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Why Musical Groove Makes Us Move: An Electroencephalographic Investigation

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WHY MUSICAL GROOVE MAKES US MOVE: AN ELECTROENCEPHALOGRAPHIC
INVESTIGATION

By

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Bachelor of Arts – Psychology
Bachelor of Music – Music Performance
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2011

A thesis submitted in partial fulfillment
of the requirements for the

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Abstract

Moving to the groove of the music is a phenomenal and universal human behavior. Common characteristics to most dance music include a salient beat, rhythmic complexity, and a dynamic musical structure. What is unknown, however, is *why* music has the power to promote physical movement. Musical rhythm and motor processing are tightly linked activating brain areas important for motor preparation and execution. While studies demonstrate that the motor system is active during beat processing, it is still unclear how *musical groove*, a beat-influenced quality to music that makes us want to move, can engage these motor areas. Here, I performed a novel investigation to understand how high-groove music can enhance sensorimotor processing. In contrast to previous work that utilized transcranial magnetic stimulation, I used electroencephalography to measure motor-related neural activity on a fine temporal scale during continuous music listening. Specifically, I measured the lateralized readiness potential, an event-related potential related to motor activation and response execution. I predicted that music with high amounts of groove would promote sustained motor area engagement. Particularly, I hypothesized that high-groove music, as defined by Janata et al. (2012), would promote greater motor system priming than low-groove music, noise, or silence, resulting in faster neural activation during both response preparation and execution. Furthermore, I anticipated that neural measures would correlate with subjective music ratings, with earlier onsets and greater amplitudes of neural motor activity relating to higher musical groove scores.

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For Dad, who taught me to love the groove.

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CHAPTER 1

Introduction

Music is a powerful instigator of action. It is common for a person to bob one's head, tap one's foot, or dance along to music (Honing, Ladinig, Háden, & Winkler, 2009). It seems that the more we move to music, the more we enjoy it (Janata, Tomic, & Haberman, 2012). From as early as five months old, infants emotive enjoyment when moving to music (Zentner & Eerola, 2010). Engagement with music continues into adulthood, serving as a regulator of emotions and moods (Laukka, 2007; Saarikallio & Erkkilä, 2007; Schäfer, Sedlmeier, Städtler, & Huron, 2013). By using the body as a mediator between one's subjective music listening experiences and the music itself, it can offer the listener a greater meaning to music (Merleau-Ponty, 1945). Whether or not we are able to control our movement to music, there is an experiential component of how those movements drive our cognition that is related to personal intention and expression (Leman, 2012). While dance and music are universal to world cultures (D. E. Brown, 1991; Nettl, 2000; Pinker, 2003), the origins of movement to music are still unclear. Though it might be assumed that moving to music evolved from social bonding practices, such as dance or marching in synchrony, there may be biological factors that subserve this unique, human response.

Action-Related Cognition

Previous work has looked toward embodied cognition, or cognitive processing influenced by the body's interaction with the environment, to help tease apart the possible reasons for why we move to music. Wilson's claim that "off-line cognition is body based" describes how the

sensorimotor system can be used covertly in abstract cognitive activities. For example, when we first learn to count, we are often taught to make large movements with our fingers, assigning each digit as a counter. Wilson inferred that as our mental processes become more developed, these mental structures evolve to function separately from their originally associated physical outputs, allowing us to count in our heads efficiently without making these overt movements (M. Wilson, 2002).

According to Hebb's cell assembly theory, neurons that fire together, wire together: there is evidence that sensorimotor activation goes beyond mere counting. During action-related semantic word comprehension, there is not only activation in brain regions important for language processing (i.e., Broca's and Wernicke's areas), but also in premotor (pMC) and primary motor (M1) cortices. Additionally, dual activation of language and motor areas occurs when reading action-related words such as pick, kick, or lick. This was further confirmed by overlaying functional resonance images of participants performing these actions. Regardless of whether the participant physically kicked or only read "kick", the leg area of the motor system was engaged (de Lafuente & Romo, 2004; Hauk, Johnsrude, & Pulvermüller, 2004).

Besides visual word cues, auditory perception of action words can also engage motor areas. Pulvermüller et al. (2005) found that cognitive meaning access during action word recognition is an early and automatic response. Once an action word is spoken, semantic activation in the associated language and motor areas occurs within 200 ms after perception (Pulvermüller, Shtyrov, & Ilmoniemi, 2005). Furthermore, semantic meaning access of action also broadens to sentence comprehension. When listeners hear action-related sentences, they habitually stimulate motor regions associated with the described action (Buccino et al., 2005).

Auditory-Motor Coupling

The semantic meaning of action is not limited to language comprehension. Just the sounds of actions, such as paper tearing, typing, and walking, actuate the specific sensorimotor areas associated with that task (i.e., hand muscle activation when typing) (Aziz-Zadeh, Iacoboni, Zaidel, Wilson, & Mazziotta, 2004), music listening can also stimulate motor-related networks. For instance, experienced pianists show more motor system activity than non-pianists when asked to listen to piano pieces (Haueisen & Knösche, 2001) especially when listening to pieces that were previously rehearsed (D'Ausilio, Altenmüller, Olivetti, & Lotze, 2006). Because musicians have had long-term practice of timing specific movements to sounds, the communication between auditory and motor networks is well-rehearsed; however, this audiomotor recognition network can engage quickly even in naïve musicians. After novice musicians underwent five days of piano training, functional magnetic resonance imaging (fMRI) revealed greater bilateral activation in fronto-parietal motor regions when listening to trained music compared to untrained music (Lahav, Saltzman, & Schlaug, 2007).

Some research suggests that audiovisual mirror neurons are responsible for auditory perception engendering motor system engagement (Keysers et al., 2003; Kohler et al., 2002; Pizzamiglio et al., 2005). In animal studies, Kohler et al. (2002) found that the same neurons in the rostral ventral premotor cortex would fire regardless of whether macaque monkeys saw and heard the action or just heard the action. Similarly, the audiomotor activation patterns seen in rehearsed music studies are found in the heart of this frontoparietal mirror neuron circuit (D'Ausilio et al., 2006; Haueisen & Knösche, 2001; Lahav et al., 2007; Zatorre, Chen, & Penhune, 2007) paralleling what has been shown in other human action-observation tasks (Buccino et al., 2005; Calvo-Merino, 2005; Grèzes, Armony, Rowe, & Passingham, 2003; Haslinger et al., 2005; Iacoboni, Molnar-Szakacs, Gallese, Buccino, & Mazziotta, 2005; Lotze et

al., 2006). Evidence indicates that non-action and action sounds are processed by two separate neural systems. Using electroencephalography (EEG) on humans, Pizzamiglio et al. (2005) found that action-related sounds modulated posterior superior temporal and premotor areas while non-action-related sounds activated the temporal pole bilaterally with no motor area engagement.

