials that occur at a steady rate. To illustrate, consider the neural response to an isochronous tone sequence (e.g., a metronome). Each tone that occurs in the isochronous sequences elicits a single evoked potential. Since all the tones occur with a regular periodicity, the evoked potentials also occur at the matching rate, referred to as entrainment to the frequency of the periodic stimulus. This series of regularly occurring evoked potentials is referred to as a SS-EP. By transforming SS-EPs in the frequency domain we can measure the strength of the SS-EP in terms of power; larger evoked responses in the time domain translate to greater power in the frequency domain. Resonance theory suggests that certain events in a rhythm are perceived as more salient than others because the events occur in the more excitatory phase of the neural oscillation, which enhances the transient EP caused by that event. Since the phase of the neural oscillations has a regular periodicity, it means that the enhancement of these EPs also occurs with a regular periodicity as well. This regular increase in salience of some events compared to others is how we get a sense of the beat. Therefore the SS-EPs at the frequency of the beat should show increased power when undergoing spectral analysis.

In fact, this is what a pair of studies by Nozaradan and colleagues (2011) and Nozaradan, Peretz, Missal, and Mouraux (2012) recently investigated. In the first study, Nozaradan and colleagues (2011) had participants listen to an isochronous tone sequence from which they could extract a 2.4 Hz beat. While remaining completely still participants imagined the beats in groups of two (e.g., **1** 2 **1** 2 etc.) or groups of three (e.g., **1** 2 3 **1** 2 3). The researchers predicted that not only would the isochronous sequence elicit a SS-EP at the 2.4 Hz beat frequency, but that grouping of beats into binary and ternary meter would also elicit a distinct SS-EP at half the beat frequency, and at one third of the beat frequency, respectively. In line with their predictions, the researchers found a SS-EP at the beat frequency as well as at half the beat frequency (1.2 Hz) when participants imagined a binary meter, and at one-third of the beat frequency (0.8Hz) when participants imagined a ternary meter. These findings indicate two things: participants can impose a perceptual metric interpretation on isochronous tone sequences, and that entrained neural responses occur at the rate of the imposed interpretation.

1.6 SS-EPs to tag the beat in more complicated rhythms

A second study extended the findings of the first with short, repeating, and syncopated rhythms instead of isochronous tones. The rhythms induced the perception of a regular beat even though a note did not always occur on the beat. Therefore, if an enhancement of the SS-EP response was observed at the beat rate, the researchers could conclude that this enhancement was, at least in part, driven by perception of a beat, rather than being only driven by the notes in the rhythm. Again, consistent with predictions, researchers were still able to observe a SS-EP at the beat frequency for each syncopated rhythm. Taken with the results of the previous study, these studies provide compelling evidence that enhancements of the SS-EP response can be interpreted as neural markers of beat and meter perception.

1.7 SS-EPs as a marker for beat perception without attention

To date, previous investigations of SS-EP enhancement as a marker of beat perception have used either isochronous or short repeating rhythms, and participants' attention has always been focused on the stimuli. This repetition of the rhythm poses a potential confound. Because the previous rhythm sequences have been predictable, participants could have learned the specific rhythmic sequence, and as such, started to anticipate when the next event (i.e., tone) would occur. It has been shown that anticipation of a rhythmic event occurring can enhance the evoked response to that event when it occurs (Iversen et al., 2009; Lakatos et al., 2008; Schroeder & Lakatos, 2009). In other words, the evoked response is greater for events that occur when they are expected to. Therefore, the enhancement of the SS-EPs to previous rhythms could be explained in terms of increased responses to expected rhythmic events rather than as a result of beat perception. The current study sought to answer two questions: is attention necessary for beat perception? And secondly, can we observe SS-EP enhancement at beat and meter related frequencies in response to non-repeating rhythms similar to the enhancement observed in previous studies?

1.8 Design

To answer these questions I created non-repeating rhythms. By using non-repeating rhythms participants would not be able to learn the rhythmic sequence of the stimuli and therefore could not anticipate when the next tone in the rhythm would occur. The only feature of the rhythms that could be predicted was the beat itself. If SS-EPs are a marker of beat perception we should observe SS-EP enhancement at the beat frequency in non-repeating rhythms similar to the enhancement observed in repeating, syncopated rhythms.

1.8.1 Behavioural verification of stimuli

Two types of non-repeating rhythms were made: those with a perceivable beat, and those without a perceivable beat. First, a behavioural experiment was designed to verify that a beat was perceivable only in the rhythms that were designed to have a perceivable beat. To measure beat perception, I used a sensorimotor synchronization (SMS) paradigm (Iversen et al., 2009; Patel et al., 2005; Repp, 2005b), in which I measured the variability and asynchrony of participants' tapping as they tapped along to the beat while listening to the two types of rhythms. Although variability and asynchronies when tapping can be reduced with musical training (Carolyn Drake, Penel, & Bigand, 2000; Repp & Doggett, 2007; Repp, 2010), moving in synchrony with a beat is something that virtually everyone can do (Patel et al., 2005; Phillips-Silver et al., 2011a). For this reason, SMS paradigms are widely used to test the ability to perceive a beat in a rhythmic stimulus. Participants have smaller tapping variability and asynchronies when tapping to rhythms that have a strong beat, and larger variability and asynchronies when the beat is weak or difficult to find (Patel et al., 2005; Snyder & Krumhansl, 2010). In other words, rhythms with strong metrical structures often correspond with high temporal expectations of when the beat will occur; therefore synchronization accuracy is high (Desain, 1992; Large & Jones, 1999). If the stimuli are valid, tapping should be less variable and have lower absolute asynchronies for the beat stimuli than for the non-beat stimuli.

1.9 Summary

Previous studies using ERPs have found that beat perception is encoded both pre- and post- attentively, however, some of the discrepancy might in part be attributed to how cognitively demanding the specific metrical violations were to detect. The more recent method of using SS-EPs to directly observe neural entrainment using EEG is a promising methodology to use to solve this stalemate. One reasons for this is that distinct SS-EPs are elicited for beat and meter frequencies. Also, SS-EPs arise spontaneously, and can be modulated by top-down metrical imagery. However, because all research using SS-EPs has been conducted using either isochronous or short, repeated rhythms as stimuli it is still unclear if SS-EPs are truly a marker of beat perception or if SS-EPs arise as artifacts of the enhanced response to anticipated events (Lakatos et al., 2005). To answer these questions first non-repeating rhythms were created and tested to verify that rhythms that were supposed to contain a perceivable beat did, and those that were not supposed to, did not. Once the rhythms were verified the rhythms were used in an EEG experiment to investigate if SS-EPs still arose at the beat frequency in response to the non-repeating stimuli, and to determine if beat perception was dependent on attention.

Chapter 2: Experiment 1 – Sensorimotor Synchronization verification of stimuli

2.1 Introduction

2.1.1 Use of beat and non-beat, non-repeating rhythms

In the past, steady-state evoked potentials (SS-EPs) have been elicited using either isochronous tones (Nozaradan et al., 2011; Nozaradan, Zerouali, Peretz, & Mouraux, 2013) or short repeating sequences (Nozaradan et al., 2012). Using short repeating segments, and especially the isochronous tones, meant that participants could theoretically start anticipating specific tone onsets as soon as they learned the patterns. Additionally, although in one study the repeating sequences varied in complexity, which made detecting the beat easier or harder, the rhythms always contained a perceivable beat (Nozaradan et al., 2012). For these reasons it is not clear if SS-EPs are truly neural markers of beat perception, or if SS-EPs are a stimulus-driven response to regularity. To further investigate the question of what SS-EPs are indexing, I compared the SS-EP response to non-repeating stimuli both with and without a perceivable beat. By using non-repeating rhythms participants would not be able to guess what specific rhythmic pattern would come next. The only regularity would be the beat. Thus, if the SS-EP response to non-repeating rhythms is similar to that found in previous research, it would support the idea that SS-EPs are a marker of beat perception. It was also important to compare the response to beat and non-beat stimuli. As only stimuli with a perceptible beat have been investigated, the response to stimuli in which no beat is perceived is unknown. If the same pattern of SS-EP enhancement in beat stimuli is also observed in non-beat stimuli, it would suggest that SS-EPs might be indexing something other than beat perception. To answer these questions I created a number of non-repeating, beat and non-beat rhythms that were validated in Exp. 1 using a sensorimotor synchronization task (cf. Iversen, Repp, & Patel, 2009; Patel, Iversen, Chen, & Repp, 2005; Repp, 2005).

2.1.2 Creating beat stimuli

The rhythms for the beat condition were 40 metric simple (Grahn & Brett, 2007; Povel & Essens, 1985) sequences with a tone occurring every 909.2 ms, which was the presumed beat rate. The 909.2 ms between beats was divided into four 227.3 ms segments, giving four possible positions for tones to occur (see Fig. 1). For the time between each beat, the way in which tones filled these positions made up a rhythmic segment. For example, one segment might have tones in all four positions (every 227.3 ms), whereas another segment might only tones in the first and third position (each one being 454.6 ms apart), or perhaps in the first position only and nothing in the other positions (a duration of 909.2 ms before the start of the next rhythm segment). What is important is that there was always a tone in the first position of every segment. The different positions have different salience when establishing the metrical structure of a rhythm: the first position is the most salient, the third position is the next most, and the second and fourth positions are least salient when establishing metrical structure (Ladinig, Honing, Haden, & Winkler, 2009). Therefore, having tones in the first position of every rhythm segment should create a strong percept of the beat at that position, every 909.2 ms (1.1 Hz). It was expected that most participants would sense the beat rate corresponding to the tones in Position 1, this would give the sense of a 1.1 Hz beat rate. However, it was possible that participants could perceive the beat at half the rate of the intended 909.2 ms beat-rate (C Drake & Botte, 1993; Martens, 2011). That is, participants could potentially feel the beat at both the first and third positions even though a tone was not always present at the third position as it was in the first position.

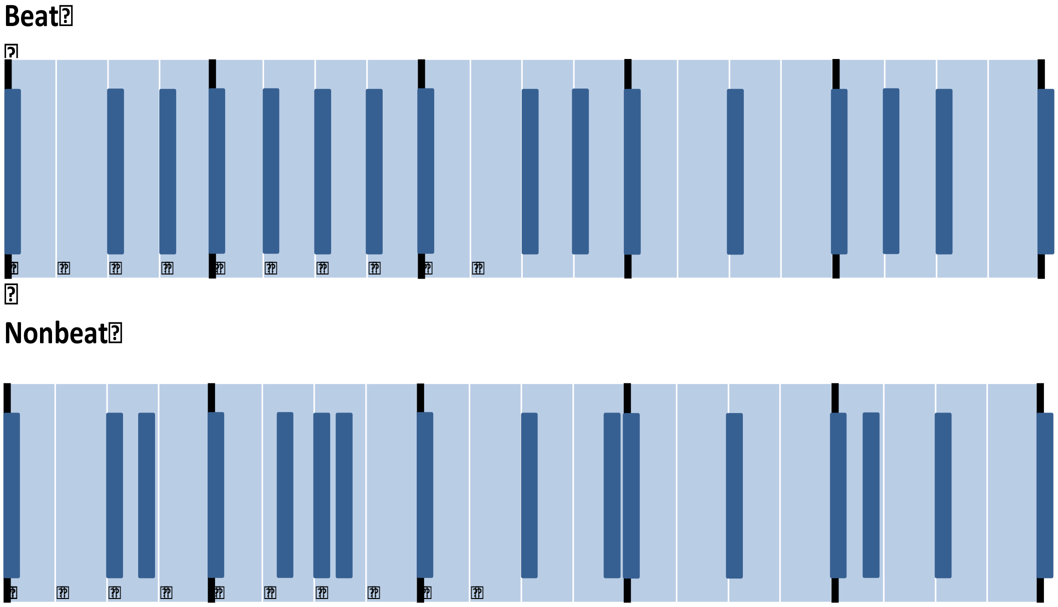

Figure 1: Tone onsets for beat and non-beat rhythms: Dark blue bars represent a tone, light blue background represents silence, black bars indicate 909.2 ms groups, and breaks in light blue background indicate 227.3 ms quartile sub-divisions of 1.1 Hz (909.2 ms) beat

Although particular rhythm segments might have been duplicated in a single rhythm sequence, the rhythm segments did not repeat in a predictable way. This is unlike the rhythmic sequences used in previous research (Nozaradan et al., 2012), which were comprised of short 2.3 or 3.2 second segments that repeated a number of times. The current rhythms were “front-loaded” with metrically strong rhythmic segments (Povel & Essens, 1985). That is, the first 15 seconds of the rhythm was comprised of more metrically strong segments than metrically weak ones (see Table 1). The second half of the rhythms contained equal numbers of strong and weak patterns. This was done to establish a strong percept of the beat early in the rhythm which would be continued throughout the duration of the rhythm. The strong and weak patterns were pseudo-randomly selected (see Appendix A) using a program in Matlab 7.14.0 (Mathworks).

Metrically Strong Interval Patterns	Metrically Weak Interval Patterns
[1 1 1 1]	[1 3]
[1 1 2]	[3 1]
[2 1 1]	[4]
[2 2]	

Table 1: Strong and weak metrical patterns used to create the rhythms in the stimuli; based on Povel & Essens (1985); Strong patterns give a much more obvious sense of beat than weak patterns do

2.1.3 Limitations of beat perception

To make the non-beat rhythms we used a method first demonstrated by Demany and Semal (2002). The researchers were interested in whether participants could detect an isochronous tone sequence if other tones were played at random intervals between tones in the isochronous sequence. The researchers created rhythms in which the inter-onset-interval (IOI) of every other tone was constant but the IOI of adjacent tones varied randomly. Thus, if tones in the sequence were divided into odd (tone 1, 3, 5, etc.) and even (tone 2, 4, 6, etc.) categories the odd tones would be isochronous while the even tones would be heard at random intervals between two odd tones or the even tones would be isochronous while the odd tones were randomized. Trials were presented in blocks in which either all tones were the same pitch, or even tones were a different pitch than odd tones. Before each trial, the computer that presented the stimuli randomly selected whether or not an isochronous tone sequence would be present or not. Participants reported whether or not they thought an isochronous sequence was present after each trial. The researchers found that while the isochronous sequence was almost flawlessly detected in the alternating pitch condition, participants, in general, were not able to detect the underlying isochronous sequence when all the tones were the same pitch. Thus, the researchers concluded that randomly presented tones in the isochronous sequence were enough to disrupt the perception of the steady periodicity if all of the tones were the same pitch.

2.1.4 Creating non-beat stimuli

Using a similar technique as Demany and Semal (2002) the rhythms for the non-beat condition were derived from the rhythms in the beat condition (see Appendix B). To disrupt beat perception, tones occurring in the second and fourth position were jittered, while tones occurring in the first and third position remained in the same temporal position (Fig. 1). Tones occurring in the second and fourth position were jittered by shortening or lengthening the IOI preceding the tone by one of five pre-determined intervals (31.8, 50.0, 72.3, 100.0, or 131.8 ms). The IOI following the tone was adjusted by an equal and opposite amount (i.e., if preceding IOI was shortened, then the following IOI was lengthened) so that the IOI between the tones that preceded and followed the jittered tone was preserved. For example, if tones were present in positions one, two, and three, the IOI between tone one and tone two would be shortened by some amount to jitter the onset of tone two. Then, to preserve the original IOI between tones one and three, the IOI between tone two and tone three would be lengthened by the same amount of time that that IOI between tone one and two was shortened. In this way, the periodicity of tones in the first and third positions was maintained while tones in the second and fourth position were jittered to disrupt beat perception (Demany & Semal, 2002). Maintaining the underlying periodicity of the stimuli was important so that comparisons could be made between the beat and non-beat conditions during Exp. 2. Since the underlying periodicity is maintained in the stimuli, this should also maintain the power of this frequency in the stimuli. This is important because it is possible to observe an auditory steady state response purely as a stimulus driven response in higher bands (e.g., 40Hz and 60Hz) which is modulated by stimulus intensity (Zhang, Peng, Zhang, & Hu, 2013). So if one of the conditions had more power at the beat frequency (i.e., 1.1 Hz) then it would be much more difficult to tell if differences in the neural response at that power were simply reflections of the differences in power of the physical envelope of the stimulus, or the differences were caused by beat perception per se.

