Western University
Scholarship@Western

Brescia Psychology Undergraduate Honours Theses | School of Behavioural & Social Sciences

Spring 4-5-2017

Exploring Neural Entrainment and Beat Perception Through Movement

Sarah M. Schwanz
Brescia University College, sschwanz@uwo.ca

Follow this and additional works at: https://ir.lib.uwo.ca/brescia_psych_uht

Part of the Biological Psychology Commons

Recommended Citation
Schwanz, Sarah M., "Exploring Neural Entrainment and Beat Perception Through Movement" (2017). *Brescia Psychology Undergraduate Honours Theses*. 5.
https://ir.lib.uwo.ca/brescia_psych_uht/5

This Dissertation/Thesis is brought to you for free and open access by the School of Behavioural & Social Sciences at Scholarship@Western. It has been accepted for inclusion in Brescia Psychology Undergraduate Honours Theses by an authorized administrator of Scholarship@Western. For more information, please contact tadam@uwo.ca, wlswadmin@uwo.ca.

Exploring Neural Entrainment and Beat Perception Through Movement

Sarah M. Schwanz

Honours Psychology Thesis
Department of Psychology
Brescia University College
London, Ontario, Canada
April 2017

Thesis Advisor: Dr. Jessica A. Grahn

Abstract

The way humans move to music has a large impact on how music is synchronized to, interpreted, and enjoyed. It is understood that movements to music aid in beat perception, and neural oscillations have the ability to entrain to musical rhythms. This study attempted to link these two well-established phenomena by exploring the use of movement to simple and complex musical rhythms to enhance neural entrainment. Ten undergraduate students engaged in 60 simple and complex musical rhythms, either tapping along to the beat or listening without movement, while undergoing EEG recording. Although the differences in brain response amplitude were not significant, brain activity responses to movement to complex rhythms were numerically greater than those prior to movement or movement to simple rhythms. These findings suggest that movement to complex musical rhythms has the potential to enhance neural entrainment, however a larger sample is needed to see these effects.

Exploring Neural Entrainment and Beat Perception Through Movement

An interesting phenomenon involved with music is how it compels individuals to move (Janata, Tomic, & Haberman, 2012). Synchronizing body movements to music is a universal human behaviour, and clearly demonstrates how the perception of auditory rhythms can associate with movement (Leman, 2007; Phillips-Silver, Aktipis, & Bryant, 2010). As an example, musicians, dancers, as well as non-musically trained individuals, often move their bodies in order to find and keep track of a beat. It has been well established that movements to music aid in beat perception (Phillips-Silver & Trainor, 2007). This is possible because humans have the ability to entrain or synchronize, with an external stimulus (Phillips-Silver et al., 2010), such as a musical rhythm. However, the neural representation of movement aiding beat perception remains unclear (Chemin, Mouraux, & Nozaradan, 2014).

Movement in time to music is seen across cultures (Phillips-Silver & Trainor, 2005; Tranchant, Vuvan, & Pretz, 2016). Humans spontaneously move to musical rhythms by nodding the head, bouncing, clapping or dancing in time with the perceived beat in a musical stimulus (Tranchant et al., 2016). Past research has studied this behavior through finger-tapping synchronization (Tranchant et al., 2016), including the use of the Beat Alignment Test (BAT), which is used to assess beat-based production and perception abilities using tapping (Müllensiefen, Gingras, Stewart, & Musil, 2013). Moving in such a way to the beat of music also enables individuals to enhance their perception by distinguishing between a strong or weak beat within the rhythmic pattern (Phillips-Silver & Trainor, 2005).

It is clear that the beat of rhythmic musical patterns can elicit movement, and this movement can then influence the auditory perception of that rhythm (Phillips-Silver & Trainor, 2008). The way humans move enhances listening and has a significant impact on how music is interpreted, enjoyed, and synchronized to (Phillips-Silver & Trainor, 2008; Tranchant et al., 2016). In this way, there is a strong link between bodily movement and perception of rhythms (Phillips-Silver & Trainor, 2007). Specifically, auditory and motor systems interact when processing musical rhythms (Su & Pöppel, 2012). As a part of these two interconnected systems, vestibular stimulation and information, such as a shift in balance or movement of the head, plays a large role in beat finding in music. It has been shown that bouncing to a specific beat while listening to a rhythmic pattern can influence the perception and understanding of that rhythm (Tranchant et al., 2016). In fact, musicians often use evident body gestures in order to convey the timing or the beat in music (Phillips-Silver & Trainor, 2008). When teaching music, individuals start by feeling the beat in the body through expressive body movements. As one becomes more familiar with the particular rhythm, the listener may no longer need to move to hear the beat (Phillips-Silver & Trainor, 2008); however, even passive listening can continue to activate motor regions of the brain (Grahn & Brett, 2007).

Movement to music has been a focus of study regarding various motor regions and the neural basis of rhythm, the coordination between the body and environmental stimuli such as music, as well as the variability, stability, and adaptability of entrainment or synchronization (Ross & Balasubramaniam, 2014). These research examples provide intriguing explanations as to why humans move when listening to music (Manning & Schutz, 2013).

An example of such research comes from Phillips-Silver and Trainor (2007), who have demonstrated that movements performed in time with musical patterns can enhance the perception of complex musical rhythms. Manning and Schutz (2013) have also demonstrated how moving to the beat can improve the perception of musical timing. In their study, participants listened to a series of beats and were asked to determine if the last tone in the sequence was consistent with the preceding rhythmic pattern: as in, on or off the beat. During half of the trials, participants tapped along with the beat, while in the other half, they listened without moving. In conditions where the final tone occurred off of the beat, later than expected, performance in the movement condition was significantly more accurate than the no-movement condition (Manning & Schutz, 2013). This provides a clear demonstration of how moving in time to a rhythm can enhance the perception of the beat, as well as it allows the individual to become more in tune with the rhythm they are listening to. Using the same procedure, Manning and Schutz (2016) conducted a similar study investigating how movement aiding beat perception is seen in percussionists and non-percussionists, this time tapping along in half of the trials using a drumstick. The results showed no significant difference between percussionists and non-percussionists; however, both groups performed significantly better when tapping along with the sequence compared to individuals only listening (Manning & Schutz, 2016). Each of these studies offers strong evidence that being able to move in time with a musical rhythm, such as tapping along, enhances beat finding abilities, even in more complex rhythmic patterns.