Musical Groove

Not only does reading or hearing the word “dance” activate leg-related sensorimotor areas, but listening to dance music can also engage motor regions (Ross, Warlaumont, Abney, Rigoli, & Balasubramaniam, 2016; Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller, 2013; E. M. F. Wilson & Davey, 2002). Songs by artists such as Stevie Wonder, James Brown, and Michael Jackson are often played in dance-themed movies or at weddings because they encourage people to dance. Music by these artists, along with songs from genres like pop, rock, hip hop, funk, soul, electronic music, and R&B, all share a musical characteristic that causes spontaneous movement (Butler, 2006; Danielsen, 2006; Greenwald, 2002; Janata et al., 2012; Witek, Clarke, Wallentin, Kringelbach, & Vuust, 2014). Groove is the musical quality that consistently compels us to move (Janata et al., 2012). It is musical groove’s perfect combination of a salient beat, rhythmic complexity, and musical structure that not only urges humans to dance, but makes it the cornerstone of understanding the sensorimotor networks involved in complex, auditory-induced movement.

What is unique to music compared to action-related sounds is its foundation in rhythm. From a young age, not only do humans feel pleasure when moving to music, but particularly when they synchronize their movements with the song’s underlying pulse or beat (Huron, 2006; Witek et al., 2014; Zentner & Eerola, 2010). The beat is the periodic pulse of the music (often clapped along with at a concert) regularly played by a percussive or low-pitched instrument such

as the drums or bass (Drake, Penel, & Bigand, 2000; Large & Palmer, 2002; Parncutt, 1994; Van Dyck et al., 2013). Surveys indicate that the presence of a strong beat is pertinent to the feel of musical groove (Janata et al., 2012). A beat that is easy to grasp from a rich musical background serves as an anchor for our accompanying physical movement (Hove, Keller, & Krumhansl, 2007; Maurer & Mondloch, 2004; McAdams, 2013; Witek & Clarke, 2014).

Madison et al. (2011) indicate that beat salience, or the level of repetitive rhythmical patterning occurring at a comfortable movement rate, is an important contributor to groove. This is because predictive timing, or the internal mechanism for following music, facilitates human synchronization (Kauranen & Vanharanta, 1996; Snyder & Krumhansl, 2001). Most dance music ranges from 60-200 BPM with the regular peak tempo, or beats-per-minute (BPM), most suitable for dancing at 125 BPM (van Noorden & Moelants, 1999). This is also seen as most people's average preferred tempo and allows for the easiest and most accurate synchronization of movement to a beat (Michaelis, Wiener, & Thompson, 2014). Because music's beat-to-beat variability is not much bigger than a few percent from the beat interval (Madison & Merker, 2002), it allows for precise synchronization of one's physical movement to the music as well as with others. In turn, beat synchronicity promotes a pleasurable listening environment – a consistent response to hearing music that “grooves” (Janata et al., 2012). The positive affect that one experiences from synchronizing to a musical beat is thought to be transferred to surrounding individuals creating a shared pleasurable experience (Cirelli, Einarson, & Trainor, 2014; McGuinness & Overy, 2011; Overy & Molnar-Szakacs, 2009; Trost et al., 2014; Vacharkulksemsuk & Fredrickson, 2012; Witek et al., 2014; Zentner & Eerola, 2010).

Beat perception occurs not only in brain areas that process sound, but extends to sensorimotor networks involved in complex movement. Perception of a musical beat (i.e.,

hearing a beat in musical patterns without moving) as well as tapping along to a beat engages motor-related brain areas including the pMC, basal ganglia (putamen), supplementary motor cortex (SMA), and cerebellum (Chen, Penhune, & Zatorre, 2008; Grahn & Brett, 2007; Kung, Chen, Zatorre, & Penhune, 2013; Zatorre et al., 2007). These “motor planning regions” are recruited during beat perception of an unambiguous pattern (Fujioka, Trainor, Large, & Ross, 2012) and may possibly participate in beat perception of an ambiguous pattern (Iversen, Repp, & Patel, 2009). In these listening paradigms, magnetoencephalography (MEG) measurements indicated larger evoked neural responses only in the beta frequency range (20-30Hz), the same frequency at which the motor system sometimes oscillates (Fujioka, Ross, & Trainor, 2015).

Some researchers suggest that the primary role of motor planning regions, particularly the pMC, is for timing in sequences (Rauschecker & Scott, 2009). Therefore, because musical beats are periodic in nature at a rate similar to everyday human movement (i.e., several 100 ms intervals shown in walking or arm swinging), the auditory system may recruit motor areas as a resource in making precise temporal predictions. Patel & Iversen (2014) speculate that this communication between the auditory and motor planning systems during musical beat perception is bidirectional. They state that first, neural impulses from the auditory system travel to the motor planning system to give information about the timing of auditory events. These auditory signals affect the timing of periodic motor planning within these motor planning areas. Then, these resulting motor planning signals travel back to the auditory system to provide information that predicts upcoming beats (Patel & Iversen, 2014).

Beyond a salient musical beat, syncopation is a characteristic of musical groove’s complex rhythmic structure. Syncopation is defined as rhythmic events that produce expectancy violations by emphasizing weak beats and understating strong beats (Janata et al., 2012; Keller &

Schubert, 2011; Longuet-Higgins & Lee, 1984; Madison, 2006; Madison & Sioros, 2014; Sioros, Miron, Davies, Gouyon, & Madison, 2014; Temperley, 1999; Witek et al., 2014). An example of syncopation is in the song *Here Comes the Sun* by The Beatles. As explained by Temperley (1999), the lyrics deviate from their “normal” placement (Figure 1). Rather than aligning stressed syllables with strong metrical beats (i.e., on-beats), which is common in Western music, they are displaced by half a beat, creating an emphasis, or accent, on the off-beat (Figure 1B). Janata et al. (2012) found that listeners identified music as greater in groove when it had more syncopation. Witek et al. (2014) further found that musical groove ratings correlated with syncopation in an inverted U fashion (i.e., Wundt curve). A moderate amount of syncopation related to the greatest perception of groove regardless of whether the music is naturally syncopated or if syncopation is synthetically added (Huron & Ommen, 2006; Keller & Schubert, 2011; Witek et al., 2014).

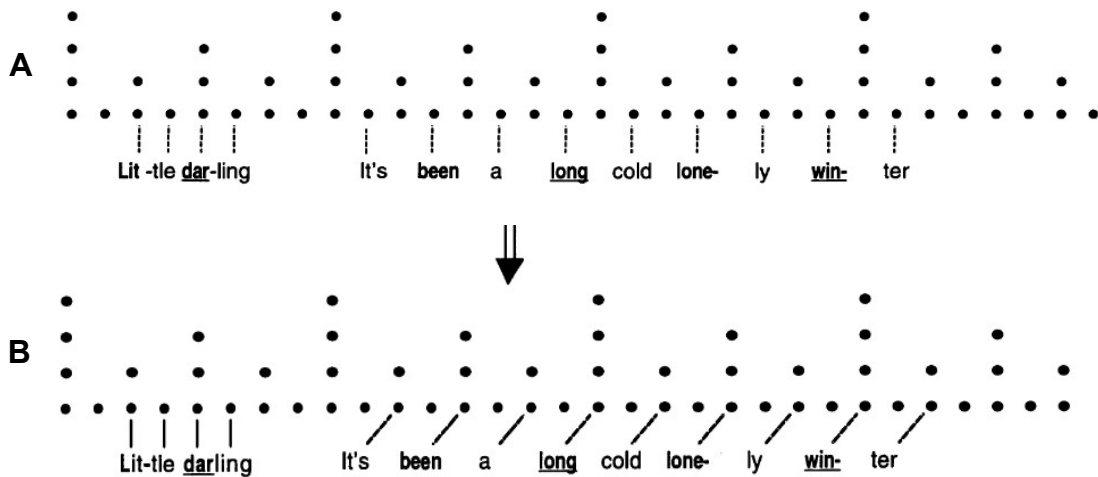


Figure 1. Excerpt from *Here Comes the Sun* by The Beatles explained by Temperley (1999). Lines with 4 dots show the beginning of the measure (i.e., beat 1 of the measure); lines with 3 dots shows the second strongest beat (i.e., beat 3 of the measure); lines with 2 dots shows the other on-beats (i.e., beats 2 and 4 of the measure); one dot shows the off-beats. The top figure (A) indicates where the text aligns with the beats (i.e., off-beats in the music). The bottom figure (B) shows how the text is syncopated. Lines connect the text with the following on-beat it is anticipating.