2.1.5 Dependent variables (Coefficient of Variability and asynchrony)

Sensorimotor paradigms, in which participants tap along with the beat while listening to a rhythm, have been commonly used to test for beat perception (Iversen et al., 2009; Patel et al., 2005; Repp, 2005b). These paradigms measure, among other things, asynchrony (how accurate a tap is relative to a beat) and variability (how stable the timing of a series of taps is). Although musical training can improve tapping performance (lower asynchrony and variability) (Drake, Penel, & Bigand, 2000; Repp & Doggett, 2007; Repp, 2010), moving in synchrony with the beat is something that untrained participants can easily do (Patel et al., 2005; Phillips-Silver et al., 2011b; Repp, 2010; Zendel, Ross, & Fujioka, 2011). Previous research has shown that tapping asynchrony and variability are larger when participants tap along to rhythms with a weak or ambiguous beat, and smaller when participants tap with rhythms with a strong or obvious beat (Patel et al., 2005; Snyder & Krumhansl, 2010). Rhythms with strong metrical structures (i.e., that elicit a strong sense of the beat) elicit greater synchronization accuracy (i.e., lower asynchrony and variability) than rhythms with weak metrical structure, by creating high temporal expectations of where the beat will occur (Desain, 1992; Large & Jones, 1999). For this reason, I predicted that tapping asynchrony and variability would be larger when participants were tapping with the non-beat rhythms than when tapping with the beat rhythms.

2.2 Methods

2.2.1 Participants

Thirty-four participants took part in the study (12 male; Age: 18-33 years, M= 21.12, SD= 3.14; 30 right-handed) after providing written consent. All participants reported listening to music for at least one hour a week except one (range: 0-40 hours/week; M= 12.56, SD = 9.84). Participants had a wide range of musical training with 24 reporting some form of formal training (0-14 years, M= 4.66, SD = 4.12), and 6 reporting more than 10 years of lessons. Eleven participants (1 male; 8 with musical training) reported a history of dance training. Four dancers actively practiced at the time of the study. None of the participants had a history of hearing disorder, and none were taking any drugs or medications at the time of testing. This study was conducted with the approval of the Health Sciences Research Ethics Board at Western University.

2.2.2 Materials

Auditory stimuli. The auditory stimuli were created and presented with MatLab 7.14.0 (MathWorks) using the Psychtoolbox extensions (Brainard 1997; Pelli 1997). Stimuli for the beat condition consisted of 40 unique rhythmic sequences (see Appendix A), each lasting 33.64 seconds. These sequences were composed of a series of rhythmic intervals. The events consisted of a brief sound (990 Hz pure tone with a 40 Hz amplitude modulation lasting 50 ms with a 5 ms rise and fall time) then a silent period. The length of the silent period was adjusted to give intra-onset intervals (IOIs) of 227.3, 454.6 671.9, or 909.2 ms. The events were grouped together such that there was a tone onset every 909.2 ms, which gave a primary beat rate of 1.1 Hz. In addition to the 1.1 Hz, the rhythms also produced a periodicity at 454.6 ms (2.2 Hz). These periodicities are in a range known to be salient for human beat perception (C Drake & Botte, 1993; Martens, 2011).

The stimuli for the non-beat condition were 40 rhythms (see Appendix B) derived from the 40 rhythms used in the high beat salience condition. Each 909.2 ms beat interval was subdivided into four 227.3 ms periods that marked the possible tone onset positions for each rhythm segment (the time between two beat positions). Rhythms were modified so that the tone onset starting on the second and fourth subdivision of the beat (i.e., starting at +227.3 ms or +681.9 ms after the beat event, or position one) were alternately delayed or accelerated. The length of these IOIs lengths were adjusted by appending or subtracting one of five randomly selected lengths (31.8, 50.0, 72.3, 100.0, or 131.8 ms) to the silence of the event. Manipulating the IOIs in this way was done to disrupt subjective perception of the beat (Demany & Semal, 2002) while maintaining periodicity at 1.1 Hz and 2.2 Hz in the stimuli. It was necessary to use multiple levels of jitter to keep the jitter unpredictable and random so that perception of the beat was interrupted while maintaining power at the beat frequency (1.1 Hz) in the acoustic signals. Although maintaining power at the primary beat rate was not a vital part of Exp. 1, it will be important during the EEG recording for Exp. 2.

2.2.3 Procedure

The auditory stimuli were presented using QuietComfort® 3 Acoustic Noise Cancelling® headphones at a comfortable volume for the participant. Participants were asked to tap along with the perceived beat while listening to the rhythm sequences. Tapping times relative to the start of the trial were recorded by pressing a response button on an ErgoDex DX1 Input System (South Dakota, USA). After completing 4 practice sequences the test stimuli were presented in four blocks of 20 sequences each. Each sequence was preceded by a countdown of five seconds. Each block took approximately 13 minutes to complete and contained both the high and low salience sequences presented in a random order.

2.2.4 Analysis

Tapping rate. To determine the time between taps (inter-tap interval; ITI) the time of the preceding tap was subtracted from the time of the current tap. For example, if the preceding tap occurred 15.2 seconds after the start of the trial and the current tap occurred 16.1 s after the trial start then the ITI for those taps would be 0.9 s. ITIs that were less than half of the 227.3 ms interval (i.e., 116.3 ms) were removed because these were unlikely to be intentional responses as they were too short: people cannot generally tap that quickly (Martens, 2011), and it is more than twice as fast as people perceive the beat. Outlying ITIs were removed in two passes. First, the mean of the remaining ITIs was calculated, and any ITIs greater or less than 2.1 times the mean were removed. This pass mainly removed breaks where participants stopped tapping after they had begun. In these breaks they may have 'lost' the beat percept, and been searching for it again. Then the mean was recalculated and in the second pass, outliers greater or less than 0.7 times the mean were removed. The second pass eliminated large ITIs that were caused by missed button presses, usually during stable beat perception. This process removed 2.46% of ITIs.

Stability. To determine how stable the taps were for each participant the coefficient of variance (COV) was calculated. COV was computed by dividing the standard deviation of the ITIs by the mean ITI for each trial. The COV indicated how variable a participant's tapping was for each trial relative to the beat rate at which they tapped. This is useful because people may perceive the beat in a rhythm at different rates (Martens, 2011) and tapping at longer rates is more variable than shorter rates (Repp, 2005a, 2005b; Zendel et al., 2011). The coefficient of variance is thus a normalized measure of ITI variability.

Synchronization. In addition, to determine how well the each participant was able to synchronize with the beat, both the raw asynchrony and the coefficient of asynchrony (COA) were calculated. Raw asynchrony was calculated as the absolute difference between each individual tap time and the nearest beat time relative to the start of stimulus. For example, if the beat occurred at 15.456 seconds, and the tap occurred at 15.471 s, the asynchrony would be 15.471-15.456 = 0.014 s. As with COV, faster tapping rates leads to shorter asynchronies (Repp, 2005a; Zendel et al., 2011) so asynchrony was normalized by dividing the mean asynchrony by the mean ITI to give an unbiased estimation of asynchrony regardless of the tapping rate. The raw asynchrony and COA give an indication of how well participants synchronized to the beat, both as an absolute measure and as a proportion of the mean ITI for each trial.

2.3 Results

Paired-sample t-tests were conducted for COV, asynchrony, COA, and mean ITI to test for behavioural differences between the high and low beat salience stimuli. The coefficient of variability was significantly lower when participants were tapping to the rhythms in the beat condition (M= 0.138, SD= 0.095) than to rhythms in the non-beat condition (M= 0.149, SD= 0.098; $t_{(33)} = -2.13$, $p = 0.02$). Thus, tapping to non-beat rhythms was significantly less stable than tapping to beat rhythms (see Fig. 2).

Participants also had smaller asynchronies in the beat condition than the non-beat condition (see Fig. 2) both as an absolute measure (raw asynchrony: M_{high}= 0.060, SD_{high}= 0.026; M_{low}= 0.069, SD_{high}= 0.027; $t_{(33)}$ = -3.90, p < 0.001) and as a proportion of the beat rate (COA: M_{high}= 0.088, SD_{high}= 0.047; M_{low}= 0.102, SD_{high}= 0.052; $t_{(33)}$ = -3.08, p = 0.002). This indicates that participants were significantly worse at synchronizing their taps to the beat in non-beat rhythms than in beat rhythms.

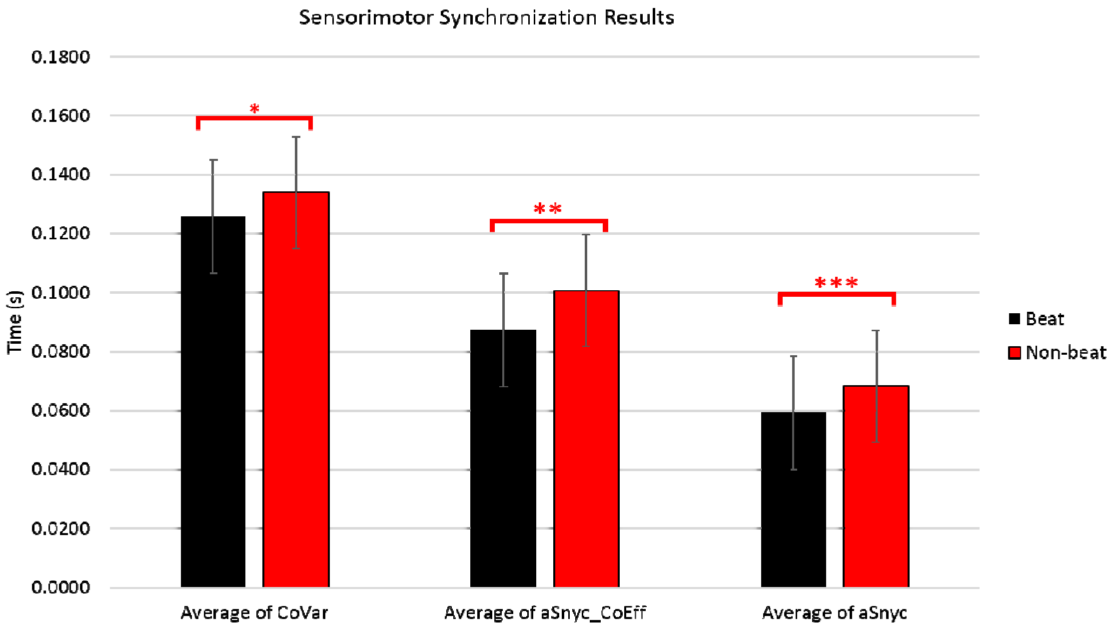

Figure 2: Comparative results of the SMS tasks; Black bars represent performance in the beat condition, red bars represent performance in the non-beat condition; lower scores indicate better performance on each task. ***Note:*** ******p***<0.01, *****p***<0.05, ******p***<0.001.**

Mean ITI did not differ significantly between beat (M= 0.830, SD= 0.342) and non-beat (M= 0.822, SD= 0.314) conditions ($t_{(33)}$ = 0.48, p > 0.05), indicating that participants tapped at similar average rates for both types of stimuli.

2.4 Discussion

In general, participants tapped more variably and showed greater tapping asynchronies in the non-beat condition compared to the beat condition. These findings are consistent with previous studies using a similar technique to obscure periodicity (Demany & Semal, 2002). The significant differences in behavioural performance in SMS in this study verified that significant perceptual difference in the extent that a beat was induced did indeed exist between the two stimulus conditions, making them appropriate stimuli to be used as beat and non-beat stimuli in Exp. 2. One possible explanation of the increased variance in the non-beat condition is that the less salient beat leads to lower or less precise temporal expectancies of where the beat will occur (Demany & Semal, 2002). Lower temporal expectancies result in participants being less able to find and synchronize with the beat in the non-beat condition compared to the more reliably occurring beat in the beat condition. The participants may therefore make more adjustments to their tapping rate in order to prevent larger asynchronies and ITI drift associated with off beat tapping (Repp, 2010).

Additionally, participants might have tapped rhythm of the stimuli instead of the beat, when they were unable to detect the periodicity of the stimuli in the non-beat condition. This pattern of tapping would have added to the larger variances and asynchronies in the non-beat condition. By obscuring the underlying periodicity of the rhythms using jittered tone onsets (Demany & Semal, 2002) the rhythm sequences became unpredictable. Previous research has shown that when participants try to tap to a consistent periodicity in an unpredictable sequences, the taps tend to echo the pattern of the rhythm in that sequence rather than a steady beat (Repp, 2010). In other words, when participants cannot perceive a steady beat they tend to tap reactively to each tone. This creates tapping patterns that reflect the rhythm of the sequence rather than the beat.

Mean ITI was analyzed in part with the intention that it would provide a measure of what rate each participant tapped on each trial in each condition, however, I was not confident with the results of the measure for a number of reasons. First, the distribution of mean ITI for each trial was bi-modal (Fig. 3), which makes interpretation of the mean ITI less meaningful. The bi-modality of distribution of mean ITIs is also the reason that the mean ITIs for the beat and non-beat condition, when averaged across the trials in that condition, are less than the intended beat rate (of 909.2 ms).

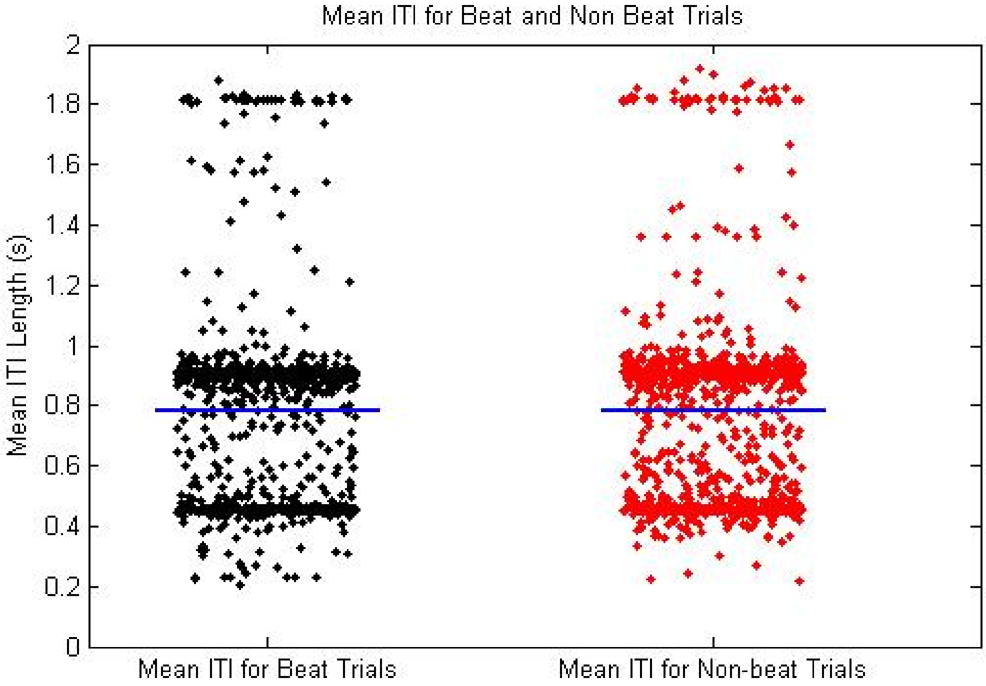

Figure 3: Mean ITIs for each trial in the beat and non-beat conditions (respectively); Black dots represent the mean ITI for each trail in the beat condition, while red dots represent the same in the non-beat condition; the mean for each condition is represented by the blue line.

In addition, there was the problem of ‘switch trials’. A switch trial occurred when a participant started tapping at one rate, but then switched to another possible beat rate part way through the trial (usually by doubling or halving the initial beat rate). Not only does this affect the mean ITI for that trial, but it also affects the variability and coefficient of variability of the taps (as they are both derived from the mean). If participants switched tapping rates from one plausible beat rate to another plausible beat rate mid-trial, the trial itself should not necessarily be excluded, because the participant demonstrated that they had a sense of the beat, but were just unsure at which metrical level to tap. Unfortunately, no automatic algorithm exists to separate trials in which the participant intentionally switches rates from one plausible beat rate to another plausible beat rate, from trials in which the participant tapped at multiple different rates as a result of attempting to find the beat in the non-beat stimuli. However, the results between conditions did not significantly differ whether potential switch trials were left in or excluded. It simply means that analyzing each trial to get a reliable measure of the mean ITI for that trial requires manual analysis.