Another point to consider however is the type of movement used to aid beat perception. Tranchant et al. (2016) suggested different movement types might differentiate in influencing beat perception. In their study, Tranchant et al. (2016) investigated bouncing and clapping; both considered natural synchronous movements to music. It was found that clapping; an upper extremity function similar to tapping, was better able to synchronize with the beat compared to bouncing. This indicates particular types of movements should be considered, and upper extremity movements preferred when studying beat perception (Tranchant et al., 2016).

The study also found performance was correlated with beat saliency or sense of beat. Higher the beat saliency, meaning a greater sense of beat in a rhythm, facilitated better synchronization of body movements and in turn, better beat perception (Tranchant at al., 2016). This indicates that lower rhythmic complexity is better able to provide strong beat information; however, it may also suggest that more complex rhythmic structures require movement synchronization in order to extract the beat information more effectively. Similarly, Su and Pöppel (2012) investigated the effect of various body movements such as nodding the head or tapping the foot, on the listeners' ability to synchronize to the beat of a complex auditory sequence where the beat was difficult to discover. In this study, those who moved to the sequences using both types of movement, exhibited higher stability of synchronization in comparison to those who only listened (Su & Pöppel, 2012). Furthermore, the results indicated that preventing those from moving to a rhythm reduced their ability to find the beat (Su & Pöppel, 2012). This study differs from Tranchant et al. (2016) in that type of movement did not produce different abilities of beat perception, for example, better beat perception using the higher extremities. However, these studies produced similar results demonstrating that bodily movement is able to enhance auditory perception of an ambiguous or complex musical rhythm.

Movements to music are considered to be exploratory movements of the environment that are often rhythmic in nature, and have been suggested to involve some neural entrainment (Chemin et al., 2014). This is the method in which rhythmic processes in the brain synchronize to beats found in external rhythmic stimuli (Grahn, 2012), which may be in the form of musical beats and rhythms. There are many different types of entrainment, neural entrainment to music being only one, which act through various sensory modalities including auditory, visual, tactile and vestibular (Ross & Balasubramaniam, 2014). The external environment is filled with information that is perceived as rhythmical such as waves on the shore, footsteps, changes in light level, tides of the ocean, weather patterns, and daylight cycles (Phillips-Silver et al., 2010).

The biological rhythms of organisms synchronize or entrain to these and other cyclical processes (Phillips-Silver et al., 2010).

Neural entrainment specifically to music can also be referred to as neural resonance. The neural resonance theory of music posits that beat perception is the result of entrainment of neural oscillations to the beat frequency (Tierney & Kraus, 2015). Neural oscillations result from the interaction of excitatory and inhibitory neurons, which are periodically increasing and decreasing, creating a steady pattern (Grahn, 2012; Large, 2008). These oscillations mimic and entrain to the beat frequency of rhythmic stimuli (Grahn, 2012; Large, 2008; Tierney & Kraus, 2015). If the frequency of a musical stimulus is equal to the oscillations, the two will be in precise synchrony, also known as entrainment (Large, 2008). Through this process, entrainment to sound, particularly musical stimuli, is the most precise and accurate (Ross & Balasubramaniam, 2014), which may be because music is a predominant source of external rhythmic stimuli (Grahn, 2012).

Neural entrainment, or neural resonance to music, is defined as a phase locking of neural oscillations to the rhythmic structure of music (Grahn, 2012; Tierney & Kraus, 2015). This is supported by research such as a study conducted by Tierney and Kraus (2015) who presented participants with a single song with a super-imposed tone that was either on or off of the beat. It was shown that the on-beat condition produced greater neural entrainment, which supports the idea that with higher saliency or sense of beat, neural entrainment is more easily achieved, rather than to a complex rhythm.

Although simple rhythms appear to be easily entrained to, this cannot be said for complex rhythms. Phillips-Silver and Trainor (2007) have suggested that neural entrainment to complex musical rhythms is not only defined by audio features of sound but is also shaped by bodily movements. In other words, movement to complex musical rhythms may also aid in neural entrainment, as well as beat perception. However, evidence for this relation is currently unclear. One known study addressing this issue, conducted by Chemin et al. (2014), had right-handed participants listen to a repetitive rhythmic sequence before and after moving their bodies to the rhythm. The musical stimulus consisted of rhythmic patterns of 1.2 s, which were looped for 33 s each. During movement trials, the participants tapped along to the beat using their right hand. However in a second session, participants were able to move in any way they desired that matched the beat, such as clapping, nodding the head, tapping the foot, or swaying the torso (Chemin et al., 2014). From electroencephalography (EEG) recordings, the researchers found that brain activity following body movements performed to the beat of the rhythm, particularly tapping, was significantly increased, suggesting that movement can improve neural entrainment (Chemin et al., 2014).

Similar to this and Phillips-Silver and Trainor's (2007) proposal, the current study addressed the connection between neural entrainment and movement to musical rhythms. Because movement to rhythms is known to enhance beat perception, particularly to complex rhythms, and neural oscillations have been shown to entrain to musical rhythms, this study attempted to connect these two well-established phenomena.

It was hypothesized that moving to musical rhythms would aid in the neural entrainment to the same rhythm. More specifically, that movement would significantly enhance neural entrainment to complex musical rhythms, while not necessarily simple rhythms, which have an easily perceived beat without the assistance of movement.