Syncopation aids in the aesthetically-pleasing listening experience that is unique to music with groove (Janata et al., 2012). When listening to music with rhythmic complexity, such as syncopation, our motor system associates specific motor effectors with certain hierarchical timescales (Patel & Iversen, 2014). Syncopated music anticipates the on-beat (Witek et al., 2014), prepping the listener to synchronize their limbs not only to the music (Toivianen, Luck, & Thompson, 2010), but also with others, cultivating a more enjoyable listening experience. In addition, syncopation adds a small degree of metrical instability creating rhythmic tension (Temperley, 1999). This violates the listener's rhythmic expectancies of a predictable beat, evoking arousal (Huron, 2006; Keller & Schubert, 2011; Steinbeis, Koelsch, & Sloboda, 2006).

If beat salience and syncopation solely determined musical groove perception, Janata et al. (2012) would have found non-melodic, rhythm-forward songs, such as drum loops, to be rated the highest in groove; however, this was not the case. Looking at Janata et al. (2012)'s song library, the highest-rated drum loop (AHH08_loop10) was given an overall score of 58.1 while the highest-rated polyphonic song (Superstition) was rated 108.7. What is fascinating about musical groove is that it seems to be a collection of musical characteristics, based in rhythm as well as melody, that creates this idiosyncratic feeling. Thus, there is a growing curiosity in how instrumentation, timbre, and musical structure can also furnish musical groove.

In Western musical structure, it is common to have the instrument with the lowest pitch or the darkest timbre (i.e., composed of low frequency components) play the salient beat (Hove et al., 2007; Hove, Marie, Bruce, & Trainor, 2014) and have instruments with a higher pitch or timbre (i.e., composed of high frequency components) play the melody (Fujioka, Trainor, & Ross, 2008; Fujioka, Trainor, Ross, Kakigi, & Pantev, 2005; Marie & Trainor, 2013, 2014; Trainor, Marie, Bruce, & Bidelman, 2014) and the syncopated, less salient beats (Maurer &

Mondloch, 2004; Temperley, 2009; Witek & Clarke, 2014). Originally, because instruments of a lower timbre tend to be easier to hear (Hove et al., 2007; McAdams, 2013), they were thought to be more stable, giving the listener a more grounded feeling. This experience may be attributed to how human's auditory physiology is organized. When listening concurrently to two streams of tones, Hove et al. (2014) found that timing deviations in the brain were better detected in lower-pitched streams than in higher-pitched streams. Additionally, when asked to tap along to these pitch streams, there were timing shifts in participants' taps when low pitches occurred earlier compared to when high pitches were earlier. This revealed that motor synchronization may be more influenced by lower pitches in polyphonic (i.e., multiple voice) listening (Hove et al., 2014).

In the context of polyphonic music listening, Witek & Clarke (2014) found that in songs played by three instruments of different timbres, they were rated as the least stable and had the most tapping variability when the bass drum (lowest in timbre) played syncopated rhythms and the hi-hat (highest in timbre) played the salient beat, or tactus. Though the authors predicted that music would be rated more stable if there were more instruments playing the tactus compared to those that played the syncopation, this was not always the case. Only musical combinations of the bass drum playing the tactus and the hi-hat playing the syncopation were rated as the most stable. More recently, follow-up research to the Hove et al. (2014) study found that during simultaneous two-pitch stream listening, regardless of whether the timing deviation was early or late, when low pitches occurred earlier in time than high pitches, timing deviations were better detected on both perceptual and neural levels (Wojtczak, Mehta, & Oxenham, 2017). These results refute what was found by Hove et al. (2014) indicating a lack of superior temporal encoding at low frequencies; however, these results may corroborate why people rated the

bass/tactus-hi-hat/syncopation sound combination in the Witek et al. (2014) most stable. The sound of stability in human auditory processing could be due to its asymmetry in the perceptual and neural encoding of synchrony, resulting in better tolerance of low-frequency sound delays (Wojtczak et al., 2017). Therefore, whether the low-frequency sound is on or off the beat, when it is preceded or followed by a syncopated high-frequency sound, the listener's perceptual and motor systems may be more aware of this processing asynchrony.

In turn, it seems that non-rhythmic musical characteristics, particularly instrumentation and timing, can also influence how we emotionally perceive music (Dalla Bella, Peretz, Rousseau, & Gosselin, 2001; Grewe, Nagel, Kopiez, & Altenmüller, 2007). Hurley et al. (2014) found that music with more instruments were rated as higher in groove. Furthermore, when entrances of instruments were staggered across time, not only was music rated as higher in groove, but there was more sensorimotor coupling, measured as a function of synchronized tapping to the music's beat (Hurley, Martens, & Janata, 2014). As researchers continue to untangle the relationship between beat and syncopation, several sources agree that multiple instruments are needed to provide the enjoyable balance of anticipation and stability heard in songs with musical groove.

Primary Motor Cortex Engagement in Musical Groove

Research thus far has found that action-related words such as “dance” can engage M1 while perceptions of beat and complex rhythms actuate premotor regions. When it comes to listening to dance music, however, there is conflicting evidence as to whether songs with musical groove can activate M1 on the neuronal level. Using transcranial magnetic stimulation (TMS), a neuroimaging technology widely used to investigate M1, there is evidence of corticospinal excitation while listening to rhythmic music. TMS pulses were delivered over the M1 areas

mapped to the tibialis anterior (TA) and the lateral gastrocnemius (LGN) muscles while listening to either rock music or white noise (E. M. F. Wilson & Davey, 2002). Wilson & Davey (2002) found corticospinal facilitation and inhibition in both the TA and LGN while listening to rock music compared to white noise. More recently, Stupacher et al. (2013) employed on- and off-beat TMS pulses on musicians and non-musicians while they listened to high- and low-groove music. Motor-evoked potentials (MEPs) measured from the first dorsal interosseous (FDI) indicated greater corticospinal excitability during high-groove music listening compared to low-groove listening in musicians with greater excitability when the TMS pulses were delivered on the beat. There were no differences in low-groove corticospinal excitability between musician and non-musicians; however, there was significantly less corticospinal excitation in non-musicians during high-groove listening compared to low-groove listening. In contrast, evidence from postural sway during groove listening indicates that musical experience does not significantly influence balance control. When asked to listen to high-groove and low-groove music while standing on a force platform, high-groove music promoted the least amount of postural sway variability in both groups. Because high-groove music has a more salient beat, the authors posit that more entrainment to a beat associates with less postural sway variability (Ross et al., 2016).