However, even though the mean ITI is difficult to interpret with the current analysis, the results of the COV, asynchrony, and coefficient of asynchrony indicate that the conditions differ in the extent that they have a clear beat. In the next chapter, I examine the neural response to the beat and non-beat rhythms, and how that response differs when participants attend or do not attend to the rhythms.

Chapter 3: Experiment 2 – EEG investigation of SS-EPs

3.1 Introduction

3.1.1 Use of visual stimuli

Previous research investigating the effect of attention on beat and meter perception has diverted participants' attention from the metrical structure in the stimulus to detection of a change in stimulus features unrelated to beat and meter (Geiser, Ziegler, Jancke, & Meyer, 2009; Ladinig et al., 2009). These studies, however, have yielded contradictory findings. As mentioned previously, using ERPs, Geiser and colleagues (2002) found an early negative deflection in the EEG to alterations in metrical structure when participants were attending to the timing of the stimuli (attended), but not when they were detecting pitch changes (distracted), suggesting that metrical interpretation of a rhythm requires that the temporal nature of the rhythm be attended to. Contradictory to these findings, Ladinig and colleagues (2009) found that even when participants attended to detecting small intensity changes in the noise stream (i.e., when they were distracted from the rhythm stream), early negative deflections in the EEG were larger for omissions of metrically important rhythmic events than for metrically unimportant events. The larger deflections for metrically important positions, even during distraction, suggest that metrical processing is pre-attentive.

It is possible that that the contradictory findings resulted from differences in the type of metrical violations employed by the researchers. One study changed the metrical structure but did not have any silent gaps in the auditory stream (Geiser et al., 2009), while the other did not change the metrical structure, but had salient silent gaps (Ladinig et al., 2009). Detecting changes to a metrical structure may be more cognitively demanding than detecting omissions of metrically relevant notes within an unchanging metric structure. The contradictory findings could be explained not only by the difference in the cognitive demand between the two tasks, but also by the differences between the type of stimuli, the type of change being detected, and the types of distractor tasks that participants performed.

Alternately, perhaps metrical interpretation is not a dichotomous phenomenon, but an aggregate process that uses both pre-attentive and post-attentive processes. In other words, perhaps some lower-level aspects of metrical structure may be encoded pre-attentively, whereas as there are higher-level aspects that require attention to be encoded. For example, low frequency oscillatory entrainment that gives rise to greater evoked responses on metrically important events may occur automatically, and therefore may be sensitive to physical differences in the stimulus, such as sound versus silence. Thus, low-level oscillatory processes could account for response differences when metrically anticipated notes are omitted, as in Ladinig et al. (2009). In contrast, re-interpretation of metrical structure in an unbroken auditory stream, as in Geiser et al., (2009), may require more top-down, attention dependent processes.

Another factor that might have contributed to the contradictory findings is that the attentional diversion in the Ladinig and colleagues study (2009) may not have been sufficient to prevent the metrical structure of the rhythms from being perceived. Because the rhythms consisted of short segments that repeated for the duration of the study, and participants were still attending to the auditory modality (albeit to a white noise stream rather than to the rhythms themselves), it is possible that participants may have been able to build a perception of the metrical structure over time. Simply directing attention to another auditory task (e.g., detecting pitch changes of the notes, or intensity changes in background white noise) may be insufficient for preventing perception of metrical structure, particularly when the rhythms repeat. In addition, the stimulus driven response to the white noise stream could introduce EEG responses to that noise into the EEG recording. For these reasons, the current study used non-repeating rhythms, and directed participants' attention to the visual modality to complete a rapid serial visual presentation (RSVP) task.

3.1.2 RSVP review

RSVP tasks have been commonly used for testing attention in visual attention research. RSVP tasks usually involve presenting a series of visual stimuli rapidly; each stimulus (e.g. picture, letter, number, etc.) might only be presented for between 100 ms and 300 ms (c.f., Dell'Acqua, Turatto, & Jolicoeur, 2001; Potter, Chun, Banks, & Muckenhoupt, 1998). The rapid presentation of the stimuli makes RSVP tasks attentionally demanding. In fact, RSVP tasks can be so attentionally demanding that cues in the auditory modality may not even be perceived when monitoring an RSVP stream (Folk, Ester, & Troemel, 2009; Santangelo, Ho, & Spence, 2008; Spence & Santangelo, 2009). Therefore, to direct attention away from the auditory stream in the current experiment, participants completed an RSVP task.

3.1.3 Design

The study sought to answer two questions; is beat perception attentionally dependent and do non-repeating rhythms elicit enhancement of SS-EPs at beat-related frequencies? To answer these questions, I compared the power spectra of EEG recordings while participants were listening to rhythms. The frequencies of interest in the rhythm are the primary beat rate (909.2 ms/1.1 Hz) and the secondary beat rate (454.4ms/2.2 Hz). Also present in the stimuli is a periodicity of

4.4 Hz (227.3 ms), which corresponds to the smallest interval length of the rhythm, so entrainment at this frequency could plausibly be observed as well. Although this 4.4 Hz periodicity is more rapid than is usually perceived as a beat (Demany & Semal, 2002; C Drake & Botte, 1993; Martens, 2011), it is close to the lower end of the perceptible beat range found in previous research. Therefore, power at 4.4 Hz may also be enhanced, although no specific predictions were made about the 4.4 Hz frequency. Even though periodicity of the 4.4 Hz response is faster than people typically feel a beat, this frequency is considered to be a beat-related frequency because it is a harmonic of the primary beat frequency of 1.1 Hz. Also, the 4.4 Hz periodicity is present in the stimuli as one of the subdivisions of the primary beat rate (227.3 ms = 4.4 Hz). Comparisons of the power at beat-related frequencies (1.1 Hz, 2.2 Hz, and 4.4 Hz) and beat-unrelated harmonics of the primary beat frequency (i.e., 3.3 Hz and 5.5 Hz) were made across four conditions: attending to beat rhythms (attended beat condition), attending to non-beat rhythms (attended non-beat condition), distracted from beat rhythms (unattended beat condition), and distracted from non-beat rhythms (unattended non-beat condition). This two (attended or unattended) by two (beat and non-beat rhythms) design allowed for comparisons that investigated the effects of both attention and presence of a perceptible beat on neuronal entrainment to non-repeating rhythms.

Consistent with recent research using SS-EPs as a measure of beat perception (Nozaradan et al., 2011, 2012), the power spectra for EEG recordings and the stimulus envelopes were calculated using Fast Fourier Transform (FFT). The power spectrum gives the distribution of power over the range of frequencies contained in a signal. Although the range of frequencies is continuous, the FFT breaks the spectrum in to smaller discrete ranges (e.g., power at 1.1 Hz may technically be the power between 1.098Hz and 1.102Hz), called frequency bins. The range of the frequency spectrum and the width of the bins depend on recording parameters of the signal. For example, a higher sampling rate means larger spectral range, and longer epochs or recordings means narrower bin width. Complex waves, like those of an EEG, can be mathematically modeled using sine and cosine functions. The Fourier Transform calculates an estimate of the frequencies and amplitudes of functions needed to model the complex wave of the EEG. The power at each frequency bin is a measure of the amplitude each of these simple waves occurring within that bin's frequency range, such that greater amplitude means more power. Of particular interest are the primary beat frequency (1.1 Hz), the beat related harmonics (2.2 Hz and 4.4 Hz), and the unrelated harmonics (3.3 Hz and 5.5 Hz). Increased power in one condition relative to another is referred to as enhancement. Enhancement can be thought of in two ways: as global enhancement (i.e., power is increased across all frequencies in one condition relative to another) or as selective enhancement (i.e., power is only increased at certain frequencies in one condition, while others are unaffected). For example, global enhancement of all frequencies (beat-related and beat-unrelated) may be observed when comparing the attended and unattended non-beat conditions. In contrast, selective enhancement of beat-related frequencies (1.1 Hz, 2.2 Hz, and 4.4 Hz), but not beat-unrelated frequencies (3.3 Hz and 5.5 Hz), may be seen in the attended versus unattended beat condition.

To determine if beat perception requires attention, I compared selective SS-EP enhancement of beat-related frequencies (seen in previous research (Nozaradan et al., 2011, 2012)) in attended and unattended stimuli. Global enhancement of all frequencies in the attended condition may be a general effect of attention unrelated to beat perception. However, selective enhancement of beat-related frequencies would provide evidence that beat perception is specifically modulated by attention. To distinguish global vs. selective enhancement, the power spectra for attended and unattended rhythms were compared for beat and non-beat rhythms separately. If the pattern of enhancement for attended compared to unattended beat rhythms was similar to the pattern of enhancement for attended compared to unattended non-beat rhythms, then only a global effect of attention, unrelated to beat perception, can be concluded. However, if the enhancement patterns of attended and unattended beat rhythms differed from the enhancement patterns of attended and unattended non-beat rhythms, then this would be evidence that attention modulates beat perception. If beat and non-beat rhythms show different patterns of enhancement when attended and unattended, then it would suggest that attention is required for beat perception. Specifically, I predicted that beat-related frequencies (i.e., 1.1 Hz, 2.2 Hz, and 4.4 Hz) should show greater enhancement than beat-unrelated frequencies (i.e., 3.3 Hz and 5.5 Hz) when beat rhythms are attended compared to unattended.

Moreover, if enhancement of beat-related frequencies for beat rhythms was greater than for non-beat rhythms, it would support previous findings that enhancement of SS-EPs at beat-related frequencies is a neural marker of beat perception (Nozaradan et al., 2011, 2012). Previous work used beat rhythms that repeated over and over again. Thus, although it is likely that the SS-EP enhancement at beat-related frequencies did indeed reflect beat perception, it may also reflect the predictability of the rhythm after a few repetitions, rather than beat perception per se. In the real world, beat perception occurs even in response to rhythms that have never been heard before, and do not repeat over and over again. Therefore, if enhanced SS-EPs at beat-related frequencies are observed in the response to the non-repeating beat rhythms used in the current study, this would provide stronger evidence that the enhanced SS-EP response truly reflects beat perception. Furthermore, enhancement for the non-beat rhythms should be greatly reduced or absent altogether, as beat perception is minimal to non-existent in these rhythms, even though periodicity is still present in the stimulus at 1.1 and 2.2 Hz. In contrast, if the pattern of enhancement is similar for beat and non-beat conditions, it would suggest that SS-EPs index another mechanism (perhaps one that detects temporal the regularity present at 1.1 Hz and 2.2 Hz, but is unrelated to beat perception).

In summary, if attention is necessary for beat perception, and SS-EPs can be enhanced by beat perception in non-repeating rhythms, the beat and non-beat rhythms should show different patterns of enhancement in attended and unattended conditions. Specifically, beat frequencies (i.e., 1.1 Hz, 2.2 Hz, and 4.4 Hz) should show greater enhancement than non-beat frequencies (i.e., 3.3 Hz and 5.5 Hz) when beat rhythms are attended to compared to when they are unattended (during a concurrent RSVP task).

3.2 Methods

3.2.1 Participants

Thirty-one participants (27 from Exp.1; 11 male; Age: 18-33 years, *M* = 21.26, *SD* = 3.25; 28 right-handed) took part in the study after providing written consent. All participants reported listening to music for at least one hour per week except one (range 0 – 40 hours/week; *M* = 13.90; *SD* = 9.92). Twenty-four of the participants reported some musical training (range: 0-14 years; *M* = 5.36, *SD* = 4.22); seven reported more than 10 years of lessons. Ten participants (one male; eight with musical training) reported a history of dance training; four participants routinely practicing on a weekly basis at the time of testing. None of the participants had a history of hearing disorder and were not taking any drugs or medications at the time of testing. This study was conducted with the approval of the Health Sciences Research Ethics Board at Western University.

3.2.2 Materials

Auditory stimuli/presentation. Participants listened to the same auditory stimuli used in Exp. 1 presented over earphones at a comfortable volume using E.A.R.Tone, 3A insert earphones (E.A.R. Auditory Systems). Each 33-second rhythm was preceded by 10 seconds of silence to make a 43-second trial. Each 43-second trial was preceded by a three second count down that appeared on the computer screen in front of the participant. In the attended condition the program automatically waited two seconds following the end of one rhythm before starting the count down for the next. In the unattended condition the program waited for the participant to indicate the number of targets they saw in the previous trial. The program then waited for one second before starting the three-second countdown for the next trial. Rhythms were presented in blocks of 10 trials. Each block took approximately eight minutes to complete and there were eight blocks all together. There was a self-paced rest between each block, with a longer one after the fourth block so that the impedance of the EEG electrodes could be checked and corrected if needed. The entire experimental session lasted approximately two hours.

Visual stimuli. All visual stimuli were presented as white objects on the black background of a computer screen. During attended conditions participants were presented with a white fixation cross on a black background. The fixation cross was approximately three centimeters high by three centimeters wide, and was presented in the middle of the screen slightly below eye level of the participant. During the unattended condition the visual stimuli were white letters on the same black background presented in the middle of the screen, slightly below eyelevel of the participant. Both upper and lower case letters were used as targets and distractors in the RSVP steam so the size of the letters were either 1.5 centimeters or 2.25 centimeters high. A set of test stimuli was presented to the participant before the start of each testing session to ensure that participants could see the letters clearly.

3.2.3 Procedure.

During the EEG, participants completed two block types: attended and unattended. During attended blocks, while listening to stimuli participants were instructed to either keep their eyes focused on a fixation cross presented on a computer screen in front of them, or to close their eyes (as long as they were able to stay awake with their eyes closed).

During the unattended blocks participants completed a Rapid Serial Visual Presentation (RSVP) task while the auditory stimuli played. The RSVP task consisted of a string of letters presented one at a time, rapidly in the middle of a computer screen. Participants monitored the stream of letters in order to count the number of "x"s that appeared in the string. At the end of each trial the participant reported whether he or she saw an even or odd number of "x"s. Participants indicated their response by pressing a button on a CMU Response Box (Electrical Geodesics Inc.). Participants pressed the button labelled "1" if they counted an odd number of targets, or the button labelled "2" if they counted an even number of targets. Responses were made at the end of each trial to keep the EEG recording free of components or noise elicited by the motor response, and to limit participant movement during the trial. Importantly, the visual stimuli were presented at a rate of 6.986 Hz (every 145 ms), which was not a natural harmonic of the beat rate of the stimuli. Thus, any neural activity associated with the visual onset of the letters in the

RSVP task would not interfere with the response to the auditory stimuli at any of the frequencies of interest.

3.2.4 Data Collection and Analysis

EEG Recording. Participants were seated comfortably in a chair in front of a computer monitor. Participants were instructed to minimize any head or body movements, and reduce eye blinking and jaw clenching as much as possible during the recording. EEG was recorded using a 128-channel high-density electrode array from Electrical Geodesics Inc. (EGI; Eugene, OR, USA). Electrode impedances were kept below 50 kΩ. The signals were amplified and digitized using a sampling rate of 250 Hz, and referenced to the vertex electrode. Acquisition and recording of the EEG singal was done with a MacPro 4.1 running NetStation 4.5.1

EEG Analysis. Data from the EEG recordings were high-pass filtered above 0.3 Hz and trials were epoched (from -13 s to +33 s from the onset of the sound) using EEGLab (Delorme & Makeig, 2004) extension of MatLab. The lengthy portion preceding the onset of the sound was used later for spectral baseline removal. Bad channels and trials were removed in EEGLab, using a variance-based algorithm to identify bad channels. Bad channels were removed and interpolated from surrounding channels. The signal was then referenced to the common average. Bad trials were then removed using the same variance based algorithm. Only a few trials were removed (< 2%), and never more than one or two trials per participant. The data were then epoched again into two conditions: sound and silence. The sound epochs included data from +2 s to +32 s from the onset of the sound. This was to avoid transient evoked potentials elicited by the onset of the sound, and because it takes a few oscillations before the neural response entrains to the incoming stimulus (Nozaradan et al., 2012). Data were averaged across trials for each participant and then Fast Fourier Transforms were performed on the entire length of the sound and silence epochs separately. Performing the Fourier transform on the long-lasting epoch in this experiment is justified by (1) the assumption that beat and meter perception are stationary throughout the trials, and (2) it allows for better frequency resolution of the EEG frequency spectrum (Nozaradan et al., 2012). Spectral baseline removal was performed by subtracting the frequency spectrum of the silence from the frequency spectrum of the sound condition. This was done to control for systematic changes in the EEG signal that might have arisen from differences caused by participants closing their eyes during some blocks but not others, signal drift, or electrolyte in the net drying, etc.