Method

Participants

Undergraduate students (*N* = 10; six female, four male, M_{age} = 18.5 years, age range: 18-20 years) in a Psychology 1000 course at Western University were recruited through the research participation SONA system and randomly assigned to either the movement condition or no-movement condition (five participants in each group). The participants were right-handed and free of any hearing deficits and were compensated one course credit per hour for their participation. Data sets collected from two participants were excluded from the study due to a system malfunction and noisy EEG recordings.

Materials

A demographic questionnaire was used to gather basic information on each participant including age, gender, handedness, musical training, and any hearing deficits.

Continuous EEG recordings were taken at 2048 Hz with a passband from 0.16 to 100 Hz, using the BioSemi Active-Two amplifier system with 64 active electrodes mounted in an elastic cap. Two additional electrodes, the common mode sense (CMS) active electrode and the driven right leg (DRL) passive electrode, were used as reference and ground electrodes, respectively. Data were recorded from the electrodes affixed to the left and right mastoids for later re-referencing. Triggering at the onset of each tone was accomplished using a Cedrus StimTracker. All EEG data were analyzed offline using custom Matlab scripts (Mathworks, Inc.) and Fieldtrip software.

Auditory rhythms were generated based on 36 rhythmic patterns created by Grahn and Brett (2007) (See Appendix A). From these rhythms, 10 simple and 10 complex rhythms were chosen through pilot testing within the Grahn Lab. The simple rhythms had a relatively strong sense of beat and high saliency ratings, while the complex rhythms did not induce a strong sense of beat and had lower saliency ratings. Each of the simple and complex rhythms were selected as a matched pair consisting of the same interval set, although arranged in a different order resulting in either a simple or complex sequence. The tempos of these rhythms were then modified to create three different versions at 200 ms, 225 ms, and 250 ms respectively. Using this method, 60 unique rhythms were created for this study: 30 simple and 30 complex with three different tempi.

The simple and complex auditory rhythms used in this study were generated using Matlab software (Mathworks, Inc.) and were played through a Steinberg UR-22 USB sound card. Each of the rhythms was presented over Sennheiser HD 25-1 II on-ear headphones.

The production and perception subtests of the BAT (Müllensiefen et al., 2013) were presented over a laptop and used to assess beat-based production and perception abilities (See Appendix B).

A post-experiment questionnaire was used to evaluate how well the participant understood the task, difficulty level, and their level of concentration.

Procedure

Participants were randomly assigned to either the movement condition or the no-movement condition. Once written informed consent was obtained, the participants were asked to complete a demographic questionnaire. Participants in both conditions were prepared for EEG recording and engaged in a hearing threshold task in order to collect individual hearing levels, and add volume to the stimuli to ensure each participant experienced the same level of sound.

Participants then proceeded to the experiment in which 60 trials comprised of 30 simple and 30 complex rhythms were presented in a random order. The 60 trials were split into six segments consisting of 10 trials each, to allow the participant to have short breaks every 10 trials. Each trial in the session was divided into three separate blocks. During the first block, participants were instructed to listen, without moving, to the first musical clip. Following this in the second block, those in the movement condition were instructed to tap along on the keyboard to the same musical rhythm previously presented with their right hand, while participants in the no-movement condition listened to the rhythm again without moving. In the third block, all participants listened to the rhythm for a third time without moving. This three-block trial design was repeated 60 times using 30 simple rhythms with three tempi (10 rhythms per tempo: 200 ms, 225 ms, 250 ms), and 30 complex rhythms with three tempi (10 rhythms per tempo: 200 ms, 225 ms, 250 ms). During the session, participants were asked to detect a random target defined as a tone different from all of the rest, presented in 10% of the trials. After completing a trial, participants were asked if the tone was present.

Following the EEG experiment, all participants completed the production and perception subtests of the BAT. During the production subtest, participants were presented with nine song clips and asked to tap along to the beat using the computer keyboard. During the perception subtest, the participants were presented with 17 song clips over which a sine-tone metronome was superimposed. The metronome either aligned with the beat (four trials), was phase shifted with respect to the beat of the music (i.e. too early or too late; five trials), or was period shifted (i.e. too fast or too slow; eight trials). Participants indicated whether the metronome was “on” or “off” the beat of the music by pressing one of two buttons on the computer keyboard.

After completing the post-experiment questionnaire following the BAT, the participants were debriefed and dismissed from the study.

Data preprocessing and analysis

Data were preprocessed according to two pipelines. The first involved re-referencing to averaged mastoids, high-pass filtering (0.1 Hz, 11792 points, Kaiser window), and low-pass filtering (40 Hz, 90 points, Hann window) the raw data from each segment. Data were then divided into individual trial epochs, which ranged from -1.5 to 20 s with respect to the stimulus onset. Data were downsampled to 256 Hz, and then data from all segments were combined. Individual trials were subsequently removed if the amplitude range exceeded 200 µV.

For frequency-domain analysis, only the time window ranging from 1 to 19 s with respect to the rhythm onset was considered, in order to avoid contamination by onset and offset responses. Single-trial time-domain signals were zero-padded and multiplied with a Hann window, then submitted to a fast Fourier transform (FFT). The resulting frequency spectra were averaged over trials.

Results

A 2 x 2 x 2 Mixed Analysis of Variance (ANOVA) was conducted on brain response amplitude (µV) measurements taken from the first and third block of each trial, before and after the condition block respectively. The analysis revealed no significant main effect of condition, $F(1, 6) = 2.08$, $p = .20$, $\eta_G^2 = .23$, indicating that individuals in the movement condition (M = 0.00, SE = 0.01) did not differ in brain response from individuals in the no-movement condition (M = 0.02, SE = 0.01). It also revealed that simple rhythms (M = 0.02, SE = 0.01) and complex rhythms (M = 0.00, SE = 0.00) did not produce significant differences in brain response when individuals engaged with them $F(1, 6) = 2.10$, $p = .20$, $\eta_G^2 = .08$. Similarly, brain responses to the musical rhythms before (M = 0.01, SE = 0.01) and after (M = 0.01, SE = 0.01) the condition block did not significantly differ, $F(1, 6) = 0.17$, $p = .70$, $\eta_G^2 = .00$.