It is clear in the beat perception literature that the motor planning network has an important role in predicting beat timing; however, there is little converging evidence indicating the role of M1 in perceiving complex musical rhythms. In musical groove, there are multiple layers of musical rhythmic patterns. Unlike the motor planning system, which can quickly identify and communicate predictive musical timing to the auditory system, the primary motor system may not work as efficiently. If multiple rhythmic layers oscillate at different beat

frequencies, they may overlap and consistently activate M1 during the entirety of the listening experience. Therefore, music with more hierarchical rhythmic layers and a more salient beat, like musical groove, could influence sustained M1 priming resulting in faster neuronal firing.

Previous work has used EEG to investigate auditory-motor coupling while tapping to a musical beat (Gerloff et al., 1998; Hove et al., 2014; Mayville, Bressler, Fuchs, & Kelso, 1999; Nozaradan, Peretz, & Keller, 2016; Praamstra, Turgeon, Hesse, Wing, & Perryer, 2003); however, none have used EEG to investigate motor system activated during continuous music listening, and in particular, *musical groove* listening. Because of its superior temporal timing compared to neuroimaging techniques (e.g., fMRI and MEG) that have already been used to study music-motor interactions, EEG is an essential tool in understanding the precise timing of neural activity: it measures neural post-synaptic activity that occurs after timed perceptual events. Here, I employed EEG to collect event-related potentials (ERPs), particularly the lateralized readiness potential (LRP), while participants listened to music that varied in its level of groove to understand how musical groove can prime the neural preparation and execution of movement.

The Lateralized Readiness Potential

Originally described by Kornhuber & Deecke (1964) as the *bereitschaftspotential*, the lateralized readiness potential (LRP) is the most studied ERP related to motor preparation and execution (Smulders & Miller, 2012). It is usually observed during a visual choice task: participants make quick button responses to one stimulus with the right hand and to another stimulus with the left hand. The LRP is known to arise from M1 100-200 ms before the execution of a choice response (Brunia & Vingerhoets, 1980; Coles, 1989; De Jong, Coles, Logan, & Gratton, 1990; Leuthold & Jentzsch, 2002). Thus, this ERP is an indicator of

preparatory motor activity that precedes the physical response (Kappenman et al., 2016; Smulders & Miller, 2012).

Using EEG to measure the LRP is an appropriate neuroimaging technique to investigate motor processes involving rich music stimuli. First, LRPs are largely generated from M1, a motor area that operates through a dopaminergic loop with the basal ganglia (Luck et al., 2009; Rammsayer & Stahl, 2006). The brain sources of the LRP thus include some important to beat perception (Chen et al., 2008; Grahn & Brett, 2007; Zatorre et al., 2007) and to pleasure found in music listening (Blood & Zatorre, 2001; Goldstein, 1980; Koelsch, 2014; Panksepp, 1995; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011; Sloboda, 1991).

Second, ERPs during complex music listening are difficult to study because our brains naturally oscillate to the music's underlying rhythm. In principle, this oscillation could mask the ERP that is produced during a simultaneous motor task. To extract the LRP, a difference wave is created before averaged epochs (i.e. windows) are statistically analyzed. By subtracting ipsilateral from contralateral responses, naturally-occurring sound-evoked responses and other non-lateralized neural information is removed leaving only motor-related activity, the LRP (Coles, 1989).

Finally, the LRP can be partitioned into stimulus-locked (time-locked to the visual stimulus; S-LRP) and response-locked (time-locked to the participants' response; R-LRP) epochs allowing for separate measurements of preparation and execution processes, respectively. In the S-LRP, the latency between the stimulus onset and the LRP onset (stimulus-to-LRP interval), reflects the amount of time needed to begin cognitively preparing the appropriate response after seeing the visual stimulus. Similarly, in the R-LRP, the latency between the LRP onset and the response onset (LRP-to-response interval) reflects the amount of time needed to execute the

appropriate response after the response has been cognitively selected and prepared (Smulders & Miller, 2012). For instance, it has been previously reported that those diagnosed with schizophrenia have poor motor control; however, the source of the motor control was unclear. Kappenman et al. (2016) found that compared to healthy controls, schizophrenic patients only showed significantly larger stimulus-to-LRP intervals (S-LRP), without significantly different LRP-to-response intervals (R-LRP). Therefore, response preparation, rather than response execution, was the culprit for reduced motor control in schizophrenic patients. In addition to latency analyses, amplitudes are routinely calculated for both S-LRP and R-LRP: smaller amplitudes are often caused by broader waveforms, indicating more variable response preparation and execution, respectively (Kappenman et al., 2016; Kappenman & Luck, 2012; Luck et al., 2009).

Up until this point, researchers have investigated the LRP during purely visual tasks; there is little published on the influence of *auditory* stimuli on the LRP (Gong, Hu, & Yao, 2012; Miller, Ulrich, & Rinkenauer, 1999). Because I am interested in how different types of music could prime the motor system, I saw the LRP as a reliable motor-related potential that can be evoked during concurrent music listening. Therefore, I executed a novel investigation using passive music listening to manipulate response preparation and execution. Because musical groove can behaviorally and neurologically engage motoric activity, I predicted that music rated as higher in groove (established by Janata et al., 2012) would elicit earlier LRPs and faster reaction times to visual stimuli.

CHAPTER 2

Methods

Participants

All experimental procedures were approved by the University of Nevada Las Vegas' (UNLV) Institutional Review Board. Twenty-eight normal hearing adults (< 25 dB HL pure tone frequencies from 500-8000 Hz) were recruited using UNLV's SONA participant pool. Participants received course credit for participation in the study. Three participants were excluded due to a history of traumatic brain injury resulting in a concussion or a subdural hematoma; one participant was excluded due to study incompleteness; and three participants were excluded for having an extreme amount of EEG artifact rejection (of the remaining N , all but one had < 29% artifact rejection). The final 21 participants were between the ages of 18-30 years ($M = 21.76$ years, $SD = 4.073$ years) and had no history of learning, neurological, and motor disorders. All but one participant was right-handed. Prior to testing, participants were asked to complete a questionnaire informing us of his or her demographics, musical experience, dance experience, language experience, and listening preferences. Fifteen participants self-reported having prior musical experience (of those people, age start: $M = 10.33$ years old, $SD = 3.086$ years old, range = 5-13 years old; years of practice: $M = 5.00$ years, $SD = 4.520$ years, range = 1-16 years) and twelve participants self-reported having prior dance experience (of those people, age start: $M = 8.67$ years old, $SD = 4.637$ years old, range = 3-16 years old; mean years of practice: $M = 5.11$ years, $SD = 8.343$ years, range = 1-27 years). Of these participants, eight had both music and dance experience.

Stimuli

Songs were selected from the Janata et al. (2012) music library (see Table 1 for a complete list). Groove category was determined by the ratings reported in Experiment 1 of Janata et al. (2012). All selected songs were performed in a 4/4 time signature. Because tempo and instrumentation influence groove perception (Janata et al., 2012), five high groove and five low groove songs were matched based on tempo, instrumentation, vocals, and meter. Four out of the five high groove/low groove matched pairs were selected from those used in Stupacher et al. (2013). Ideally, all 20 songs would have been grouped into 10 high groove/low groove matched pairs; however, given the desire to use the most highly-rated and lowly-rated songs and that high groove and low groove songs are of different genres (e.g. high groove songs are of mostly the “soul” genre while low groove songs are mostly of the “rock” and “folk” genres), it was impossible to create matched pairs for all songs in this library. Using the software Audacity 2.1.2 (Mazzoni, 2016), stimuli were truncated to 15-second (behavioral) and 65-second (EEG) segments and normalized to be the same volume. Like what was used in Janata et al. (2012), song stimuli were segmented based on what is presented in the iTunes song preview, starting at ~45 seconds into the song.