Stimuli Processing. The amplitude of the sound envelope of the stimuli was extracted by performing a Hilbert transform on each of the stimuli. The stimuli were then down-sampled from 44100 Hz to match the sampling rate of the EEG (250 Hz). The average envelopes for the beat condition and the non-beat condition were obtained separately. A discrete Fast Fourier Transform (FFT) was then performed on each average sound envelope to extract the power spectrum for each of the beat conditions. Paired samples *t*-tests were then performed on the power values at each of the beat frequencies (1.1 Hz, 2.2 Hz, and 4.4 Hz).

3.3 Results

Comparing the power in the stimulus envelopes (Fig. 4) indicated that although power at 1.1 Hz was slightly higher in the beat condition ($M_{(beat)}$=3.93x10^{-4}, $SD_{(beat)}$=9.48x10^{-5}; $M_{(non\text{-}beat)}$=3.84x10^{-4}, $SD_{(non\text{-}beat)}$=1.17x10^{-4}), it not significantly different ($t_{1.1\ \mathrm{Hz}(39)}$=-1.77, p=0.085) between the beat and non-beat stimuli. However, power at both 2.2 Hz and 4.4 Hz did differ significantly ($t_{2.2\ \mathrm{Hz}(39)}$=-5.10, p<0.001; $t_{4.4\ \mathrm{Hz}(39)}$ =-2.18, p=0.036) between the two conditions. Therefore, the stimulus envelope of the beat and non-beat stimuli differed enough that beat and non-beat could not be considered to be two levels of the same factor as initially intended. As a result, the EEG responses to beat stimuli were analyzed separately from the responses to the non-beat stimuli. Therefore, separate 2 (Attended/Distracted) by 5 (frequencies of interest [1.1, 2.2, 3.3, 4.4, and 5.5 Hz]) repeated measures ANOVAs conducted on the power at each frequency for beat and non-beat stimuli. The selected frequencies were integer multiples of the primary beat frequency (1.1 Hz). Planned contrasts (paired t-tests) compared the Attended and Distracted conditions at each frequency.

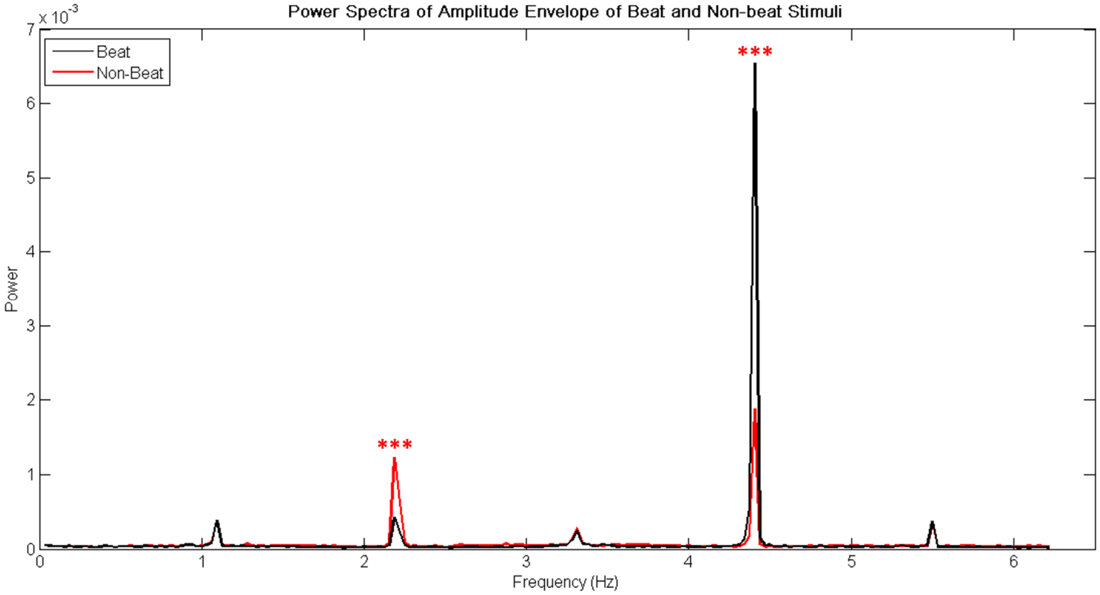

Figure 4: Average Power of Stimulus Envelope in Beat and Non-Beat conditions; power does not significantly differ at intended beat frequency of 1.1Hz, but does differ significantly at 2.2 Hz and 4.4 Hz. This means that SS-EP enhancement at these frequencies could not be compared between the beat and non-beat conditions since the stimulus driven response would be significantly different also. *Note*: ***p<0.001.

3.3.1 Repeated Measures ANOVAs

The repeated measures ANOVA on the beat condition found a significant main effect of attention ($F_{(1,30)} = 6.46$, $p = 0.016$; $M_{attended} = 1.180$, $SD = 0.086$, $M_{unattended} = 0.955$, $SD = 0.067$). The power of the EEG response was significantly greater when attending to the stimuli than when attending to the RSVP task. No significant effect of attention was found in the EEG response to the non-beat stimuli ($F_{(1,30)}$ = 2.55, p=0.120; $M_{attended}$ = 0.934, SD = 0.072, $M_{unattended}$ = 0.835, SD = 0.061) indicating that the enhancing effect attention was only seen when rhythms contained a perceivable beat.

There was a significant main effect of frequency in both the beat and non-beat conditions ($F_{(4,120)}$ = 79.58 and $F_{(4,120)}$ = 30.21 respectively, p < 0.001), but there were no significant interactions between attention and frequency in either condition. Thus, the effect of attention did not differ for different frequencies in either condition. The main effect of frequency is not meaningful, as the power of the beat frequency and its harmonics differs in the stimulus envelope, so also would be expected to differ in the EEG response.

3.3.2 Planned Contrasts

Paired samples t-tests were conducted to compare the power of the EEG at the pre-planned frequencies of interest (1.1 Hz, 2.2 Hz, 3.3 Hz, 4.4 Hz, and 5.5 Hz) between the attended and unattended conditions in the beat and non-beat conditions separately (see Fig. 5). Responses in the attended condition were significantly larger at 2.2 Hz ($t_{(30)}$ = 2.86, p = 0.004) and 4.4 Hz ($t_{(30)}$ = 2.01, p = 0.027). In the unattended condition, the only significant enhancement is at 4.4 Hz ($t_{(30)}$ = 2.33, p = 0.031). The differences in the patterns of enhancement between these two conditions suggest that beat frequencies are selectively enhanced when a beat is perceivable in the rhythm.

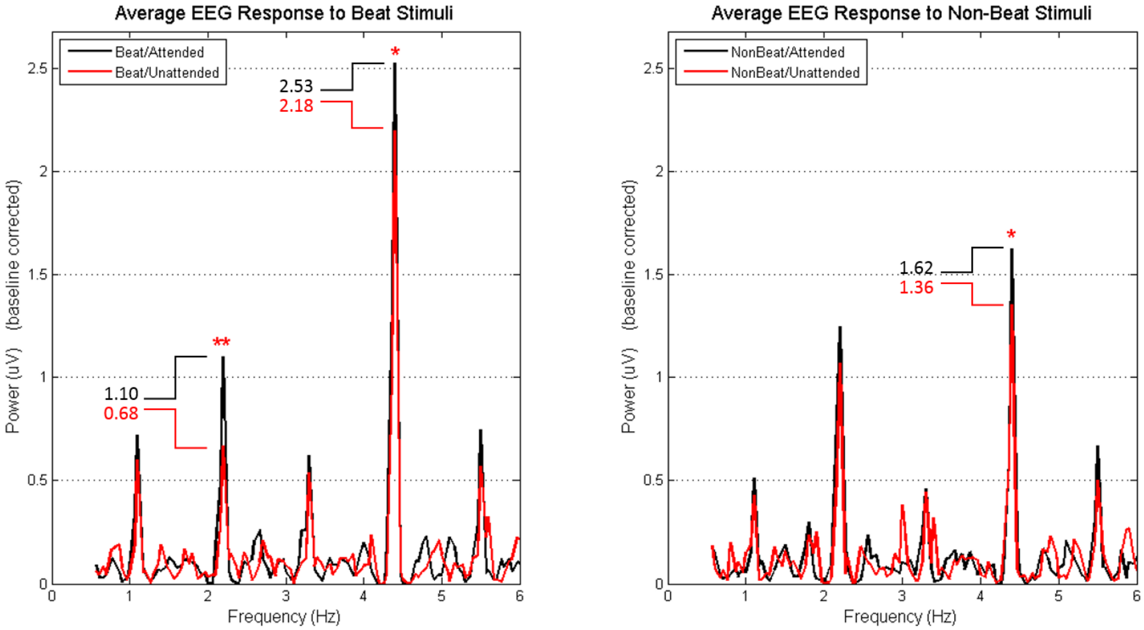

Figure 5: Average EEG response to beat and non-beat stimuli when attended and unattended; left: comparison of average EEG power for beat rhythms, right: average EEG power for non-beat rhythms; black = stimuli attended, red = stimuli unattended. *Note:* *$p<0.01$, **$p<0.05$.

3.4 Discussion

I found enhancement of SS-EPs at beat-related frequencies (2.2 Hz and 4.4 Hz) when stimuli containing a perceivable beat were attended to compared to when the stimuli were unattended, whereas only 4.4 Hz was enhanced by attending to the stimuli in the non-beat condition. That is, enhancement of beat-related SS-EPs was only present when a beat could be perceived in the rhythms. These results suggest that the beat perception response was only enhanced by attention when a beat was present. When a beat was not present (i.e., in the non-beat condition) the neural response when attending to the stimuli and when distracted from the stimuli was similar. Increased variability and asynchrony of taps to the non-beat rhythm in Exp. 1 suggests that perception of the beat was absent, or at least less robust than in the beat condition. However, there was still greater power in the EEG signal at beat-related frequencies than beat-unrelated frequencies. One possible explanation of this is that power at the beat frequencies represents a stimulus driven response. Therefore, because power at beat-related frequencies remained even though percept of the beat was reduced, the occurrence of increased power at beat-related frequencies cannot be taken as a marker of beat perception by itself. However, the selective enhancement of the SS-EPs at the beat frequencies, specifically 2.2 Hz and 4.4 Hz, when attention was directed to the rhythms with a perceivable beat supports previous research that suggests selective enhancement of beat-related frequencies compared to beat-unrelated frequencies is a marker of beat perception.

Furthermore, selective enhancement of the power of the SS-EPs at beat-related frequencies was modulated by attention to the stimuli. The differences in the patterns of selective enhancement of SS-EPs at beat-related frequencies compared to beat-unrelated frequencies when a beat was perceivable provides evidence that attention is required for beat perception. However, until the relative enhancement of SS-EPs at beat frequencies (see Nozaradan et al., 2011) can be compared directly between the beat and non-beat conditions it cannot be said for certain that beat perception is dependent on attention or if the differences between the two conditions are due to acoustic differences in the stimuli. Future work should examine the relative enhancement when a beat is present compared to when it is absent (e.g., metrically complex and non-metric).

Chapter 4: General Discussion

4.1 Sensorimotor synchronization

In Exp. 1, the significantly larger asynchronies and variance in the tapping for the non-beat condition compared to the beat condition verified that the beat/non-beat manipulation of the stimuli was successful. The poorer tapping performance in the non-beat condition is in line with previous findings showing that percept of an underlying periodicity can be disrupted by randomizing intervening IOIs (Demany & Semal, 2002). The larger asynchronies and variances in the non-beat condition suggested that the rhythms were appropriate to use in Exp. 2 as beat- and non-beat-inducing. What is useful about these rhythms is that they have similar power at the 1.1 Hz beat frequency. As part of the steady state response is stimulus-driven, it is important that power at the compared frequencies is matched in the beat and non-beat conditions, if those two conditions are to be meaningfully compared. If the beat condition contained more power at 1.1 Hz than the non-beat condition, then any differences in the EEG responses at 1.1 Hz may be driven by these stimulus differences. It was also expected that power at 2.2 Hz would be similar, or perhaps reduced, in the non-beat condition compared to the beat condition. However, as discussed earlier, this was not the case. In fact, the opposite was true, and power at 2.2 Hz was greater on average in the non-beat condition than in the beat condition. This result was counterintuitive and is in need of further exploration.

4.2 EEG: Selective enhancement of beat-related SS-EPs

Using the beat and non-beat rhythms verified in Exp. 1, I found an attention-related enhancement of the EEG power at beat-related frequencies in the beat stimuli, but not in the non-beat stimuli. It was possible that attending to the stimuli would have caused a global enhancement and power of the EEG would have been increased across all frequencies. However, selective enhancement at beat-related frequencies was observed. That is, there was greater enhancement of the power at 2.2, and 4.4 Hz frequencies when participants attended to the rhythms compared to when they were distracted by a visual task. Importantly, enhancement was not observed for the beat-unrelated frequencies (3.3 and 5.5 Hz) suggesting that attention selectively enhanced beat perception, rather than enhancing the overall EEG response driven by the acoustical input of the rhythms. Moreover, the selective enhancement by attention at beat-related frequencies was not observed in the non-beat condition other than at 4.4 Hz, which is a rate that is considered too rapid to feel a beat (Demany & Semal, 2002; C Drake & Botte, 1993; Martens, 2011; Repp, 2005b). Selective enhancement of beat-related frequencies in the beat condition, but not in the non-beat condition suggests that attention modulates the neural response to beat perception.

4.3 Enhancement of attention in beat but not in non-beat

The pattern of selective enhancement found in the attended vs. unattended conditions for each of the rhythm conditions also supports the idea that enhancement of SS-EPs is a marker of beat perception. In the beat condition, SS-EPs at beat-related frequencies were selectively enhanced compared to beat-unrelated frequencies when participants attended to the stimuli, but not when they were distracted by the RSVP task. This contrasts with the non-beat condition, in which the power of the neural response was similar (with the exception of the 4.4 Hz response) between the two attention conditions. This suggests that attention did not have globally enhancing response (increasing power across all frequencies), but rather, only enhanced the response at beat-related frequencies, and only when a beat was present. Selective enhancement of beat-related frequencies in only the beat condition, not the non-beat condition, provides evidence that perception of beat and meter depends on attention. However, the finding of attentionally induced enhancement at 4.4 Hz in the non-beat condition is somewhat puzzling.

4.4 Enhancement in non-repeating rhythms

The attended beat condition was most similar to the conditions present in previous research in which participants' attention was directed to the stimuli (Nozaradan et al., 2011, 2012). In the current study selective enhancement of power in the EEG was observed at beat-related frequencies but not beat-unrelated frequencies. This is consistent with previous studies that also observed selective enhancement at beat frequencies but not at beat-unrelated frequencies. The difference between this study and the previous investigation (Nozaradan et al., 2012) is that the rhythms in this study were non-repeating, whereas rhythms in previous studies were comprised of short repeating segments. Even though the rhythms in the current study did not repeat, the same pattern of selective enhancement of the EEG response at beat-related frequencies was observed. Finding a similar enhancement in non-repeating rhythms supports that idea that enhancement of the SS-EPs at beat-related frequencies is a neural marker of beat perception. Unfortunately, until the enhancement has been measured relative to the power present in amplitude envelope of the rhythms themselves, it is difficult to say exactly what amount of the SS-EP response is stimulus driven and what amount results from beat perception.