No significant interactions were found, including the interaction between rhythm type and condition, $F(1, 6) = 0.52$, $p = .50$, $\eta_G^2 = .00$, as seen in Figure 1; suggesting that neither movement or lack of movement changed brain responses to simple or complex musical rhythms.

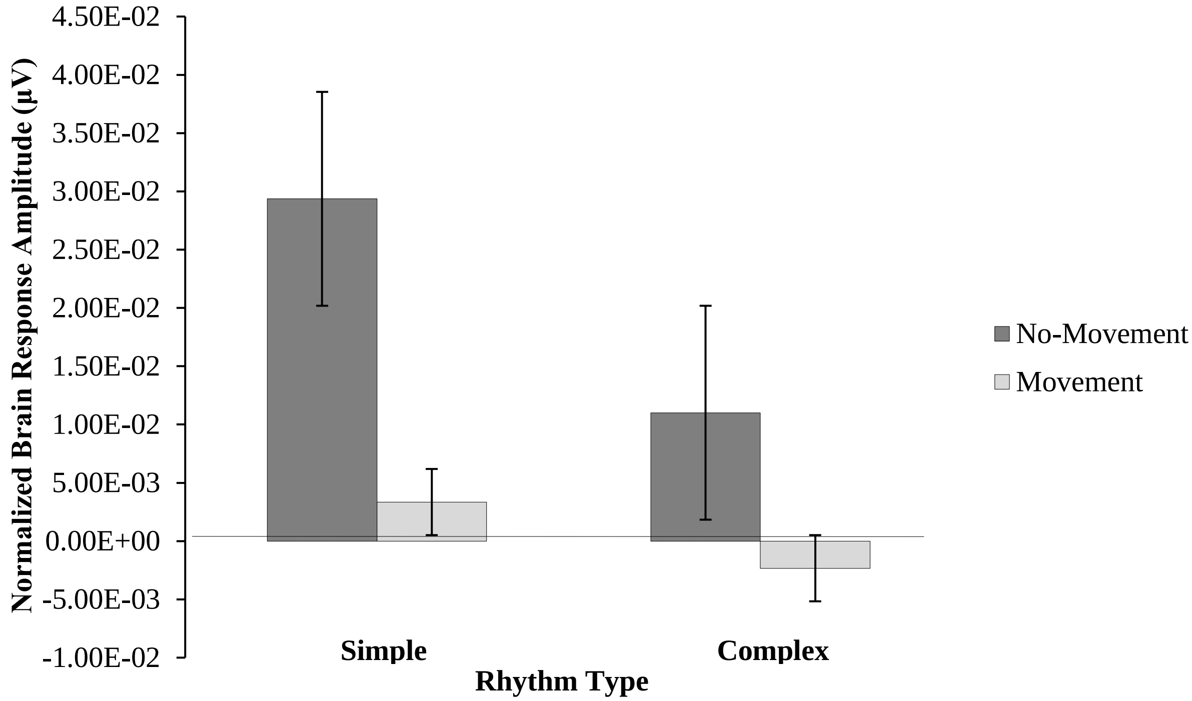

Figure 1. Mean brain response (µV) to simple and complex rhythms compared between the movement and no-movement conditions. No differences were found for either simple or complex musical rhythms between movement and no-movement. However, the no-movement condition brain responses for both rhythm types are numerically greater than the movement condition.

The interaction between block and condition, shown in Figure 2, was also not significant, $F(1, 6) = 0.42$, $p = .55$, $\eta_G^2 = .10$, and implies that there were no differences in brain response before or after the condition block, with or without the use of movement. As can be seen in Figure 3, simple and complex rhythms also did not produce significantly different brain responses before or after the condition block, $F(1, 6) = 2.54$, $p = .16$, $\eta_G^2 = .24$.

Ultimately, there was no significant interaction between rhythm type, block, and condition, $F(1, 6) = 3.91$, $p = .56$, $\eta_G^2 = .01$, illustrated in Figures 4 and 5. Suggesting that individuals' brain responses did not differ for simple or complex musical rhythms with the induction of movement to the beat, or lack thereof, after listening during the first block.

An A priori power analysis revealed that 52 participants would be needed for this interaction to become significant at the .95 statistical power level.