Song Name	Artist	Groove Category	Genre	Janata et al. (2012) Groove Rating	BPM
Superstition	Stevie Wonder	High	Soul	108.7	96
Lady Marmalade	Patti LaBelle	High	Soul	102.5	112
It's a Wrap (Bye, Bye)	FHI (Funky Hobo #1)	High	Soul	105.9	96
Flash Light	Parliament	High	Soul	105.1	108
Mama Cita	Funk Squad	High	Soul	101.6	96
Sing, Sing, Sing	Benny Goodman	High	Jazz	97.4	124
Look-Ka Py Py	The Meters	High	Soul	92.5	175
Bring the Funk	Ben Harper	High	Soul	89.9	104
I Used to Love Someone	Anthony Hamilton	High	Soul	88.7	92
Bad Tune	Earth, Wind, and Fire	High	Soul	86.2	120
Cheeseburger in Paradise	Jimmy Buffet	Low	Rock	48.6	140
Orion's Belt	The String Cheese Incident	Low	Rock	47.9	140
Comfortably Numb	Pink Floyd	Low	Rock	42.3	64
Bryter Layter	Nick Drake	Low	Folk	40.4	128
Better Man	Pearl Jam	Low	Rock	39.8	124
Space Oddity	David Bowie	Low	Rock	38.7	140
Ray Dawn Balloon	Trey Anastasio	Low	Rock	38.5	81
Flandyke Shore	The Albion Band	Low	Folk	36.5	92
Beauty of the Sea	The Gabe Dixon Band	Low	Rock	32.1	113
Sweet Thing	Alison Brown	Low	Folk	30.9	96
Must Be Dreaming	Frou Frou	Mid	Rock	60.9	148

Table 1. Songs used in practice and experimental trials

Spectrally-matched noise tracks were generated in the MATLAB 2016b programming environment (The Mathworks, Natick, MA, USA). For each groove category (high/low), 65-second .wav files of all 10 songs were averaged to generate a grand average wave file. Then, using the function *fft*, the fast Fourier transform (FFT) (Frigo & Johnson, 1998) of the grand average wave file was taken to obtain the frequency information. Next, the envelope of the FFT was taken using the function *envelope*. To make a noise file, white Gaussian noise was generated using the *wgn* function, then was transposed into the frequency domain by taking the FFT. To match the frequency envelope of the grand average song to the white noise, the grand average envelope was multiplied by each component of the white noise FFT matrix (*grand average envelope * white noise FFT*). To transpose the white noise back into the temporal domain, the inverse FFT was taken (*ifft*). Each mono channel was scaled to its maximum amplitude to ensure equal stereo scaling. The two generated spectrally-matched noise files (high groove and low groove) were then imported into Audacity and normalized to match the intensity of the individual songs. A silent file was generated and truncated to a 65-second clip in Audacity.

Part I: Electroencephalography

EEG data were collected from Ag/AgCl electrodes using the Biosemi ActiveTwo 64-electrode system placed on the scalp according to the International 10/20 system. Eye movements were monitored using electrodes on the outer canthi and on the inferior and superior areas of the left orbit. Additional electrodes were placed on the left and right mastoids, and 1/2 centimeter in front of the preauricular point of the left and right ear. Responses were recorded un-referenced in LabView 2.0 (National Instruments, Austin, TX) digitized at 1000 Hz and collected with an online bandpass filter of 0.1 to 500Hz. Offset voltage was < 25 mV for all electrodes.

Visual and auditory stimuli were presented using Presentation (Neurobehavioral Systems, Inc., Albany, CA) software on a Dell 22-inch LCD monitor (monitor information) using EA-3 ear inserts (Etymotic Research, Elk Grove Village, IL). The symbols “@” and “#” were used as visual stimuli, presented on the center of the screen in white on a black background measuring at a visual angle of 3.4095 degrees. In between response trials, a fixation cross, also in white on a black background (measuring at this visual angle), was visible to limit lateral eye movements. The monitor was viewed at a distance of 42 inches.

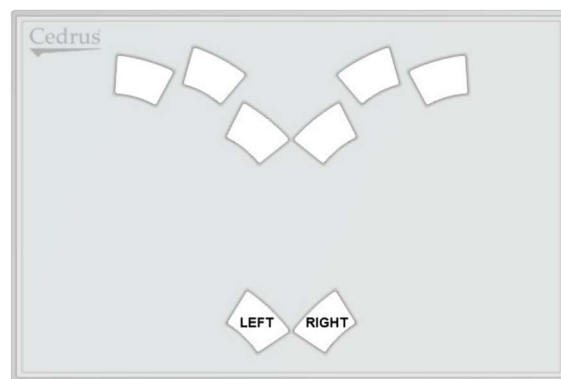


Figure 2. Left and right response buttons on Cedrus RB-830

The experiment began with two practice trials to ensure participants were performing the task correctly. Practice trial 1 was presented in silence. Practice trial 2 was performed while concurrently listening to “Must Be Dreaming” by Frou Frou, a mid-groove song, as categorized by Janata et al. (2012). During practice, a mid-groove song was preferred to a high- or low-groove song to prevent unbalanced exposure to a particular auditory stimulus category prior to testing. For each practice trial, participants were asked to make left- and right-hand button presses to either the symbol “@” or the symbol “#” using the bottom two buttons on the Cedrus RB-830 (see Figure 2 for button locations) as quickly and as accurately as possible. Responses in

the two practice trials were counterbalanced to rehearse both stimulus-to-response mapping orientations. For example, if practice trial 1 assigned left-hand button presses to the symbol “@”, the left-hand button presses for practice trial 2 was assigned to the symbol “#”. The duration of each practice trial was 65 seconds: the first 5 seconds were used as auditory preparation for the trial followed by 60 seconds of active button presses. Audio tracks were played for the entire duration of a trial. Each visual stimulus was presented for 200 ms followed by a blank inter-stimulus interval (ISI) of either 1100, 1200, 1300, or 1400 ms presented randomly with a rectangular distribution. No single ISI was presented twice in a row. The fixation cross was shown during the ISI. For each practice trial, a total of 40 stimuli were presented, 20 for each hand. Hand choice was also presented randomly. In order to continue onto practice trial 2, participants needed to correctly respond to > 80% of the stimuli (> 32/40 stimuli). If they failed to complete practice trial 1 with at least 80% correct trials, they were asked to repeat practice trial 1.

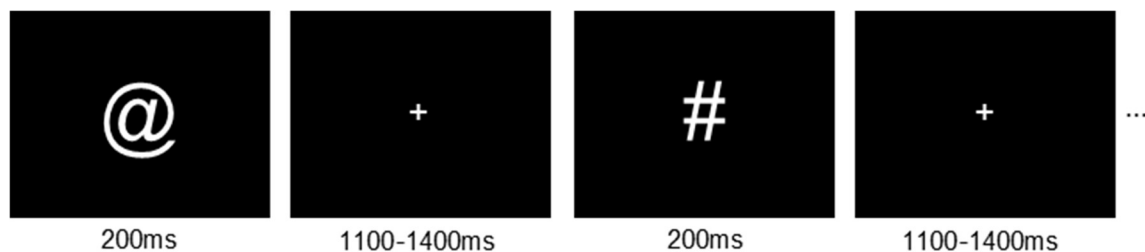


Figure 3. Example trial sequence in both practice and experimental tasks.