4.5 Limitations

There were also some limitations of the study. One issue is that power at 2.2 Hz wasn't identical between the beat and non-beat rhythms. This is important because there is still increased power in the EEG signal at both beat-related (1.1 Hz, 2.2 Hz, and 4.4 Hz) compared to beat-unrelated (3.3 Hz and 5.5 Hz) frequencies in the non-beat unattended condition. This pattern suggests that some of the power of SS-EPs in the EEG signal is stimulus driven. Therefore, to give an estimate of how much of the SS-EP is beat perception and how much is stimulus driven, the acoustic properties of the of the stimulus envelope need to be taken into consideration before enhancement of the SS-EPs at beat-related frequencies can be compared between beat and non-beat conditions. Previous research in this area has accounted for the contributions of the stimulus envelope using a z-score procedure across the peaks of the frequencies of the envelope spectra (Nozaradan et al., 2012). Using the z-scores allowed researchers to determine which frequencies stood out from (had more power than) the other frequencies, but also how much they stood out relative to the others. Transforming the power at each frequency into a z-score allowed the relative power of the frequencies of interest in the stimulus envelope to be compared to the relative power of the same frequencies in the EEG signal. If the same relative power was observed at the same frequencies in both the stimulus envelope and the EEG signal, then there was no enhancement of any frequencies in the SS-EP relative to what would be expected based on the stimulus power. Conversely, if the relative power of beat-related frequencies were greater in the EEG signal compared to the power of those same frequencies in the stimulus envelope, then SS-EP enhancement occurred.

Using the *z*-scores also allows relative enhancement at beat-related frequencies to be compared across conditions in which the envelope spectra were not matched. This procedure would be particularly useful in the current study to determine whether the EEG power at 2.2 Hz was greater in the beat condition (relative to 2.2 Hz power in the beat rhythms) than in the non-beat condition (relative to 2.2 Hz power in the non-beat rhythms). However, the use of non-repeating rhythms in this study made the FFT analysis of the sound envelope more complicated than in previous research, thus this analysis will need to be worked out in the future. Controlling the power at 2.2 Hz, as well as at 1.1 Hz, is important because, although many people tapped at 1.1 Hz as well as at 2.2 Hz, people are generally more sensitive to periodicities in the 2.2 Hz range (Demany & Semal, 2002; C Drake & Botte, 1993; Martens, 2011; Repp, 2010). In other words, even though *production* of the beat (tapping) occurs at 1.1 Hz, previous work suggests that *perception* of the beat (SS-EPs) may occur more commonly at 2.2 Hz, thus, analysis of both frequencies is of interest.

4.6 Future directions

Future analyses could examine each individual EEG trial based on what rate that participant tapped the beat on that trial in the behavioural experiment. The analyses in the current study focused on 1.1 Hz and 2.2 Hz in all beat rhythms, but the actual rate that the beat was perceived may have differed from individual to individual, and even from trial to trial within an individual. Therefore using the mean response across all trials of a condition may not be the most sensitive approach. Because beat perception tends to be hierarchical (people have access to multiple levels of the metric hierarchy at once, and can switch their tapping from one to another by doubling or halving their tapping rate) it is unlikely that perceiving a beat at 1.1 Hz means that NO beat was perceived at 2.2 Hz, but these analyses could improve the sensitivity of the EEG analyses to the beat most prominently perceived by each individual on each trial.

4.7 Conclusions

Attention selectively enhanced beat-related frequencies compared to beat-unrelated frequencies when rhythms contained a perceivable beat, but this selective enhancement did not occur when a beat could not be perceived. Selective enhancement of beat-related frequencies occurred only when a rhythm with a perceivable beat was attended to, even in non-repeating rhythms. The findings provide evidence that SS-EP enhancement at beat-related frequencies is a neural marker of beat perception, and that beat perception is attentionally dependent.

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Appendix A

INTERVAL WEIGHTS FOR RHYTHMS USED IN THE BEAT CONDITION

Rhythm #	Interval weights									
1	2	1	1	1	1	1	1	2	1	1
	3	1	3	1	1	1	2	4	2	2
	2	1	1	3	1	4	4	2	1	1
	1	1	2	1	1	1	1	1	3	1
	1	2	2	2	1	1	2	3	1	4
	4	1	1	1	1	4	4	3	1	4
	2	1	1	4	2	2	2	2	3	1
	1	1	2	1	1	1	1	4	3	1
	1	3								
2	2	1	1	3	1	1	3	1	3	3
	1	4	2	1	1	4	1	1	1	1
	1	1	1	1	2	2	2	2	1	1
	2	1	1	2	1	1	2	3	1	1
	3	2	2	4	2	2	2	2	2	2
	4	1	3	2	1	1	1	1	2	4
	2	2	1	3	2	2	3	1	4	4
	2	2	4	3	1	1	3			
3	2	1	1	1	3	2	2	2	1	1
	1	1	2	3	1	3	1	4	4	4
	1	1	1	1	2	2	1	1	1	1
	1	1	1	1	2	1	1	2	1	1
	3	1	1	3	3	1	2	1	1	1
	1	2	1	1	2	3	1	3	1	3
	1	2	2	3	1	2	2	1	3	1
	3	2	2	1	3	1	1	1	1	3
	1	1	1	2	3	1	3	1		
4	1	1	2	1	3	4	2	2	4	1
	1	1	1	1	1	1	1	1	3	1
	1	2	1	1	1	1	1	1	2	3
	1	3	1	2	2	1	1	1	1	3
	1	1	1	2	2	2	2	2	1	3
	1	3	1	1	2	4	1	3	3	1
	2	2	3	1	2	1	1	3	1	1
	1	1	1	1	1	2	1	1	2	1
	3	4	4	1	3	1	3			

5	1 1 2 1 1 1 1 2 1 1 1 3 2 2 2 1 1 4 4 3 1 4 1 3 2 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 3 2 1 1 2 1 1 1 3 2 1 1 1 3 2 2 1 3 3 1 4 1 1 2 2 1 1 1 1 2 1 1 2 1 3 4 3 1 4 3 1 4 3 1
6	2 2 1 1 2 3 1 2 2 4 3 1 1 1 2 1 1 1 1 2 1 1 3 1 1 3 3 1 1 1 1 1 2 1 1 2 1 1 2 2 3 1 1 1 2 4 1 3 4 2 1 1 3 1 3 1 1 1 1 1 1 3 4 1 1 1 1 3 1 1 3 1 3 1 3 1 1 1 1 2 1 1 2 1 1 4 1 1 1 1
7	2 2 2 1 1 1 1 1 1 1 3 2 1 1 2 1 1 3 1 4 3 1 3 1 1 1 1 1 4 2 2 2 1 1 2 2 1 1 1 1 2 1 1 2 1 1 3 1 1 3 1 3 3 1 1 1 1 1 3 1 4 1 1 2 1 3 1 3 2 2 3 1 2 1 1 3 1 2 2 3 1 4 1 1 2 4
8	1 1 2 1 3 3 1 3 1 1 3 1 3 2 1 1 3 1 1 1 2 2 1 1 2 2 1 1 2 2 2 2 1 1 2 1 1 3 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 2 1 1 1 3 2 2 1 3 1 1 1 1 3 1 1 1 2 1 3 3 1 1 3 1 3 4 3 1 3 1 1 3 4

9	1 1 1 1 3 1 1 3 3 1 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 3 1 1 3 1 1 2 2 2 2 1 1 2 1 1 1 3 1 1 2 1 3 1 1 1 1 3 1 1 3 1 3 2 2 1 1 2 2 2 2 1 1 1 3 4 3 1 2 2 2 2 1 1 1 1 1 3 1 3 1 3 1 3 3 1
10	1 1 2 1 3 4 1 1 2 3 1 3 1 1 3 1 3 1 1 2 1 1 2 1 1 2 2 1 1 1 1 1 1 2 1 1 2 2 1 1 2 3 1 3 1 1 1 1 1 1 3 1 3 2 2 1 3 3 1 4 4 4 1 1 1 1 1 1 2 1 1 2 3 1 1 3 4 1 1 2 2 2 1 1 1 1 1 3
11	2 2 4 2 1 1 1 1 2 1 1 1 1 2 1 1 1 3 1 1 1 1 1 1 2 1 3 2 2 1 3 1 3 2 2 4 1 1 2 2 2 3 1 3 1 4 2 2 3 1 2 2 1 1 2 2 2 1 3 1 1 1 1 4 3 1 1 1 2 1 1 1 1 3 1 3 1 3 1 4 4 4
12	2 2 1 1 2 1 1 2 1 3 1 3 2 2 1 3 2 2 1 1 2 4 1 1 2 1 3 3 1 1 1 1 1 1 1 1 1 4 3 1 3 1 2 1 1 2 2 2 2 2 1 1 2 2 4 1 1 1 1 2 1 1 1 1 2 1 3 2 1 1 4 4 3 1 3 1 1 3 1 3 4 1 3

13	2 2 1 1 2 4 3 1 1 3 2 1 1 2 2 2 1 1 3 1 4 2 2 1 1 1 1 2 2 2 1 1 3 1 1 1 2 4 1 1 1 1 1 1 1 1 1 1 1 1 2 2 4 3 1 3 1 2 2 2 2 4 3 1 2 1 1 4 3 1 2 2 3 1 1 3 4 3 1 1 3
14	2 1 1 4 2 2 4 1 1 2 1 1 2 2 1 1 4 4 3 1 1 1 2 1 1 1 1 1 1 1 1 3 1 2 2 1 1 1 1 3 1 4 4 4 2 2 3 1 1 3 3 1 3 1 1 1 2 1 3 1 3 1 3 1 1 1 1 2 2 3 1 1 3 1 1 1 1 1 1 2 2 2 1 1 2
15	1 1 2 4 3 1 1 1 1 1 1 1 2 2 1 1 2 1 1 3 1 1 3 1 3 2 1 1 4 2 2 2 1 1 1 1 2 2 2 4 3 1 1 3 3 1 3 1 3 1 4 2 2 2 2 3 1 1 1 1 1 1 1 2 1 3 1 1 1 1 1 1 2 2 2 2 2 3 1 1 3 3 1 3 1
16	1 1 1 1 2 1 1 3 1 1 3 4 2 1 1 3 1 2 1 1 4 2 1 1 2 2 3 1 2 1 1 2 1 1 1 1 1 1 2 2 1 3 2 2 1 1 1 1 4 1 3 2 1 1 1 3 4 3 1 1 3 1 1 1 1 1 3 1 3 2 2 2 1 1 1 3 1 3 1 1 2 2 1 1 1 3 4
17	1 1 2 3 1 1 1 2 1 3 1 1 1 1 1 1 2 1 1 1 1 3 1 2 2 1 1 1 1 3 1 1 1 1 1 2 1 1 1 3 3 1 1 3 1 1 2 4 1 3 1 3 2 1 1 4 4 1 1 1 1 1 1 2 1 1 2 3 1 2 1 1 1 1 1 1 2 2 4 2 2 3 1 1 3 4 1 3 3 1

18	1	1	1	1	4	3	1	4	2	1
	1	2	2	2	1	1	2	2	4	3
	1	3	1	1	1	1	1	2	1	1
	2	1	1	1	1	2	4	2	2	2
	2	4	2	2	2	1	1	1	1	2
	1	1	1	1	4	4	3	1	2	2
	2	2	4	1	1	2	1	3	1	3
	3	1	1	3	3	1	3	1	3	1
19	1	1	1	1	2	1	1	1	3	1
	3	2	2	2	1	1	2	1	1	1
	1	2	1	3	1	1	2	3	1	3
	1	2	1	1	2	2	1	3	4	1
	1	2	2	1	1	3	1	1	1	1
	1	3	1	4	2	2	2	2	2	1
	1	4	3	1	2	2	1	3	2	1
	1	3	1	1	1	2	1	3	4	3
	1	1	3	3	1					
20	2	2	2	1	1	2	2	4	3	1
	4	3	1	1	1	2	2	2	2	2
	3	1	4	1	1	1	1	1	1	2
	2	1	1	1	3	3	1	2	1	1
	4	1	3	3	1	3	1	2	1	1
	3	1	1	3	2	2	2	2	1	1
	1	1	3	1	4	1	1	2	2	2
	3	1	1	1	2	4	1	1	1	1
	4									
21	2	1	1	2	1	1	2	1	1	2
	1	1	1	1	2	3	1	1	3	1
	1	2	4	4	1	3	1	3	2	1
	1	2	1	1	2	1	1	1	3	1
	1	2	4	1	1	1	1	2	2	1
	1	1	1	4	1	3	2	1	1	2
	1	1	4	1	1	2	3	1	2	2
	1	3	1	1	2	1	3	4	4	4
	1	3	1	3						

22	2 1 1 4 4 1 1 2 1 3 3 1 4 1 1 1 1 2 1 1 1 1 2 1 1 2 2 2 1 1 2 2 2 3 1 3 1 2 2 1 1 1 1 2 1 1 4 2 2 1 3 4 1 3 2 1 1 3 1 2 2 2 1 1 4 2 2 4 1 1 2 1 3 1 3 4 1 3 3 1
23	1 1 1 1 3 1 2 2 4 2 1 1 1 3 1 3 4 3 1 1 1 2 1 1 1 1 1 1 2 2 1 1 1 1 2 1 1 1 1 3 1 1 1 1 1 4 2 1 1 3 1 3 1 4 3 1 1 3 1 1 1 1 1 1 2 1 1 1 1 1 1 2 2 1 1 3 1 3 1 1 3 1 1 2 2 2 1 3 3 1 4
24	2 2 4 1 3 1 1 2 1 3 2 2 1 3 4 1 1 2 2 2 4 1 1 2 2 2 2 1 1 2 2 1 1 1 1 1 3 3 1 3 1 3 1 1 1 2 1 1 2 1 1 1 1 1 3 3 1 1 3 4 1 1 2 1 1 1 1 2 2 3 1 1 3 1 3 2 2 4 1 1 2 3 1
25	2 1 1 4 1 3 2 2 4 2 2 4 1 1 2 4 3 1 2 2 1 1 1 1 2 1 1 2 2 1 1 2 2 2 2 2 3 1 3 1 4 2 2 1 3 2 1 1 2 2 4 2 1 1 2 2 3 1 1 3 2 2 3 1 4 1 3 3 1 2 2 1 3 4

26	1 1 1 1 2 2 1 1 2 2 1 1 1 1 1 1 4 1 1 2 1 3 2 2 1 3 2 2 2 1 1 1 3 3 1 3 1 1 1 2 1 1 1 1 1 3 2 2 3 1 2 1 1 1 1 2 2 1 1 4 1 3 3 1 4 4 4 3 1 3 1 1 1 1 1 2 2 4 4 2 2 3 1
27	1 1 2 1 3 1 1 1 1 2 2 2 1 1 2 1 1 1 3 1 3 1 1 1 1 4 4 1 1 1 1 1 3 2 1 1 2 2 1 1 2 4 4 1 1 2 2 1 1 4 1 3 4 2 2 1 1 2 1 3 2 2 3 1 1 3 1 1 2 2 2 2 2 3 1 3 1 3 1 3 1 3 1
28	2 2 3 1 1 3 4 1 3 1 1 1 1 1 1 1 1 2 1 1 2 1 1 4 4 2 2 1 1 2 1 1 2 1 1 1 1 1 1 2 1 3 2 1 1 1 1 1 1 1 1 1 1 1 3 3 1 1 1 1 1 1 1 1 1 3 1 1 3 2 2 2 2 1 1 1 1 3 1 3 1 3 1 1 3 4 3 1 3 1 4
29	2 2 2 1 1 4 2 2 1 1 2 1 1 1 1 4 2 2 1 1 2 3 1 2 2 1 3 1 3 4 2 2 3 1 3 1 4 1 3 4 3 1 3 1 2 2 1 1 2 4 2 1 1 1 3 2 2 3 1 4 1 1 2 2 2 1 1 2 4 1 1 1 1 3 1 1 1 1 1

30	1 1 2 2 1 1 1 3 1 1 2 1 3 1 3 1 1 2 1 1 2 2 2 1 1 1 1 3 1 3 1 4 1 1 2 1 1 2 3 1 1 1 2 2 1 1 4 3 1 1 3 1 1 1 1 1 1 2 1 3 1 3 1 1 2 2 1 1 2 1 1 1 1 2 1 1 1 1 1 3 4 4 3 1 1 3 4 3 1
31	1 1 2 1 3 4 2 2 1 1 2 4 2 1 1 3 1 1 1 1 1 3 1 1 3 2 2 1 1 1 1 2 2 1 1 1 1 2 2 3 1 3 1 1 1 1 1 3 1 2 2 1 1 1 1 1 3 1 3 2 2 1 3 1 3 3 1 1 1 2 2 2 1 1 2 2 2 4 4 1 3 3 1 1 3
32	1 1 1 1 2 2 1 1 1 1 3 1 1 3 1 3 1 1 1 1 1 1 1 1 2 1 1 1 3 1 3 3 1 2 2 1 1 1 1 1 1 1 1 3 1 1 1 1 1 1 3 1 1 1 1 1 1 1 1 1 1 1 1 1 3 1 3 2 2 1 1 1 1 2 1 1 3 1 2 2 3 1 1 1 2 3 1 4 1 3 4 4 4 3 1
33	1 1 1 1 2 2 3 1 3 1 3 1 1 3 1 3 2 2 1 3 2 2 1 1 2 1 1 2 2 1 1 2 1 1 2 2 1 1 1 1 4 3 1 4 4 1 1 1 1 1 1 2 3 1 3 1 3 1 3 1 1 1 2 1 3 1 1 1 1 1 1 2 4 2 1 1 1 1 2 2 1 1 1 3 4 4