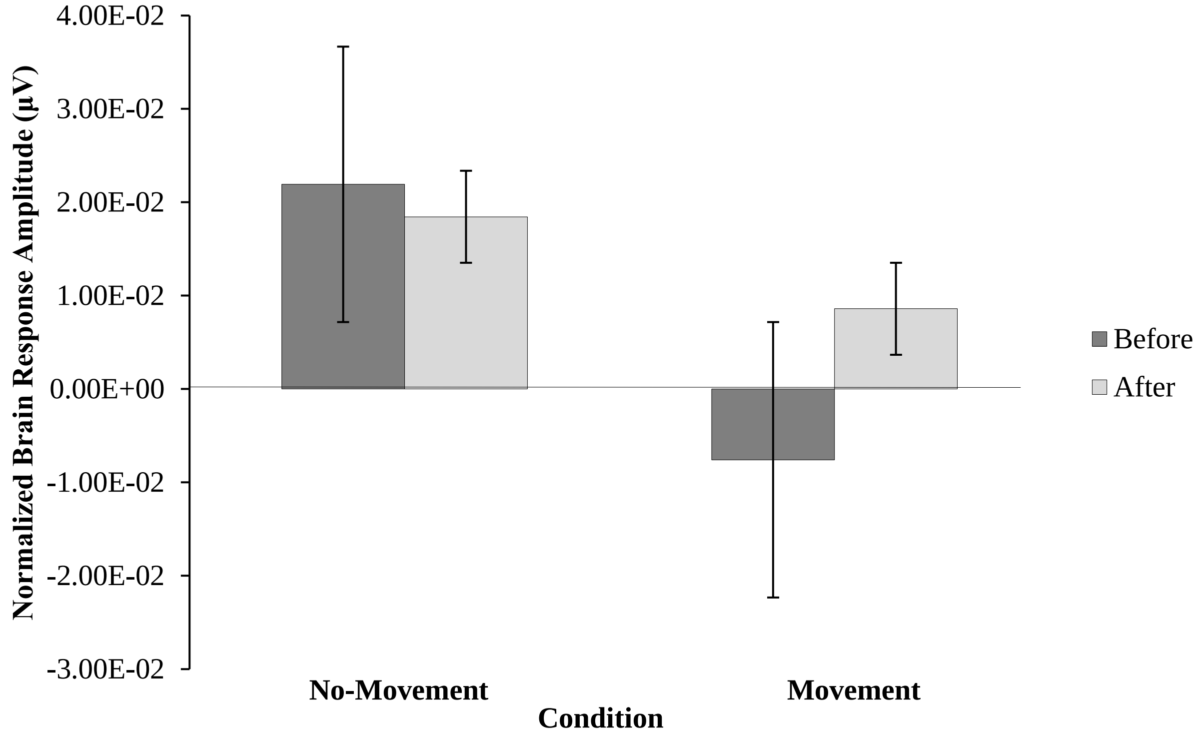

Figure 2. Mean brain activity (µV) in response to either the no-movement or movement condition. Bars illustrate the first and third block, referred to as before the condition block and after the condition block. The condition block is either no-movement or movement and produced no significant effect.

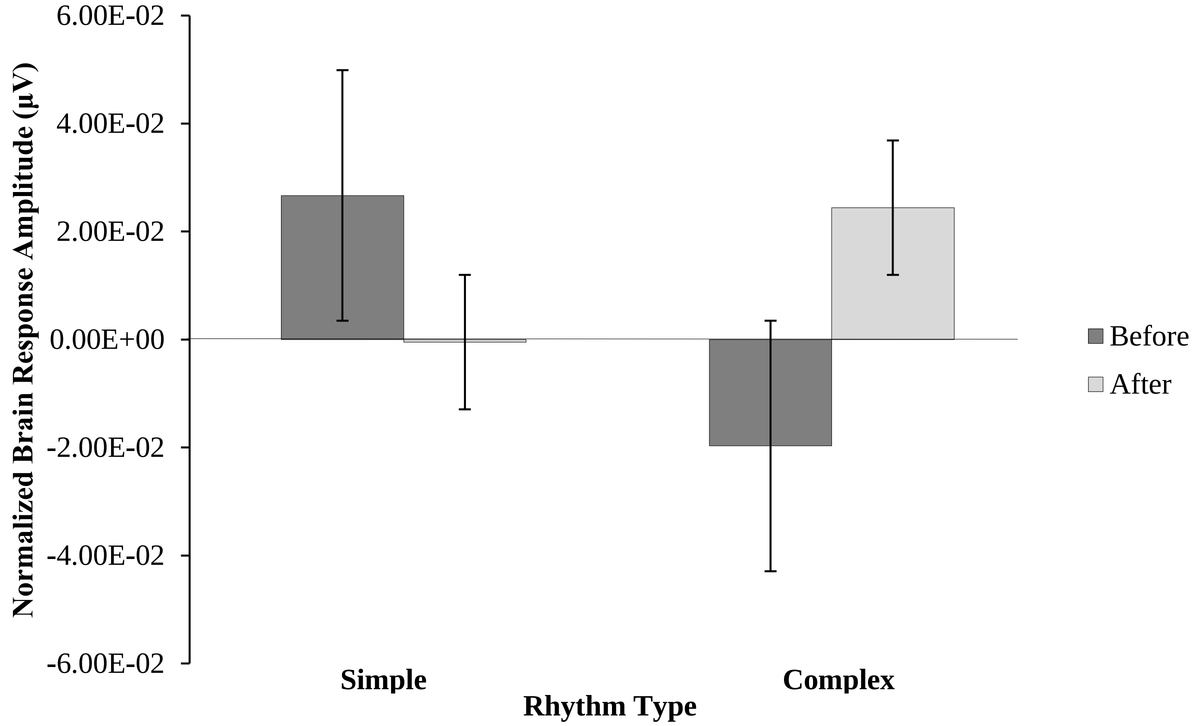

Figure 3. Mean brain response (µV) to simple and complex rhythms before and after the condition block. The interaction of rhythm type and block illustrated by the bars is not significant. However, the brain response to complex rhythms after the condition block appears numerically greater than the response to complex rhythms before the condition block.