Forty total experimental trials were presented in 4 blocks of 10 trials each. Ten high-groove songs, 10 low-groove songs, 10 spectrally-matched noise tracks (5 high-groove, 5 low-groove), and 10 silence tracks were played in a quasi-random order over the 40 trials (i.e., no two

audio tracks of the same category were played in a row). Within each block, no more than 3 audio tracks of the same category were presented. The task mimicked what was presented in the practice trials. The inter-trial interval (ITI) was five seconds. After the completion of each block, a participant-determined break occurred before proceeding onto the next block. Each block had a duration of 11.58 minutes, equaling a total experiment duration of 46.33 minutes, plus participant-determined breaks. For each auditory category, 400 left- and right-handed responses were collected, 200 responses/hand, totaling 1600 responses for the entire experiment (800/hand). Reaction times of the button presses were collected by Presentation during the entirety of the EEG study.

Part II: Stimulus Judgement

After EEG administration, a survey was administered to evaluate judgments of groove, familiarity, and likability. Participants were asked to listen to the 20 songs (10 high groove, 10 low groove) presented during the EEG paradigm in 15-second clips. After each song, participants made judgments on what they heard. Using seven-point Likert scales, participants answered the following questions: 1) “How groovy was this song?”, 2) “How much did you enjoy the song?”, and 3) “How familiar were you with this song?”. This portion of the experiment was also administered using the software Presentation (Neurobehavioral Systems, Inc., Albany, CA) over ER-3 ear inserts (Etymotic Research, Elk Grove Village, IL).

Data Processing

All EEG data were processed in Matlab 2017a using ERPLAB (Lopez-Calderon & Luck, 2014) and EEGLAB (Delorme & Makeig, 2004), both open-source software modules for Matlab. First, data were referenced to the average of the left and right mastoids and were band-pass

filtered from 0.05 Hz-100Hz half-amplitude cutoff (-6 dB) using a Butterworth infinite impulse response (IIR) filter with a roll-off of 12 dB/octave. If any channels that are not pertinent to LRP analysis (i.e., not channels C3 or C4) were especially noisy, they were topographically interpolated using EEGLAB. Then, EEGLAB's independent component analysis (ICA) was employed to identify and remove muscle and eye movement artifact. To make separate grand average waveforms of each stimulus category, each participant's continuous EEG recording was truncated into 65-second sound trials and appended into separate stimulus categories (i.e., rhythmic, melodic, vocals, silent, noise). Next, using ERPLAB's bin descriptor function, 1000 ms epochs were created while removing any epochs with incorrect responses; responses during stimulus presentation; and responses > 1200ms relative to the stimulus onset (i.e. only correct responses). Manual artifact rejection was then used to remove any epoch where a blink occurred during the LRP. Finally, in ERPLAB, average waveforms for contralateral and ipsilateral responses from electrodes C3 and C4 were generated with a stimulus-locked LRPs (S-LRP) baseline -200 to 0ms, relative to the visual stimulus onset, and a response-locked LRPs (R-LRP) baseline of -800 to -600ms, relative to the physical response. Using the Coles method calculation, S-LRP and R-LRP contralateral minus ipsilateral difference waves were created, resulting in eight averaged LRPs per participant: four S-LRPs per sound condition and four R-LRPs per sound condition (Coles, 1989). Because of the low signal-to-noise ratio of LRP difference waves, a 15Hz low-pass half-amplitude (-6 dB) Butterworth IIR filter (roll-off of 12dB/octave) was applied to averaged LRPs when measuring LRP onset latency, a common practice with LRPs (Kappenman et al., 2012, 2016; Luck et al., 2009). Mean amplitude was measured on LRPs within the original band-pass filtered range of 0.05-100 Hz.

EEG Data Analysis

All statistical tests were performed in SPSS 20 (SPSS, Inc., Chicago, IL, USA). LRP waveforms were statistically analyzed using a one-way repeated measures ANOVA (RMANOVA) with a two-tailed alpha level of 0.05: four stimulus conditions (high groove, low groove, noise, silence) are labeled as independent variables and each LRP measure (stimulus-locked (S-LRP) onset, S-LRP amplitude, response-locked (R-LRP) onset, and R-LRP amplitude) labeled as the dependent variables. When Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated, probability values were reported using the appropriate Greenhouse-Geisser or Huynh-Feldt epsilon correction for non-sphericity (Jennings & Wood, 1976). As determined by simulations using the jackknife technique, LRP onsets were measured as the time point corresponding to 50% of the peak amplitude (Miller, Patterson, & Ulrich, 1998). LRP amplitude was calculated as the mean amplitude within a measurement window relative to the baseline voltage. Measurement windows for both onset latency and mean amplitude S-LRP and R-LRPs are shown in Table 2. These windows remained the same across participants.

	Stimulus-Locked LRP	Response-Locked LRP
Onset Latency	100 to 400 ms	-300 to 0 ms
Amplitude	200 to 500 ms	-200 to 0 ms

Table 2. LRP Measurement windows

CHAPTER 3

Results

Behavior

Median reaction times (RT) and mean correct trials (see Figure 4) were statistically analyzed using a one-way RMANOVA with a two-tailed alpha level of 0.05. Stimulus condition (high groove, low groove, noise, silence) was used as an independent variable and either median RT or percentage of correct trials was measured as the dependent variable. For both median RTs and mean percentage of correct trials, Mauchly's Test of Sphericity was not violated so sphericity was assumed.

Results indicate no statistically significant differences between stimulus conditions for median RT ($F_{3,60} = 0.661, p = 0.579, \eta_p^2 = 0.032$). Statistics for mean percentage of correct trials were performed on the number of correct trials before artifact rejection. Results reveal statistically significant differences between stimulus conditions for mean percentage of correct trials ($F_{3,60} = 2.918, p = 0.041, \eta_p^2 = 0.127$); however, post-hoc pairwise comparisons using Tukey's Honest Significant Difference Test indicate no statistically significant differences between all possible pairs of mean percentages (HG vs. LG: $p = 0.593$; HG vs. noise: $p = 0.90$; HG vs. silence: $p = 0.90$; LG vs. noise: $p = 0.367$; LG vs. silence: $p = 0.587$; noise vs. silence: $p = 0.90$). A lack of significant findings between pairs could be due to the somewhat conservative nature of Tukey's HSD and this dataset's low power. Though participants on average answered more percentage of trials correctly while listening to LG music ($M = 83.512\%$, $CI = 0.914$) compared to HG music ($M = 82.232\%$, $CI = 0.790$), noise ($M = 81.821\%$, $CI = 0.601$), or silence ($M = 81.220\%$, $CI = 0.563$), post-hoc tests confirm that performances in LG were not

significantly better than performances during other stimulus conditions (*CI* denotes 95% within-subject confidence intervals (Cousineau, 2005)).