34	2 1 1 1 1 2 4 4 2 1 1 1 3 4 1 1 1 1 2 1 1 1 1 2 4 3 1 2 2 2 2 2 1 1 2 2 4 1 1 2 2 2 1 3 2 2 1 1 1 1 4 2 1 1 1 3 2 2 1 1 2 2 1 1 3 1 3 1 4 3 1 4 1 3 3 1 3 1 3 1
35	2 1 1 1 1 2 3 1 3 1 4 3 1 1 3 1 3 1 1 2 1 1 1 1 2 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 2 1 1 1 1 2 1 1 2 4 2 2 3 1 2 1 1 1 1 1 1 3 1 2 2 3 1 4 1 3 3 1 2 2 4 3 1 3 1 1 3 3 1 3 1
36	1 1 1 1 1 1 2 3 1 3 1 3 1 1 1 1 1 3 1 2 1 1 1 1 1 1 4 4 1 1 1 1 2 2 2 1 1 2 1 1 4 1 1 1 1 2 2 2 2 3 1 2 2 1 3 3 1 3 1 3 1 2 1 1 3 1 2 2 3 1 3 1 2 1 1 3 1 1 1 2 1 1 1 1 3 1 3 1 3 1
37	1 1 2 1 3 3 1 1 3 2 2 3 1 3 1 4 1 1 2 1 1 2 2 1 1 1 1 1 1 2 1 1 1 1 2 1 1 1 1 2 1 1 4 3 1 1 3 2 1 1 3 1 1 1 1 1 4 1 1 1 1 4 2 1 1 2 2 3 1 1 3 3 1 3 1 1 1 2 1 3 2 2 3 1 4 2 1 1
38	1 1 1 1 3 1 2 2 1 1 2 1 3 1 3 4 4 2 2 1 1 2 4 2 1 1 1 1 2 2 1 1 2 1 1 1 1 2 2 1 1 1 3 4 1 1 1 1 1 1 1 1 3 1 2 1 1 1 1 2 2 2 1 1 1 1 4 1 1 1 1 3 1 4 4 3 1 3 1 4 3 1 1 3 4

39	1 1 2 3 1 2 2 1 1 2 4 2 1 1 1 1 1 1 4 2 1 1 1 3 1 3 1 1 1 1 1 3 1 1 2 1 1 2 4 4 1 3 1 3 2 1 1 2 1 1 3 1 4 1 1 2 1 3 1 1 2 1 1 2 1 3 3 1 1 1 1 1 2 1 1 2 2 3 1 2 2 4 4 1 3
40	2 2 2 2 4 2 2 4 1 3 1 1 2 1 1 2 1 1 2 3 1 1 1 1 1 1 1 2 1 3 1 3 2 1 1 2 2 1 1 1 1 4 1 3 1 1 1 1 3 1 1 1 1 1 2 1 1 2 1 1 2 2 2 2 1 1 1 1 3 1 3 1 3 1 1 3 3 1 1 3 4 4 1 3 3 1

Appendix B

INTERVAL WEIGHTS FOR RHYTHMS USED IN THE BEAT CONDITION

Rhythm #	Interval weights											
1	2	0.56	1.44	1.44	0.56	0.56	1.44	2	1.22	0.78	2.56	
	1.44	3.44	0.56	0.56	1.44	2	4	2	2	2	1.44	
	0.56	2.86	1.14	4	4	2	1.44	0.56	0.42	1.58	2	
	1.22	0.78	0.66	1.34	1.14	2.86	0.56	1.44	2	2	2	
	1.14	0.86	2	2.42	1.58	4	4	1.44	0.56	0.78	1.22	4
	4	3.58	0.42	4	2	0.42	1.58	4	2	2	2	2
	3.34	0.66	0.42	1.58	2	1.14	0.86	0.78	1.22	4	3.58	
	0.42	0.66	3.34									
2	2	0.66	1.34	3.34	0.66	0.66	3.34	1.34	2.66	2.66	1.34	4
	2	1.22	0.78	4	0.86	1.14	1.22	0.78	0.56	1.44	1.22	
	0.78	2	2	2	2	0.78	1.22	2	1.14	0.86	2	
	0.42	1.58	2	3.34	0.66	0.66	3.34	2	2	4	2	2
	2	2	2	2	4	1.58	2.42	2	0.66	1.34	1.44	
	0.56	2	4	2	2	0.78	3.22	2	2	3.22	0.78	4
	4	2	2	4	2.42	1.58	1.22	2.78				
3	2	0.78	1.22	1.34	2.66	2	2	2	0.42	1.58	1.14	
	0.86	2	2.42	1.58	3.44	0.56	4	4	4	0.42	1.58	
	1.34	0.66	2	2	0.42	1.58	1.34	0.66	0.78	1.22	1.22	
	0.78	2	0.42	1.58	2	1.34	0.66	2.56	1.44	1.58	2.42	
	2.86	1.14	2	1.58	0.42	0.42	1.58	2	1.22	0.78	2	
	2.66	1.34	3.44	0.56	2.56	1.44	2	2	3.14	0.86	2	2
	0.66	3.34	1.14	2.86	2	2	0.78	3.22	1.14	0.86	0.78	
	1.22	3.14	0.86	0.78	1.22	2	3.22	0.78	2.42	1.58		
4	0.42	1.58	2	1.44	2.56	4	2	2	4	0.42	1.58	
	1.34	0.66	0.78	1.22	1.44	0.56	0.42	3.58	1.14	0.86	2	
	0.56	1.44	1.34	0.66	0.66	1.34	2	3.14	0.86	2.86	1.14	2
	2	1.34	0.66	0.86	1.14	3.44	0.56	0.78	1.22	2	2	2
	2	2	1.34	2.66	0.66	3.34	1.14	0.86	2	4	0.56	
	3.44	3.58	0.42	2	2	2.42	1.58	2	1.34	0.66	2.66	
	1.34	1.58	0.42	0.56	1.44	1.22	0.78	2	0.56	1.44	2	
	1.44	2.56	4	4	0.66	3.34	1.22	2.78				
5	0.78	1.22	2	1.44	0.56	0.56	1.44	2	1.58	0.42	0.86	
	3.14	2	2	2	1.34	0.66	4	4	2.78	1.22	4	
	1.22	2.78	2	0.56	1.44	1.22	0.78	0.66	1.34	1.58	0.42	
	0.78	1.22	1.44	0.56	2	0.86	1.14	1.58	0.42	0.56	3.44	2
	1.44	0.56	2	0.86	1.14	1.58	2.42	2	0.66	1.34	1.44	
	2.56	2	2	0.66	3.34	3.34	0.66	4	0.78	1.22	2	2
	1.44	0.56	0.86	1.14	2	1.22	0.78	2	0.66	3.34	4	
	3.58	0.42	4	2.78	1.22	4	3.58	0.42				

6		2 2 0.78 1.22 2 3.14 0.86 2 2 4 2.86 1.14 1.14 0.86 2 0.86 1.14 1.22 0.78 2 0.66 1.34 3.34 0.66 0.78 3.22 3.14 0.86 0.66 1.34 1.14 0.86 2 0.78 1.22 2 1.34 0.66 2 2 2.56 1.44 1.34 0.66 2 4 0.56 3.44 4 2 1.22 0.78 2.66 1.34 3.22 0.78 0.86 1.14 1.44 0.56 0.42 3.58 4 1.34 0.66 0.78 1.22 3.34 0.66 0.78 3.22 1.58 2.42 0.66 3.34 1.44 0.56 0.42 1.58 2 1.14 0.86 2 0.42 1.58 4 1.14 0.86 0.78 1.22
7		2 2 2 0.86 1.14 1.22 0.78 0.42 1.58 1.14 2.86 2 0.56 1.44 2 1.22 0.78 2.66 1.34 4 3.22 0.78 2.86 1.14 1.22 0.78 0.78 1.22 4 2 2 2 1.14 0.86 2 2 0.56 1.44 1.34 0.66 2 0.42 1.58 2 1.44 0.56 2.42 1.58 1.44 2.56 0.78 3.22 3.34 0.66 0.56 1.44 1.14 0.86 2.66 1.34 4 1.14 0.86 2 0.66 3.34 1.22 2.78 2 2 2.56 1.44 2 1.34 0.66 2.56 1.44 2 2 3.22 0.78 4 0.42 1.58 2 4
8		0.56 1.44 2 1.22 2.78 2.56 1.44 3.44 0.56 0.86 3.14 1.14 2.86 2 0.56 1.44 3.34 0.66 0.56 1.44 2 2 1.14 0.86 2 2 0.56 1.44 2 2 2 2 1.22 0.78 2 0.78 1.22 3.58 0.42 2 0.66 1.34 1.44 0.56 0.42 1.58 1.58 0.42 0.86 1.14 1.34 0.66 0.78 1.22 2 1.58 0.42 2 0.42 1.58 1.58 2.42 2 2 0.42 3.58 1.22 0.78 0.86 1.14 3.58 0.42 0.56 1.44 2 1.44 2.56 2.66 1.34 1.22 2.78 0.78 3.22 4 3.22 0.78 2.86 1.14 1.44 2.56 4
9		0.78 1.22 1.34 0.66 2.86 1.14 1.22 2.78 2.78 1.22 4 1.14 0.86 0.66 1.34 1.34 0.66 0.86 1.14 1.22 0.78 0.78 1.22 1.44 0.56 0.78 1.22 3.58 0.42 0.42 3.58 1.44 0.56 2 2 2 2 0.56 1.44 2 1.44 0.56 0.56 3.44 1.22 0.78 2 0.66 3.34 1.44 0.56 0.42 1.58 3.58 0.42 0.42 3.58 1.14 2.86 2 2 0.42 1.58 2 2 2 2 1.58 0.42 0.86 3.14 4 3.34 0.66 2 2 2 2 0.86 1.14 1.44 0.56 0.42 3.58 1.22 2.78 0.86 3.14 1.44 2.56 2.56 1.44
10		0.42 1.58 2 1.58 2.42 4 0.66 1.34 2 3.22 0.78 2.42 1.58 1.22 2.78 0.66 3.34 1.44 0.56 2 0.78 1.22 2 1.34 0.66 2 2 0.78 1.22 1.34 0.66 0.42 1.58 2 1.58 0.42 2 2 0.78 1.22 2 3.58 0.42 2.66 1.34 1.14 0.86 0.42 1.58 1.14 2.86 0.56 3.44 2 2 1.58 2.42 2.86 1.14 4 4 4 1.34 0.66 0.86 1.14 1.44 0.56 2 0.86 1.14 2 3.34 0.66 0.66 3.34 4 1.22 0.78 2 2 2 0.42 1.58 1.58 0.42 0.78 3.22

11	2 2 4 2 0.66 1.34 1.58 0.42 2 0.86 1.14 1.34 0.66 2 0.66 1.34 1.14 2.86 0.42 1.58 1.44 0.56 0.66 1.34 2 1.34 2.66 2 2 0.78 3.22 1.58 2.42 2 2 4 0.78 1.22 2 2 2 3.44 0.56 2.78 1.22 4 2 2 3.44 0.56 2 2 0.86 1.14 2 2 2 1.44 2.56 0.42 1.58 1.44 0.56 4 2.42 1.58 1.22 0.78 2 0.56 1.44 1.34 0.66 2.86 1.14 3.14 0.86 2.56 1.44 4 4 4
12	2 2 0.86 1.14 2 1.34 0.66 2 0.86 3.14 1.34 2.66 2 2 0.78 3.22 2 2 1.34 0.66 2 4 0.78 1.22 2 1.58 2.42 2.66 1.34 1.14 0.86 0.86 1.14 1.34 0.66 0.42 1.58 4 3.14 0.86 2.56 1.44 2 1.22 0.78 2 2 2 2 2 0.78 1.22 2 2 4 1.58 0.42 0.86 1.14 2 1.14 0.86 0.86 1.14 2 1.58 2.42 2 0.86 1.14 4 4 3.58 0.42 2.86 1.14 1.44 2.56 0.56 3.44 4 1.22 2.78
13	2 2 0.86 1.14 2 4 3.58 0.42 0.66 3.34 2 1.44 0.56 2 2 2 0.86 1.14 3.58 0.42 4 2 2 0.86 1.14 1.58 0.42 2 2 2 0.56 1.44 3.58 0.42 0.42 1.58 2 4 1.14 0.86 0.78 1.22 1.58 0.42 0.56 1.44 1.22 0.78 0.86 1.14 2 2 4 3.58 0.42 2.42 1.58 2 2 2 2 4 3.34 0.66 2 0.42 1.58 4 3.14 0.86 2 2 2.78 1.22 1.22 2.78 4 2.56 1.44 1.58 2.42
14	2 0.56 1.44 4 2 2 4 1.14 0.86 2 0.56 1.44 2 2 1.44 0.56 4 4 2.78 1.22 1.58 0.42 2 0.42 1.58 1.44 0.56 0.86 1.14 1.44 0.56 2.66 1.34 2 2 1.22 0.78 0.86 1.14 3.14 0.86 4 4 4 2 2 2.86 1.14 1.34 2.66 2.56 1.44 3.44 0.56 0.86 1.14 2 1.44 2.56 0.86 3.14 1.44 2.56 0.78 1.22 1.58 0.42 2 2 2.86 1.14 1.44 2.56 0.86 1.14 1.58 0.42 0.78 1.22 2 2 2 1.22 0.78 2
15	0.42 1.58 2 4 3.44 0.56 0.56 1.44 1.34 0.66 0.56 1.44 2 2 1.44 0.56 2 0.78 1.22 3.58 0.42 0.78 3.22 1.44 2.56 2 0.42 1.58 4 2 2 2 1.22 0.78 0.66 1.34 2 2 2 4 3.58 0.42 0.86 3.14 3.22 0.78 2.86 1.14 3.44 0.56 4 2 2 2 2 2.66 1.34 1.34 0.66 0.86 1.14 1.14 0.86 2 0.42 3.58 1.44 0.56 0.66 1.34 1.14 0.86 2 2 2 2 2 2.56 1.44 1.58 2.42 2.86 1.14 3.34 0.66