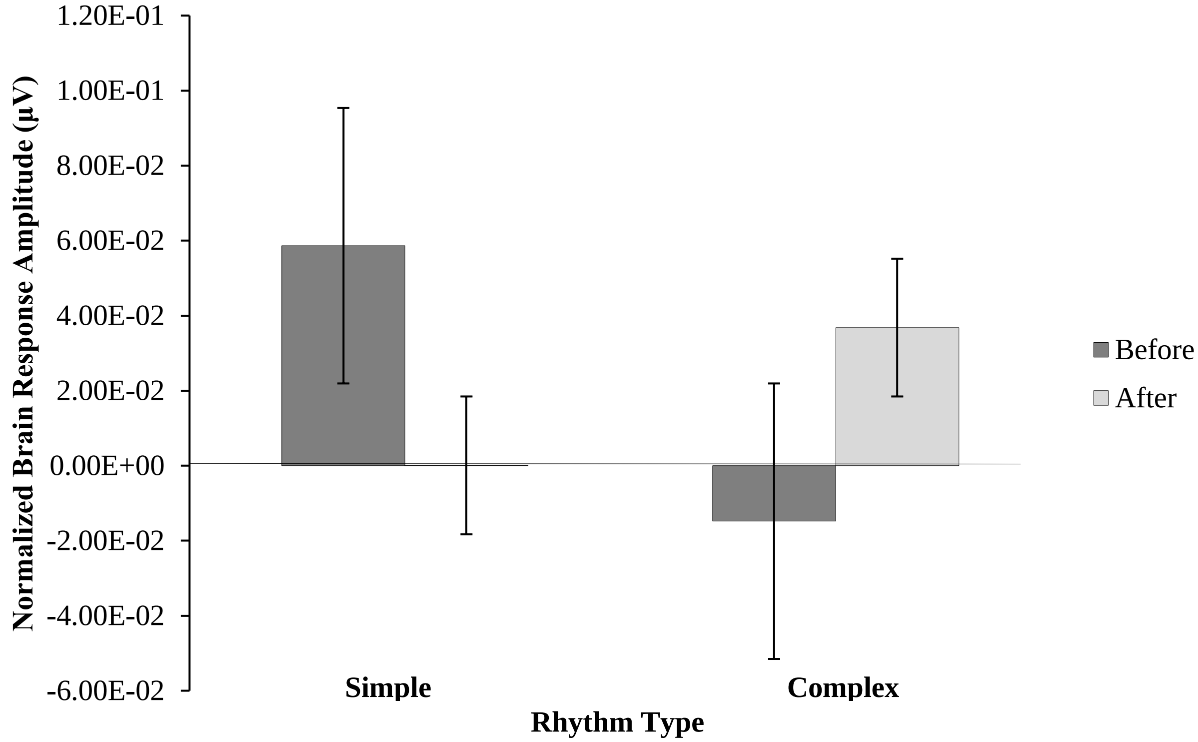

Figure 4. Mean brain response (μV) to simple and complex rhythms before and after the no-movement condition block. Bars represent the difference in brain activity between the first block and third block, with no-movement in between. No significant difference was found; however the first block of simple rhythms appears numerically greater than the third block.

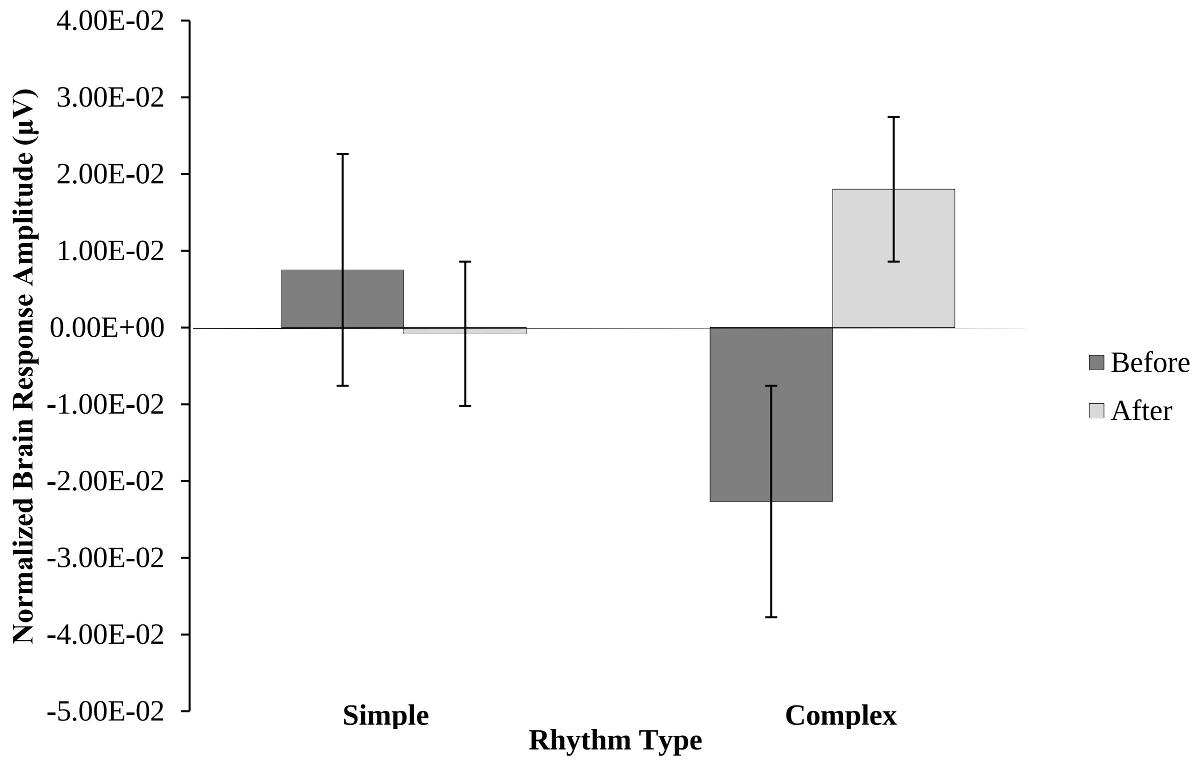

Figure 5. Mean brain response (µV) to simple and complex rhythms before and after the movement condition block. Bars represent the difference in brain activity between the first block and third block, with movement in between. No significance was found; however, the third block after movement to complex rhythms appears numerically greater than the first block before movement to complex rhythms.

Discussion

The present study focused on the link between bodily movement, beat perception, and neural entrainment by exploring the use of movement to simple and complex musical rhythms in order to enhance neural entrainment to such rhythms. It is clear that the ability to identify a strong or weak sense of beat in a rhythmic pattern allows and compels individuals to move to music (Janata et al., 2012; Phillips-Silver & Trainor, 2005, 2008). The way humans move to music enhances perception and has a significant impact on how music is synchronized to and interpreted (Chemin et al., 2014; Phillips-Silver & Trainor, 2008; Tranchant et al., 2016). Therefore, moving to musical rhythms could have the potential to promote neural entrainment.