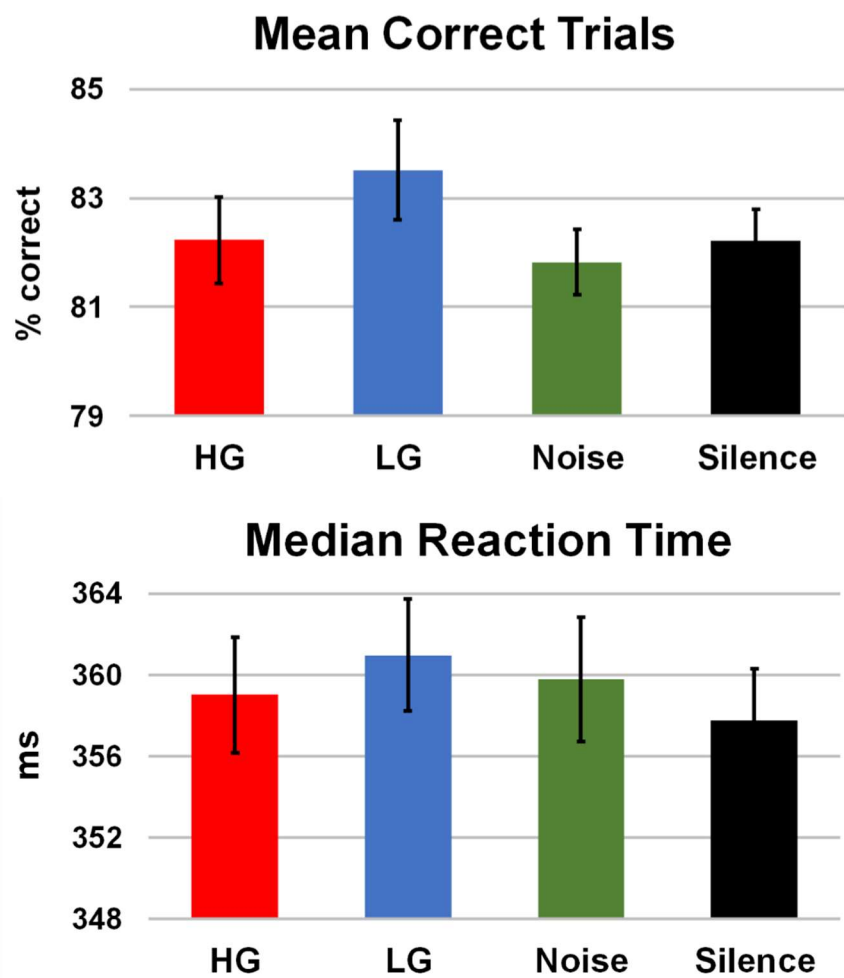


Figure 4. Bar graphs of mean percentage of correct trials (top) and median RT (bottom). Error bars indicate 95% within-subject confidence intervals (Cousineau, 2005). Results reveal no significant differences between sound conditions for both mean percentage of correct trials and median RT.

Previous investigations of musical groove failed to report relationships between corticospinal activity (or neural motor engagement measures) and subjective groove ratings (Ross et al., 2016; Stupacher, Hove, & Janata, 2016). If musical groove was responsible for heightened motor activation, I would also predict that neural (LRP) as well as behavioral motor measures (RT) would relate to personal groove ratings and not just to collective ratings of groove found by Janata et al. (2012). While musical groove is a universal phenomenon, the amount of groove felt could vary by individual. Therefore, I calculated relationships between behavioral measures using Pearson's r correlation coefficients. Table 3 shows Pearson r and associated p values for correlations between median RT and subjective music ratings. Results reveal no statistically significant differences between median RT and corresponding groove rating; median RT and corresponding likability rating; and median RT and corresponding familiarity rating for HG and LG listening conditions.

	Median RT	<i>r</i>	<i>p</i>
S-LRP onset latency	high-groove	0.642	0.002
	low-groove	0.608	0.003
	noise	0.389	0.082
	silence	0.227	0.223
S-LRP mean amplitude	high-groove	-0.117	0.612
	low-groove	-0.131	0.571
	noise	-0.136	0.556
	silence	-0.206	0.371
groove rating	high-groove	0.009	0.968
	low-groove	-0.226	0.325
likeability rating	high-groove	0.199	0.388
	low-groove	-0.297	0.191
familiarity rating	high-groove	0.197	0.392
	low-groove	-0.412	-0.063

Table 3. Pearson *r* and associated *p* values for correlations between mean ERP and behavioral variables and median RT of the corresponding variable's stimulus condition (e.g., high-groove rating x high-groove median RT). Values in bold denote significance ($p < 0.05$).

Like what was found by Janata et al. (2012), there were statistically significant correlations between groove ratings and likability ratings for both HG ($r = 0.737, p < 0.001$) and LG ($r = 0.624, p = 0.002$) listening conditions; however, there were no significant relationships between groove ratings and familiarity ratings for both HG ($r = 0.068, p = 0.769$) and LG ($r = 0.294, p = 0.196$). These relationships are plotted in Figure 5.

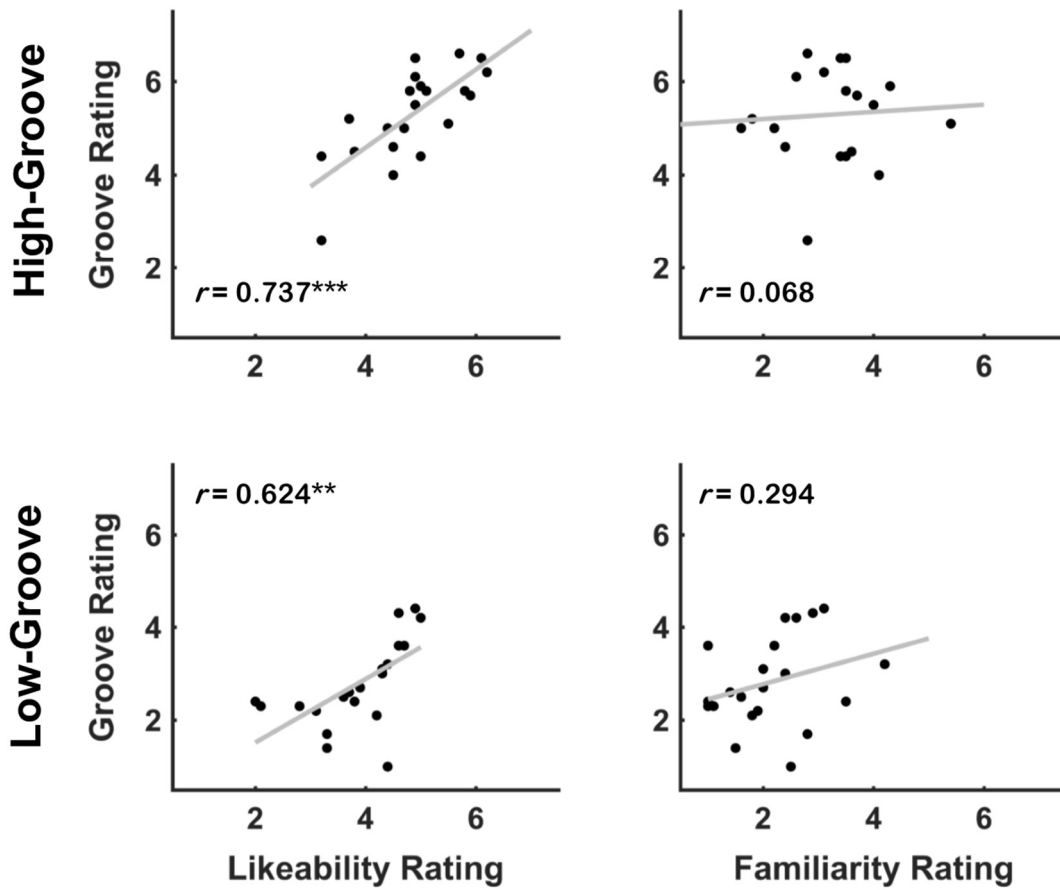


Figure 5. Relationships between mean groove rating and mean likeability rating (top and bottom left) and between mean groove rating and mean familiarity rating (top and bottom right) for HG (top) and LG (bottom) conditions. Higher groove ratings relate to higher likeability and higher familiarity ratings, though only groove rating relationships with likeability ratings for both HG and LG conditions reached statistical significance (** $p < 0.001$, ** $p < 0.005$).