16	0.66 1.34 1.34 0.66 2 0.42 1.58 3.14 0.86 0.86 3.14 4 2 1.22 0.78 2.78 1.22 2 1.44 0.56 4 2 0.56 1.44 2 2 3.58 0.42 2 0.56 1.44 2 1.22 0.78 0.42 1.58 1.44 0.56 2 2 0.42 3.58 2 2 1.58 0.42 0.56 1.44 4 1.44 2.56 2 0.78 1.22 1.58 2.42 4 2.42 1.58 1.14 2.86 0.56 1.44 1.14 0.86 0.86 3.14 1.22 2.78 2 2 2 0.42 1.58 1.14 2.86 0.66 3.34 1.34 0.66 2 2 0.66 1.34 1.22 2.78 4
17	0.78 1.22 2 3.58 0.42 0.42 1.58 2 1.34 2.66 0.78 1.22 1.14 0.86 0.56 1.44 2 1.14 0.86 0.78 1.22 3.34 0.66 2 2 0.78 1.22 1.34 0.66 2.78 1.22 1.44 0.56 0.56 1.44 2 1.14 0.86 0.66 3.34 3.34 0.66 0.56 3.44 1.22 0.78 2 4 0.56 3.44 1.14 2.86 2 0.86 1.14 4 4 1.58 0.42 0.42 1.58 1.22 0.78 2 0.78 1.22 2 3.44 0.56 2 0.86 1.14 1.14 0.86 0.86 1.14 2 2 4 2 2 3.44 0.56 0.42 3.58 4 1.58 2.42 2.78 1.22
18	0.56 1.44 1.22 0.78 4 2.56 1.44 4 2 1.44 0.56 2 2 2 0.42 1.58 2 2 4 3.44 0.56 2.78 1.22 1.58 0.42 0.66 1.34 2 1.58 0.42 2 0.86 1.14 1.44 0.56 2 4 2 2 2 2 4 2 2 2 0.56 1.44 1.14 0.86 2 0.56 1.44 1.14 0.86 4 4 2.56 1.44 2 2 2 2 4 1.34 0.66 2 0.78 3.22 1.22 2.78 2.56 1.44 1.22 2.78 2.78 1.22 3.44 0.56 2.42 1.58
19	0.78 1.22 1.14 0.86 2 0.78 1.22 1.44 2.56 0.86 3.14 2 2 2 1.58 0.42 2 0.56 1.44 1.14 0.86 2 0.78 3.22 1.14 0.86 2 2.78 1.22 3.22 0.78 2 0.86 1.14 2 2 1.34 2.66 4 0.56 1.44 2 2 1.34 0.66 2.42 1.58 1.22 0.78 0.42 1.58 3.58 0.42 4 2 2 2 2 2 0.78 1.22 4 3.58 0.42 2 2 0.42 3.58 2 1.44 0.56 2.78 1.22 1.34 0.66 2 0.66 3.34 4 3.22 0.78 0.78 3.22 3.34 0.66
20	2 2 2 0.66 1.34 2 2 4 3.34 0.66 4 2.86 1.14 1.22 0.78 2 2 2 2 2 2.42 1.58 4 1.44 0.56 0.66 1.34 1.34 0.66 2 2 0.78 1.22 1.34 2.66 2.78 1.22 2 1.44 0.56 4 0.66 3.34 3.14 0.86 2.56 1.44 2 1.44 0.56 2.86 1.14 1.34 2.66 2 2 2 2 0.78 1.22 1.58 0.42 2.78 1.22 4 1.22 0.78 2 2 2 2.56 1.44 1.22 0.78 2 4 0.78 1.22 1.34 0.66 4

21		2 0.56 1.44 2 1.22 0.78 2 0.42 1.58 2 1.58 0.42 0.56 1.44 2 3.14 0.86 0.42 3.58 1.44 0.56 2 4 4 0.56 3.44 1.44 2.56 2 0.66 1.34 2 1.58 0.42 2 0.66 1.34 1.44 2.56 0.66 1.34 2 4 1.58 0.42 0.56 1.44 2 2 1.58 0.42 0.42 1.58 4 1.34 2.66 2 0.56 1.44 2 1.22 0.78 4 0.66 1.34 2 3.58 0.42 2 2 0.56 3.44 1.22 0.78 2 0.56 3.44 4 4 4 1.58 2.42 0.56 3.44
22		2 0.86 1.14 4 4 1.34 0.66 2 0.56 3.44 3.34 0.66 4 0.42 1.58 1.34 0.66 2 0.66 1.34 1.58 0.42 2 0.56 1.44 2 2 2 1.22 0.78 2 2 2 2.86 1.14 3.58 0.42 2 2 0.42 1.58 1.14 0.86 2 0.78 1.22 4 2 2 1.22 2.78 4 0.56 3.44 2 1.14 0.86 2.42 1.58 2 2 2 1.44 0.56 4 2 2 4 0.86 1.14 2 1.22 2.78 0.86 3.14 4 1.58 2.42 2.78 1.22
23		0.42 1.58 1.58 0.42 2.86 1.14 2 2 4 2 1.14 0.86 0.42 3.58 1.22 2.78 4 2.56 1.44 1.44 0.56 2 0.42 1.58 1.58 0.42 0.42 1.58 2 2 1.44 0.56 0.66 1.34 2 1.34 0.66 0.78 1.22 3.34 0.66 0.42 1.58 1.22 0.78 4 2 0.78 1.22 3.58 0.42 2.42 1.58 4 3.58 0.42 0.86 3.14 1.14 0.86 0.66 1.34 1.58 0.42 2 0.66 1.34 1.22 0.78 0.86 1.14 2 2 1.58 0.42 2.66 1.34 3.22 0.78 0.42 3.58 1.44 0.56 2 2 2 0.42 3.58 3.22 0.78 4
24		2 2 4 0.42 3.58 1.58 0.42 2 0.56 3.44 2 2 1.58 2.42 4 0.42 1.58 2 2 2 4 1.58 0.42 2 2 2 2 0.86 1.14 2 2 1.58 0.42 0.66 1.34 1.44 2.56 2.86 1.14 3.14 0.86 2.56 1.44 1.58 0.42 2 0.78 1.22 2 1.14 0.86 0.86 1.14 1.34 2.66 2.78 1.22 1.44 2.56 4 0.86 1.14 2 1.22 0.78 0.42 1.58 2 2 3.34 0.66 0.56 3.44 1.14 2.86 2 2 4 0.86 1.14 2 3.34 0.66
25		2 0.86 1.14 4 1.44 2.56 2 2 4 2 2 4 0.86 1.14 2 4 3.14 0.86 2 2 0.56 1.44 1.22 0.78 2 0.42 1.58 2 2 1.58 0.42 2 2 2 2 2 2.78 1.22 3.14 0.86 4 2 2 0.66 3.34 2 1.14 0.86 2 2 4 2 0.66 1.34 2 2 3.34 0.66 0.86 3.14 2 2 3.14 0.86 4 0.56 3.44 3.14 0.86 2 2 0.42 3.58 4

26	0.66 1.34 1.44 0.56 2 2 0.56 1.44 2 2 1.58 0.42 0.66 1.34 1.58 0.42 4 0.78 1.22 2 1.14 2.86 2 2 0.86 3.14 2 2 2 1.44 0.56 0.56 3.44 3.44 0.56 2.66 1.34 1.44 0.56 2 0.66 1.34 1.58 0.42 0.78 3.22 2 2 3.22 0.78 2 0.66 1.34 1.34 0.66 2 2 0.42 1.58 4 1.44 2.56 2.66 1.34 4 4 4 3.34 0.66 2.66 1.34 1.44 0.56 0.56 1.44 2 2 4 4 2 2 3.58 0.42
27	0.86 1.14 2 1.58 2.42 0.42 1.58 1.44 0.56 2 2 2 0.42 1.58 2 1.44 0.56 0.56 3.44 1.34 2.66 0.42 1.58 1.14 0.86 4 4 0.86 1.14 1.14 0.86 0.42 3.58 2 1.44 0.56 2 2 0.42 1.58 2 4 4 1.22 0.78 2 2 0.66 1.34 4 1.22 2.78 4 2 2 0.56 1.44 2 1.34 2.66 2 2 2.78 1.22 1.14 2.86 0.56 1.44 2 2 2 2 2 3.34 0.66 2.86 1.14 3.44 0.56 2.66 1.34 3.44 0.56
28	2 2 2.66 1.34 1.44 2.56 4 0.42 3.58 1.34 0.66 0.66 1.34 1.58 0.42 0.86 1.14 2 1.14 0.86 2 0.66 1.34 4 4 2 2 1.34 0.66 2 0.56 1.44 2 1.44 0.56 0.42 1.58 1.34 0.66 2 0.78 3.22 2 1.58 0.42 0.56 1.44 1.44 0.56 0.66 1.34 1.22 0.78 0.42 3.58 3.14 0.86 0.86 1.14 1.22 0.78 0.86 1.14 1.44 0.56 2.66 1.34 1.14 2.86 2 2 2 2 0.42 1.58 1.22 0.78 2.66 1.34 3.34 0.66 2.42 1.58 1.14 2.86 4 2.86 1.14 3.22 0.78 4
29	2 2 2 0.42 1.58 4 2 2 1.58 0.42 2 0.86 1.14 1.44 0.56 4 2 2 0.56 1.44 2 3.58 0.42 2 2 0.86 3.14 1.58 2.42 4 2 2 2.78 1.22 3.34 0.66 4 0.86 3.14 4 3.58 0.42 2.42 1.58 2 2 1.34 0.66 2 4 2 0.42 1.58 1.14 2.86 2 2 2.56 1.44 4 1.44 0.56 2 2 2 0.56 1.44 2 4 1.22 0.78 0.86 1.14 3.22 0.78 0.86 1.14 1.14 0.86
30	0.56 1.44 2 2 1.44 0.56 0.56 3.44 1.14 0.86 2 0.56 3.44 1.22 2.78 0.56 1.44 2 1.58 0.42 2 2 2 0.42 1.58 1.14 0.86 2.86 1.14 3.34 0.66 4 0.86 1.14 2 1.44 0.56 2 2.56 1.44 1.22 0.78 2 2 0.78 1.22 4 3.14 0.86 0.78 3.22 1.34 0.66 0.78 1.22 1.14 0.86 2 0.86 3.14 1.58 2.42 0.78 1.22 2 2 1.14 0.86 2 0.56 1.44 1.14 0.86 2 0.56 1.44 1.44 0.56 0.66 3.34 4 4 3.14 0.86 0.66 3.34 4 3.34 0.66

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Appendix C
ETHICS APPROVAL FORMS

(hidden)

General Info

FileNo: 103268
Title: Feeling the beat in infants: Investigating the developmental trajectory of beat perception
Start Date: 10/01/2013
End Date: 31/08/2014
Keywords: EEG, Rhythm, Beat Perception, Infants, Steady-State Evoked Potential, Music, Head Turn,

Project Members

Principal Investigator

Prefix: Dr.
Last Name: Grahn
First Name: Jessica
Affiliation: Social Science\Psychology
Rank:
Gender:
Email:
Phone1:
Phone2:
Fax:
Mailing Address:
Institution:
Country:
Comments:

Others

Rank	Last Name	First Name	Affiliation	Role In Project
	Tsang	Christine	Social Science\Psychology	Co-Investigator
	Stojanoski	Bobby	Social Science\Psychology	Co-Investigator
Masters Student	Gibbings	Aaron	Social Science\Psychology	Co-Investigator
PhD Student	Cameron	Daniel	Social Science\Psychology	Research Support Staff

Common Questions

1. Registration Information

#	Question	Answer
1.1	Do you confirm that you have read the above information and that based on that information you are completing the correct form?	Yes
1.2	Has this study been submitted to any other research ethics board (REB)? If yes, please include the approval letter (or relevant correspondence) as an attachment in the attachments tab.	No
1.3	If YES is selected in question 1.2 above, please indicate where this project has been submitted and when.	
1.4	Is this a sequel to previously approved research?	No
1.5	If YES is selected in question 1.4 above, what is the REB number and what are the differences?	
1.6	Indicate the funding source for this study or if there is no funding simply indicate "NONE".	None
1.7	Is this a student project?	No
1.8	Please list the names of ALL Local (Western affiliated) team members who are working on this project. Please ALSO list their ROLE in the project, i.e. what exactly is it that the team member will do in this study? Please see the “i” for this question for instructions on how to link their Romeo accounts to this form so they have access to it.	
1.9	Lay summary of the study (approximately five lines).	Adult listeners will hear simple rhythms while undergoing an EEG and while tapping along with the beat of the same rhythms. Infants (approximately 6 months old) will be played these stimuli while EEG records neural activity to look for evidence of ‘feeling the beat’. Infants

		will also be tested using a head turn paradigm in which they look at a target when a change in the beat of a rhythm clip is detected. All EEG and adult behavioural data will be collected at the Brain and Mind Institute and the infant behavioural component will be conducted at Huron University College at the University of Western Ontario.
1.10	Briefly provide any plans for provision of feedback of results to participants.	None, participants are given the contact information of the Principal Investigator, and informed that they may follow up if they are interested.
1.11	If this form was started by a team member, has the role of Principal Investigator been changed to the Faculty member who will hold this role for the study? This is required for review of your submission, and any forms submitted without this change being made will be returned without being reviewed. (The blue information "i" has the instructions on how to change the role of PI.)	

2. Methodology

#	Question	Answer
2.1	Outline the study rationale, including relevant background information and justification. Cite references where appropriate.	Recently, the topic of beat perception has received increasing attention from researchers. Resonance theory has emerged as a popular framework for the neural bases of beat perception (e.g. Large, 2008; Grahn, 2009; Nozaradan, Peretz & Moreaux, 2011). Resonance theory suggests that neuronal firing patterns adapt to match (resonate) the incoming stimulus, an effect that has recently been shown in adults using human electroencephalogram (EEG) to capture steady-state evoked potentials (SS-EPs; Nozaradan et al., 2011). Although there have been investigations into the effects of attention (Lakatos, Karmos, Mahta, Ulbert, & Schroeder,

		2008) and musical training (Trainor, 2009) on beat perception, little is known about more fundamental questions such as when or how beat perception develops in the absence of training, or whether it is an innate or acquired skill. Physiologically, the auditory system becomes functional in utero after approximately 25 weeks of gestation, with critical development continuing until the infant is five to six months old (Graven & Brown, 2008). Furthermore studies have observed spontaneous movement to music in very young children (Zentner & Eerola, 2010) implying that infants can detect a beat earlier than current literature would suggest (e.g. Phillips-Silver & Trainor, 2005; Fujioka, Mourad, & Trainor, 2011). Some researchers even suggest that infants may create complex representations of the beat structure that would allow them not only to sense the beat, but would also facilitate a hierarchically ordered representation (i.e. meter induction) of rhythm (Honing et al., 2009) similar to that found in adults (Nozaradan et al., 2007; Ladinig, Honing, Háden, & Winkler, 2009; Lakatos et al., 2008). However, no one has directly investigated whether infants can detect the beat in rhythm.
2.2	Please provide a clear statement of the purpose and objectives of this project.	The present study seeks to examine whether infants can detect the beat in rhythmic sequences. The proposed research study will determine if the same neural phenomena (i.e. SS-EPs) that index beat/meter perception in adults are also present in infants. The objective of this study is to determine whether infants are sensitive to the beat in auditory rhythm. Adult data will be collected prior to infant work to ensure the paradigm is working correctly.
2.3	Describe the study	**Stimuli:** Based on previously recorded

	design/methodology and attach all supporting documents in the attachment tab.	pure tone beeps (Nozaradan et al., 2011) two types of rhythmic stimuli will be created. The first type is simple metric rhythms (i.e. rhythms that have equal time intervals between the sounds or rhythms that do not have equal time intervals between the sounds but that can parsed into regular groups of beats). The second type of stimuli is non-metric and is based on the first, except the onsets of specific tones have been altered to disrupt beat perception. Tones in the rhythms are amplitude modulated. Rhythm clips are each 33 s long. **Procedure:** *Adult*: 30 undergraduate students will be asked to make two visits to the lab: one to collect EEG data and one to collect behavioural (tapping) data. During the EEG visit participants will listen to sequentially presented, 33-second rhythm clips. Some clips will have a beat that is easy to perceive, whereas others will have a beat that is more difficult. During this time a 129 channel EEG will record their neural responses. The responses to easy and hard beat sequences will be compared. To test how attention affects beat perception, some of the stimuli will be presented when participants are attending to a different task (i.e., detecting changes in a visual pattern), rather than attending to the auditory stimuli. This session will take approximately two hours to complete. During the behavioural visit participants will listen to the same rhythm clips as heard in the EEG session, but during the behavioural visit they will be asked to tap along with the beat of the clip. This session will take approximately one hour to complete. The total time required to complete all trials in both sessions is approximately 3 hrs. *Infant EEG*: 30 infants will listen to the

		same 33-second rhythm clips as the adult participants. Past studies have demonstrated that infants may prefer faster rates than adults (Zentner & Eerola, 2010), therefore a range of speeds will be tested in order to optimize the stimuli and to assess which rates elicit the best responses in infants. During this time a 124 channel EEG will record their neural responses, and the responses from the easy and hard beat sequences will be compared. While the clips are being played, the infants will watch a silent cartoon on a small screen to keep their attention. Infant testing time will be no more than 30 minutes. Infant Behavioural: Infants will be tested individually in a go/no-go conditioned head-turn response procedure (e.g., Trainor & Trehub, 1992). The experimenter and parent will listen to masking music through headphones so as to be unaware of what the infant was hearing. During the experiment, one stimulus type (e.g., metronomic rhythms) will repeat continuously from a loudspeaker on the infant’s left. When the infant is attentive and facing the experimenter, a trial will be initiated by the experimenter. There are two types of trials: control trials, in which the same rhythmic stimulus will be presented, and change trials, in which a different rhythmic stimulus (e.g., non-isochronous rhythm) will be presented. If the infant makes a head turn of 45 degrees or greater (as judged by the experimenter after training) toward the loudspeaker within 3000 ms of the beginning of a change trial, the computer monitor under the loudspeaker will display a flashing image of Mickey Mouse for 3000 ms as a reinforcer. Head turns at other times and those that are less than 45 degrees will not be reinforced. Once the monitor is

		extinguished, the experimenter will attract the infant's attention forward again. The computer will keep track of any head turns that occurred within a 3000 ms window on change trials (hits) as well as on control trials (false alarms) to provide an index of the rate of random turning. Trials will be presented in a quasi-random order for each subject, with the constraint that no more than two control trials occur sequentially. There are two experimental stages, Phase 1 and Phase 2. During Phase 1, only change trials that are very different from the control rhythm will be presented to make the task easier. Demonstration trials, in which the change slope was presented paired with the activation of a toy, will be presented if the infant fails to turn on several trials in a row, in order to show that head turning to a change tone will be rewarded. A criterion will be set at 4 correct trials in a row within 20 trials. If the infant fails to reach criterion within 20 trials, the session was terminated. If the infant reaches criterion, Phase 2 will begin. There are no demonstration trials during Phase 2 and the change trial will be a rhythmic stimulus that is less different than the standard rhythm will be presented. Each infant will complete 24 trials in Phase 2: 12 change trials and 12 control trials.
2.4	If your submission deals with groups such as aboriginal peoples, or isolated communities, or work in other countries or cultures please indicate "YES" here and complete the Cultural Research tab of form.	No
2.5	Indicate the inclusion criteria for participant recruitment.	All infants born within 2 weeks of term, with no reports of complications at birth. All adult undergraduate students.
2.6	Considering your inclusion criteria listed above, what is the basis to exclude a potential participant?	Infants with a history of ear infections (3 or more within 6 months) Infants with a familial history of hearing impairments.