The results, although not significant, show that there are numerical differences between conditions, blocks, and rhythm types, as indicated by the brain response amplitudes when engaged in simple and complex musical rhythms by either tapping along to the beat or simply listening. These numerical differences were first illustrated in the differences between rhythm type and condition. When participants engaged in both rhythm types, they showed numerically greater responses in the no-movement condition, opposite to the hypothesis, which proposed the movement condition would produce greater responses. However, a partial explanation for this response direction could be the fact that rhythms with a higher salience rating, or greater sense of beat, naturally produce greater beat perception with or without the use of movement, as well as neural entrainment can be more easily achieved (Tierney & Kraus, 2015; Tranchant et al., 2016). This would account for the numerical trend seen in simple rhythms, while the complex rhythms perhaps were not significantly influenced due to their low sense of beat and ambiguous nature.

Similarly, the differences between block and condition did not support the hypothesis in that no significant differences were found when participants either moved during the condition block or continued to listen. Brain responses did not change from the first to the third block for participants in either condition. However when illustrated, marginal numerical differences were shown for the movement condition, indicating that brain responses to simple and complex rhythms increased after moving along with the beat. This is complementary to the suggestion that movement to musical rhythms will enhance brain activity and in turn neural entrainment, whereas lack of movement will not produce these effects, as stated in the hypothesis.

In accordance with the hypothesis, numerical differences were found between the first and third blocks, before and after the condition block respectively, when listening or moving to complex rhythms. Specifically, brain responses increased after the condition block for complex rhythms. Numerical differences were not found for simple rhythms, which agrees with the hypothesis statement that neural entrainment to complex rhythms would receive a greater benefit compared to simple rhythms.

Expanding upon this, it was proposed that moving to complex rhythms would produce the greatest brain activity and neural entrainment, as compared to moving to simple rhythms or not moving to either rhythm type. Most notably, numerical differences were found in accordance with the hypothesis in that brain response amplitude was greater in participants after moving to complex rhythms. While on the other hand, movement to simple rhythms did not produce numerically different brain responses between the first and third blocks.

Although many trends were numerically different in the hypothesized direction, the results were not significant. It was determined however, that 52 participants would be needed in order to make these results significant, indicating that significant findings in relation to the hypothesis are indeed possible.

A general trend in the current findings was brain responses for complex rhythms, as well as rhythms with the induction of movement, were numerically greater than those for simple rhythms or in the no-movement condition. There was also a numerically greater response for complex rhythms in the movement condition. These numerical differences and patterns are consistent with past literature that suggests movement can improve neural entrainment to complex musical rhythms (Chemin et al., 2014; Phillips-Silver & Trainor, 2007). For example, Chemin et al. (2014) have shown significant increases in brain activity after performing various body movements, including tapping, to the beat of a musical rhythm. The results of the current study are similar in that, numerically speaking, brain activity increased following tapping to the beat of complex musical rhythms. These graphical trends appear to be moving in a similar direction as the results given by Chemin et al. (2014), as well as they add a supplementary component that neural entrainment to complex rhythms specifically may greatly benefit from the use of movements to the beat, such as tapping.

This is also consistent with findings that define complex rhythms as having lower salience ratings and a lower sense of beat as compared to simple rhythms, which have high saliency ratings, and a greater sense of beat (Tranchant et al., 2016). Due to the high salience ratings and lower rhythmic complexity of simple rhythms, beat perception is greater and therefore neural entrainment is easily achieved. On the other hand however, examples in the literature such as a study conducted by Tierney and Kraus (2015), suggest that because of the ambiguous nature of complex musical rhythms, they are more difficult to perceive the beat and entrain to. Both Tierney and Kraus (2015), and Tranchant et al. (2016) have demonstrated that a greater sense of beat in a rhythm allows for greater synchronization of body movements, beat perception and neural entrainment. In this sense, it has been suggested that moving to the beat of a complex musical rhythm may enhance beat information within the rhythmic sequence and in turn neural entrainment. The results of the current study have the potential to demonstrate this, as the graphical trends indicate that movement by tapping, numerically increased brain responses to complex musical rhythms, whereas moving to simple rhythms did not appear to make the same difference.

Phillips-Silver and Trainor (2007) have also suggested movement to complex musical rhythms may aid in neural entrainment. Their reasoning for this stems from the researchers' findings that movements performed to the beat of musical rhythms can enhance the beat perception of complex musical rhythms. Following this finding, the researchers posited that movement enhancing beat perception might, in turn, enhance neural entrainment as well, or rather, beat perception increased by movement may then increase neural entrainment (Phillips-Silver & Trainor, 2007). Manning and Schutz (2013) have also clearly demonstrated how moving to the beat can improve beat perception. These studies both provide strong evidence that moving in time to a musical rhythm, such as tapping along, can enhance beat perception in complex rhythms. If the current results were significant, they could provide support for this theory by linking this well-established phenomenon with neural entrainment to music.

In order to increase the statistical power of these results to establish significance, a considerable increase in participants is needed. The current study included data from eight participants with a minimal age range. It would be beneficial to include 52 participants or greater, as defined by a priori power analysis, in future research; as well as to expand the age range to include a wider variety of individuals.

Another consideration to make for future research is the area in which EEG data is collected. The present study collected data from the single vertex electrode, Cz, located on top of the head at 50% along the sagittal contour and 50% along the frontal plane (Oostenveld & Praamstra, 2001). This method only samples from a fraction of the elicited brain activity. Future studies may look into recording from multiple points or over specific regions; for example recording auditory and motor cortex activity. This may bring to light a clearer picture as to where neural entrainment to music, as well as in combination with movement, originates and functions.

Future research may also consider exploring different movement types to musical rhythms in order to enhance neural entrainment. The study conducted by Chemin et al. (2014) involved multiple parts of the body including the head, torso, hands, and feet, while the current study narrowed this down further by only using the right hand to tap along to the beat. It has been shown tapping with an upper extremity such as the right hand, produces clear results in favour of both neural entrainment and beat perception (Phillips-Silver & Trainor, 2007; Su & Pöppel, 2012; Tanchant et al., 2016). Therefore, future studies may take into account different types of movement, for example upper extremities versus lower extremities, or different parts of the body and their influence on neural entrainment to complex musical rhythms.

The value of this study, and others exploring the connection between movement, beat perception, and neural entrainment to musical rhythms is that it links two well-established phenomena: beat perception and neural entrainment to music through the use of movement. This has the potential to further our understanding of how the brain responds to music, both simple and complex sequences alike, and in turn how our bodies may influence this experience. The current findings suggest that movement to complex musical rhythms has the potential to enhance neural entrainment. Although the differences in brain response amplitude were not significantly different, brain activity in response to movement to complex musical rhythms was numerically greater than that of the first block before movement, and movement to simple rhythms. In conjunction with studies that have demonstrated a significant influence of movement on neural entrainment, this study offers a promising approach to linking beat perception and neural entrainment, and enhancing neural entrainment through the use of movement.

References

Chemin, B., Mouraux, A., & Nozaradan, S. (2014). Body movement selectively shapes the neural representation of musical rhythms. *Psychological Science, 25*, 2147-2159. doi:10.1177/0956797614551161

Grahn, J. A. (2012). Neural mechanisms of rhythm perception: Current findings and future perspectives. *Topics in Cognitive Science, 4*, 585-606. doi:10.1111/j.1756-8765.2012.01213.x

Grahn, J. A., & Brett, M. (2007). Rhythm and beat perception in motor areas of the brain. *Journal of Cognitive Neuroscience, 19*, 893-906. doi:10.1162/jocn.2007.19.5.893

Janata, P., Tomic, S. T., & Haberman, J. M. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General*, *141*, 54-75. doi:10.1037/a0024208

Large, E. W. (2008). Resonating to musical rhythm: Theory and experiment. In S. Grondin (Ed.), *Psychology of time* (pp. 189–231). Bingley, UK: Emerald.

Leman, M. (2007). *Embodied music cognition and mediation technology*. Cambridge, MA: MIT Press.

Manning, F., & Schutz, M. (2013). "Moving to the beat" improves timing perception. *Psychonomic Bulletin & Review*, *20*, 1133-1139. doi:10.3758/s13423-013-0439-7

Manning, F. C., & Schutz, M. (2016). Trained to keep a beat: Movement-related enhancements to timing perception in percussionists and non-percussionists. *Psychological Research*, *80*, 532-542. doi:10.1007/s00426-015-0678-5

Müllensiefen, D., Gingras, B., Stewart, L., & Musil, J. J. (2013). Goldsmiths musical sophistication index (Gold-MSI) v1.0: Technical report and documentation revision 0.3

Oostenveld, R., & Praamstra, P. (2001). The five percent electrode system for high-resolution EEG and ERP measurements. *Clinical Neurophysiology, 112*, 713-19. doi:10.1016/S1388-2457(00)00527-7

Phillips-Silver, J., Aktipis, C. A., & Bryant, G. A. (2010). The ecology of entrainment: Foundations of coordinated rhythmic movement. *Music Perception*, *28*, 3-14. doi:10.1525/mp.2010.28.1.3

Phillips-Silver, J., & Trainor, L. J. (2005). Feeling the beat: Movement influences infant rhythm perception. *Science*, *308*, 1430. doi:129.100.58.76

Phillips- Silver, J., & Trainor, L. J. (2007). Hearing what the body feels: Auditory encoding of rhythmic movement. *Cognition, 105*, 533-546. doi:10.1016/j.cognition.2006.11.006

Phillips-Silver, J., & Trainor, L. J. (2008). Vestibular influence on auditory metrical interpretation. *Brain and Cognition, 67*(1), 94-102. doi:10.1016/j.bandc.2007.11.007

Ross, J. M., & Balasubramaniam, R. (2014). Physical and neural entrainment to rhythm: Human sensorimotor coordination across tasks and effector systems. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00576

Su, Y., & Pöppel, E. (2012). Body movement enhances the extraction of temporal structures in auditory sequences. *Psychological Research, 76*, 373-382. doi:10.1007/s00426-011-0346-3

Tierney, A., & Kraus, N. (2015). Neural entrainment to the rhythmic structure of music. *Journal of Cognitive Neuroscience*, *27*, 400-408. doi:10.1162/jocn_a_00704

Tranchant, P., Vuvan, D. T., Peretz, I. Keeping the Beat: A Large Sample Study of Bouncing and Clapping to Music. (2016). *PLoS ONE, 11*. doi:10.1371/journal.pone.0160178

Appendix A
Rhythmic Sequences

	Interval Set	*Metric Simple*	*Metric Complex*
5 Intervals	11334	31413	11343
		41331	33141
		43113	41133
	12234	22413	13242
		31422	21324
		43122	41232
6 Intervals	111234	112314	124113
		211134	214311
		211413	321411
		411231	421311
	112224	112422	122142
		211224	214221
		222114	221241
		422112	412212
	112233	221331	121233
		223113	132321
		311322	231123
		312213	323211

Appendix B
Audio Clips Used in the BAT

Prime Rib
http://www.audionetwork.com/production-music/prime-rib_15643.aspx

Never Going Back Again
http://www.audionetwork.com/production-music/never-going-back-again_17255.aspx

Psychedelic Space
http://www.audionetwork.com/production-music/psychedelic-space_9831.aspx

Four Handed Hedgehog
http://www.audionetwork.com/production-music/four-handed-hedgehog_33902.aspx

Sassy Stomp
http://www.audionetwork.com/production-music/sassy-stomp_26241.aspx

Crazy 2
http://www.audionetwork.com/production-music/crazy-2_5198.aspx

One Jump Ahead
http://www.audionetwork.com/production-music/one-jump-ahead_35559.aspx

Freedom Of The City
http://www.audionetwork.com/production-music/freedom-of-the-city_35540.aspx

Roaring Twenties
http://www.audionetwork.com/production-music/roaring-twenties_26259.aspx

For King And Country
http://www.audionetwork.com/production-music/for-king-and-country_29632.aspx

Lord Abinger Waltz
http://www.audionetwork.com/production-music/lord-abinger-waltz_19351.aspx

Switchblade 2
http://www.audionetwork.com/production-music/switchblade-2_14006.aspx