		Infants with a severe visual impairment. Infants with documented history of hearing impairments. Adults with a documented history of hearing impairment.
2.7	How many participants over the age of 18 from London will be enrolled in your study? This includes hospital and university sites within London.	30
2.8	How many participants under the age of 18 from London will be enrolled in your study? This includes hospital and university sites within London.	45
2.9	How many participants over the age of 18 will be included at all study locations? (London + Other locations = Total)	30
2.10	How many participants under the age of 18 will be included at all study locations? (London + Other locations = Total)	45
2.11	Does this study include any use of deliberate deception or withholding of key information that may influence a participant's performance or response?	No
2.12	If YES is selected in question 2.11 above, provide an explanation, including how participants will be debriefed and attach the debriefing script you will use in the attachments tab.	

3. Risks and Benefits

#	Question	Answer
3.1	List any potential anticipated benefits to the participants.	Undergraduate students may participate in the study for bonus credits toward their mark in an Introductory Psychology course, or for nominal monetary compensation.
3.2	List any potential benefits to society.	The proposed research will provide exciting new insights into how and when our universal ability to ‘feel the beat’

		develops. It will lay the groundwork for future investigations that could explore the neural mechanisms underlying beat perception. For example, do the same interactions between auditory and motor systems that support speech and language also support movement to music? This is important because music and deficits in beat perception have been linked to language processing deficits like those found in dyslexia, and a better understanding of one may reveal crucial insights into the other.
3.3	List any potential risks to study participants.	There are no known risks associated with this study.
3.4	List any potential inconveniences to daily activities.	There are no potential inconveniences to daily activities.

4. Recruitment and Informed Consent

#	Question	Answer
4.1	How will potential participants be contacted? Select all that apply. A copy of all recruitment tools that will be used must be included with this submission in the attachments tab.	Telephone|Other
4.2	Please explain in detail how the above method(s) from 4.1 will be used to recruit participants.	Adult participants will be volunteers drawn from undergraduate students in the Western University Psychology Pool or the Summer Psychology Research Pool. These are students registered in the introductory Psychology class at Western (Psychology 1000). Students have the option of volunteering to participate in research studies in the Department of Psychology at Western University in return for credit towards their Introduction to Psychology course or can receive monetary compensation for their participation. Infants will be recruited from a developmental participant database maintained by the Department of Psychology at Western. All families in this database have been contacted previously (either at the time of the

		child's birth, or through previous developmental research participation in the Department of Psychology at Western), and have provided consent to be contacted in the future for research participation. All participation is voluntary. Families in the database are under no obligation to participate in future studies. All families will be contacted by phone, and provided with a brief description of the nature of the study. If the family is interested in volunteering for the study, an appointment will be made to visit the lab for research participation. Families are provided with contact information of the lab and the experimenter, and may cancel or reschedule their appointment at any time. Participation in the present research study does not obligate families to participate in any concurrent or future research studies conducted by the principal investigator or by other researchers at Western. Families may withdraw from the Western Developmental Database at any time.
4.3	Which research team members will be recruiting the potential participants?	Aaron Gibbings, student volunteers
4.4	Does the Principal Investigator have any relationship to the potential participants?	No
4.5	Does the person recruiting the participants have any relationship or hold any authority over the potential participants?	No
4.6	If you have answered "YES" to either 4.4 or 4.5, please explain here.	
4.7	Indicate if you will be recruiting from any of the following groups specifically for this study (Select all that apply).	Students|Any Western University Research pool|Minors (under 18)
4.8	Indicate any anticipated communication difficulties (Select all	None

	that apply).	
4.9	If you have selected one of the anticipated communication difficulties above in question 4.8, please describe what procedures will be used to address this issue (e.g., the use of translated forms, translator, impartial witness, etc.).	
4.10	What method of obtaining consent will you use for participants? A copy of all forms being used for obtaining consent must be included with this submission please add to the attachments tab.	Written consent|Parental consent (must be used for children under the age of 18)
4.11	If you are unable to obtain consent or assent using one of the methods listed above, please explain here. (Note, this does not apply to cultural research, please see the Cultural Research tab).	
4.12	Indicate what compensation, if any, will be provided to subjects. For example, reimbursement for expenses incurred as a result of research, description of gifts for participation, draws and/or compensation for time. Include a justification for this compensation.	Adult participants will receive either partial bonus credits toward their course mark for participating in a research study, or (if they are not enrolled in a course that offers research credits) monetary compensation of $25. This is to motivate participants to give their time to participate. In the infant trials, the parents of the infants will be reimbursed for the expense of parking on campus, or will be reimbursed for bus fare if they do not drive. This is so that it will not cost the parents money to bring their infant in, thereby removing a possible reason not to participate. Families will also be compensated for their time with a small token gift (e.g., Junior Scientist certificate of participation and a small bath toy or board book, total value $1.50).

5. Confidentiality and Data Security

#	Question	Answer
5.1	How will data without personal	Participant consent forms will be kept in

	information be stored and protected?	a locked filing cabinet in a secure office. Data collected from the participants will not include any information that could be used to identify them and will be organized by participant number. This participant number will not be linked to any other identifying document.
5.2	If storing data electronically, where will information collected as part of this study be stored? (Select all that apply)	University network drive|University local hard drive
5.3	If OFF-SITE is selected above, please explain where and what security measures are being used.	
5.4	Western University policy requires that you keep data for a minimum of 5 years. Please indicate if you are keeping data in accordance to this policy, otherwise please comment on how your data retention will differ from University policy and why. If you will be archiving the data, please explain why and how here.	
5.5	How will study data be destroyed after this period? (if applicable)	
5.6	Are you collecting any personal information from participants?	No
5.7	If YES is selected in question 5.6 above, which personal information is being collected? (select all that apply)	
5.8	If you checked any of the personal information in 5.7 above, please justify this collection.	
5.9	Please list any agencies/groups/persons outside of your local research team who may have access to any participant's personal information and indicate why such access is required.	
5.10	Describe any coding system used to protect personal information or explain why the data must remain identifiable.	Participant trials will be coded with a participant number that will not be linked to any document or form with identifying personal information.
5.11	How will the master list, signed	Paper file (Required protection: Locked

	original consent forms or other data with personal information be stored and protected?	cabinet in locked institutional office)
5.12	If OTHER is selected in question 5.8 above, please describe.	
5.13	Does this study require you to send any of the information listed in 5.2 outside of the institution where it is collected? This includes data taken off-site from the site it is initially collected for analysis. If yes, a data transfer agreement may be necessary.	No
5.14	If you answered "YES" to 5.15, where will the data be sent?	
5.15	If you answered "YES" to 5.15, how will the data be transmitted?	
5.16	Please specify any additional details on data transmission below.	
5.17	How will study data be recorded?	Instruments
5.18	If you checked Audio Recording in question 5.17 can participants take part in the study if they do not wish to be audio recorded? This information must be included in your Letter of Information.	
5.19	If OTHER is selected in question 5.17 above, please describe.	

6. Cultural Research

#	Question	Answer
6.1	Indicate which of the following special considerations should be acknowledged when reviewing the ethical standards of your research.	
6.2	Address how the work will be dealt with and what approvals have been or will be sought from the community.	
6.3	Address how you will obtain consent from the group you are working with, if written consent cannot be	

	obtained.	

7. Confirmation of Responsibility

#	Question	Answer
7.1	As the Principal Investigator I have read the Tri-Council Policy Statement 2 and Western University's Guidelines on Non-Medical Research involving Human Subjects and agree to abide by the guidelines therein: http://www.uwo.ca/research/ethics/non-medical/guidelines.html;	Yes
7.2	I attest that all Collaborators working on this Research Study (co-investigators, students, post- docs, etc.) have reviewed the protocol contents and are in agreement with the protocol as submitted;	Yes
7.3	All Collaborators have read the Tri-Council Policy Statement 2 and Western University's Guidelines on Non-Medical Research involving Human Subjects and agree to abide by the guidelines therein;	Yes
7.4	The Collaborators and I will adhere to the Protocol and Letter(s) of Information as approved by the REB;	Yes
7.5	Should I encounter any changes or adverse events/experiences, I will notify the REB of in a timely manner; and	Yes
7.6	If the Research Study is funded by an external sponsor, I will not begin the Research Study until the contract/agreement has been approved by the appropriate university, hospital, or research institute official;	Yes
7.7	Have you exported a copy of this submission to Word using the "Export to Word" button? Note that you will be unable to submit future revisions if this is not done.	Yes
7.8	Have you uploaded the following documents, if applicable, to the attachments tab? Incomplete submissions will be returned without being reviewed.	

8. Confirmation of Responsibility - Student

#	Question	Answer
8.1	Is this a student project?	No
8.2	As the Student I have read the Tri-Council Policy Statement 2 and Western University's Guidelines on Non-Medical Research involving Human Subjects and agree to abide by the guidelines therein: http://www.uwo.ca/research/ethics/non-medical/guidelines.html;	Yes
8.3	I will adhere to the Protocol and Letter(s) of Information as approved by the REB;	Yes
8.4	I will notify the Principal Investigator as soon as possible if there are any changes or adverse events/experiences, violations/deviations in regards to the Research Study;	Yes

Attachments

Description	File Name	Created
Parental/Infant Behavioural Consent	Infant Behavioiural Consent.doc	13/08/2013
Phone script for recruiting infant behavioural participants.	Huron Phone Script.doc	13/08/2013
Phone script for infant EEG recruitment.	BMI Phone Script.doc	13/08/2013
Questionnaire or hearing related exclusionary criteria for infants	Infant Hearing Questionnaire.doc	13/08/2013
Questionnaire or hearing related exclusionary criteria for adults	Adult Hearing Questionnaire.doc	13/08/2013
Adult/Student Information and Consent Form	Adult Consent.doc	13/08/2013
Parental/Infant EEG Consent	Infant Consent.doc	13/08/2013
		13/08/2013
Tracking document for all revisions/clarifications made.	Revision Tracker Jan 2012.docx	13/08/2013
Revised Parental Letter of Information and Consent for Behavioural Portion of the Infant Study	Infant Behavioural Consent.pdf	13/08/2013
Revised letter of information and consent for the adult portion of the study	Adult Consent.pdf	13/08/2013
Revised Letter of Parental information and consent for EEG portion of infant study	Infant EEG Consent.pdf	13/08/2013

Telephone recruitment script for the behavioural portion of the infant study	Huron Phone Script.pdf	13/08/2013
Telephone recruitment script for EEG portion of infant testing.	BMI Phone Script.pdf	13/08/2013
	DOC011113-01112013101211-0003.pdf	13/08/2013

Curriculum Vitae

Aaron Gibbings

Department of Psychology, Brain and Mind Institute,
Western University, London, Ont. Email:

Education

University of Western Ontario, London, ON (August 2014)

Masters of Science, Psychology, Behavioural and Cognitive Neuroscience

Thesis Topic: *How attention and beat perception modulate neural entrainment to rhythm*

King's University College at The University of Western Ontario, London, ON (May 2012)

Honours Bachelors of Arts, Specialization in Psychology.

Thesis Topic: *The framing effects of language and social dominance orientation on the expression of prejudice towards non-human animals.*

Course work at Athabasca University, Athabasca, AB and University of Waterloo, Waterloo, ON

In class and online; 2002-2007

Awards and Scholarships

Dean's Honours List *(2009/2010, 2010/2011, 2011/2012)*

Cumulative average above 80% for the year

Full-time Continuing Scholarship

2010; $2,000.00 – Average above 85% on course work in the previous academic year

2011; $1,500.00 – Average above 80% on course work in the previous academic year

Felix Giesen Award *(2011)* - $900.00

Granted to an upper year student who balances work and school to afford his/her tuition

Western Graduate Research Scholarship *(2012/2013, 2013/2014)* - $9,900

Awarded to eligible graduate students to fund research for their thesis

Ralph S. Devereux Award in Psychology *(2012)* - $1,000

Awarded to full time Masters student specializing in topics relating to Education or Children

NSERC Alexander Graham Bell Canada Graduate Scholarship – Master's *(2013/2014)* - $17,500

Awarded to students who demonstrate a high standard of achievement in undergraduate and early graduate studies

Experience and Additional Skills

Graduate Research Assistant (2013-2014) – Western University

Awarded to a full or part time to assist him/her in becoming an independent researcher. Research relates to student's own thesis.

Poster presentations:

Gibbings, A., Stojanoski, B., Cruse, D., & Grahn, J. A., (2013). The effect of attention and beat salience on selective neuronal entrainment to non-repeating rhythms. Poster presented at the *Society for Music Perception and Cognition (SMPC) Biennial Meeting*, Toronto, ON, Canada, August 2013.

Gibbings, A., Cruse, D., Stohanoski, B., & Grahn, J. A., (2014). The effect of attention and beat slience on the steady state response to non-repeating rhythms . Poster presented at *Lake Ontario Visionary Establishment (L.O.V.E.) Annual Conference,* Niagra Falls, ON Canada, February 2014.

Gibbings, A., Cruse, D., Stojanoski, B., & Grahn, J. A., (2014). Attention and presence of a beat affect neuronal entrainment to rhythms. Poster presented at *The Neurosciences and Music - V: Cognitive Stimulation and Rehabilitation,* Dijon, France, May 29 - June 1 2014.

Guest Lecturer:

Psychology 3125G: The Creative Brain (King's University College at Western University)

Invited speaker on beat perception related neuroimaging techniques (2013)

Graduate Teaching Assistant (2012-2013) – Western University

Psychology 2830: Research Methods and Statistical Analysis

Lecturing supplemental course material in lab sections, marking assignments, proctoring exams

Psychology 2840F: Behavioural Research Methods (King's University College at Western University)

Marking student research proposals, literature reviews, and proposed analyses

Teaching Assistant Training Program (2012) – Western University

A training program offered by the Teaching Support Centre at Western designed to help graduate students become more effective teachers.

Volunteer Teaching Assistant (2010)

Marked assignments for introductory psychology class at Fanshawe College

Marked assignments and presentations for Research Methods at King's University College

Computer Skills

Competent with Microsoft Office Suite, SPSS, Matlab, EEGLab, Mac and PCs

Trade Skills

Previous work experience with framing, drywall, pluming, landscaping and home renovation

People and Management Skills

Work experience in retail and food service industries,

Supervisory experience in busy restaurant kitchens