ERP Waveforms

Figure 6 shows overlaid grand average waveforms across participants for each stimulus condition. Beside these waveforms are two bar graphs showing the average onset latency and the average mean amplitude for each stimulus condition. Results show that there are no statistically significant differences between stimulus conditions for the S-LRP onset latency ($F_{3,60} = 0.550$, $p = 0.567$, $\eta_p^2 = 0.027$) or R-LRP onset latency ($F_{3,60} = 0.396$, $p = 0.727$, $\eta_p^2 = 0.019$), indicating that neither neural response preparation nor neural response execution were influenced by music or noise listening compared to listening to silence, respectively. There were also no statistically significant differences between stimulus conditions for the S-LRP mean amplitude ($F_{3,60} = 1.860$, $p = 0.161$, $\eta_p^2 = 0.085$) or the R-LRP mean amplitude ($F_{3,60} = 1.100$, $p = 0.346$, $\eta_p^2 = 0.019$), revealing that neural motor preparatory or executory responses were no more or less variable than neural motor responses to silence.

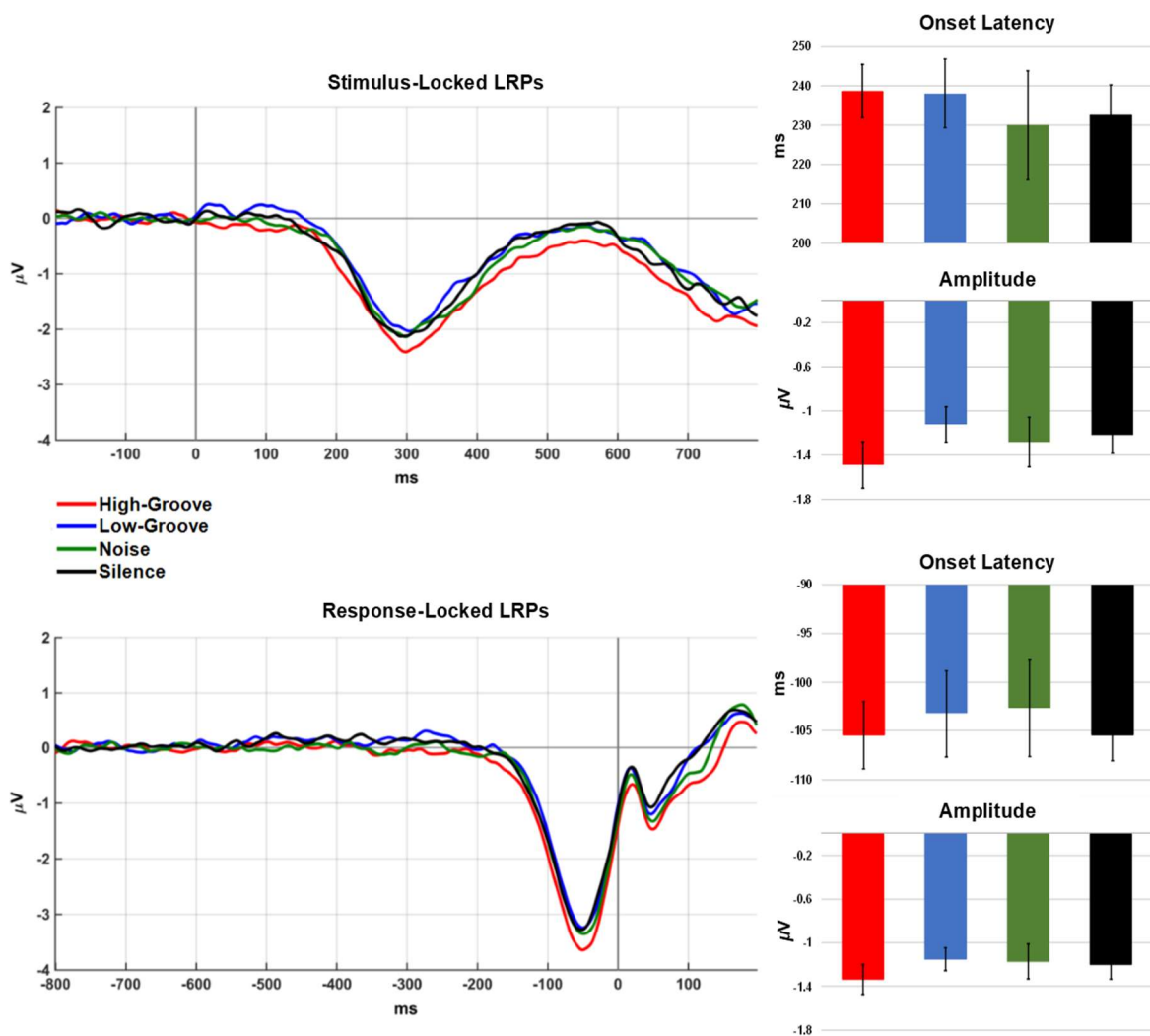


Figure 6. EEG waveforms for stimulus-locked (top) and response-locked (bottom) LRP components with high-groove (red), low-groove (blue), noise (green), and silence (black) stimulus conditions overlaid on one another. These waveforms were low-pass filtered to 30Hz for plotting purposes only. To the right of each waveform is the corresponding bar graph of the mean onset latency (top) and the mean amplitude (bottom) for each condition. Error bars indicate 95% within-subject confidence intervals (Coustineau, 2005). Results reveal no significant differences between sound conditions for stimulus- and response-locked LRP components.

Behavioral and Neural Comparisons

Relationships between neural and behavioral data were also examined using Pearson's r correlation coefficients. Correlations between neural measures and RT are listed in Table 3. Results show statistically significant positive correlations between mean S-LRP onset latency and median RT during HG listening and between mean S-LRP onset latency and median RT during LG listening (see Figure 7). These correlations indicate that with increased mean S-LRP onset latency, there was increased median RT. There were no statistically significant correlations between S-LRP onset latency and median RT for either the noise or silence listening conditions. For measures of mean amplitude, there were no statistically significant differences between S-LRP mean amplitude and corresponding median RT for all stimulus conditions. Relationships between R-LRP measures and median RT were not calculated because they are related: R-LRP epochs are based upon when responses occur (i.e., RT) and therefore are highly correlated.

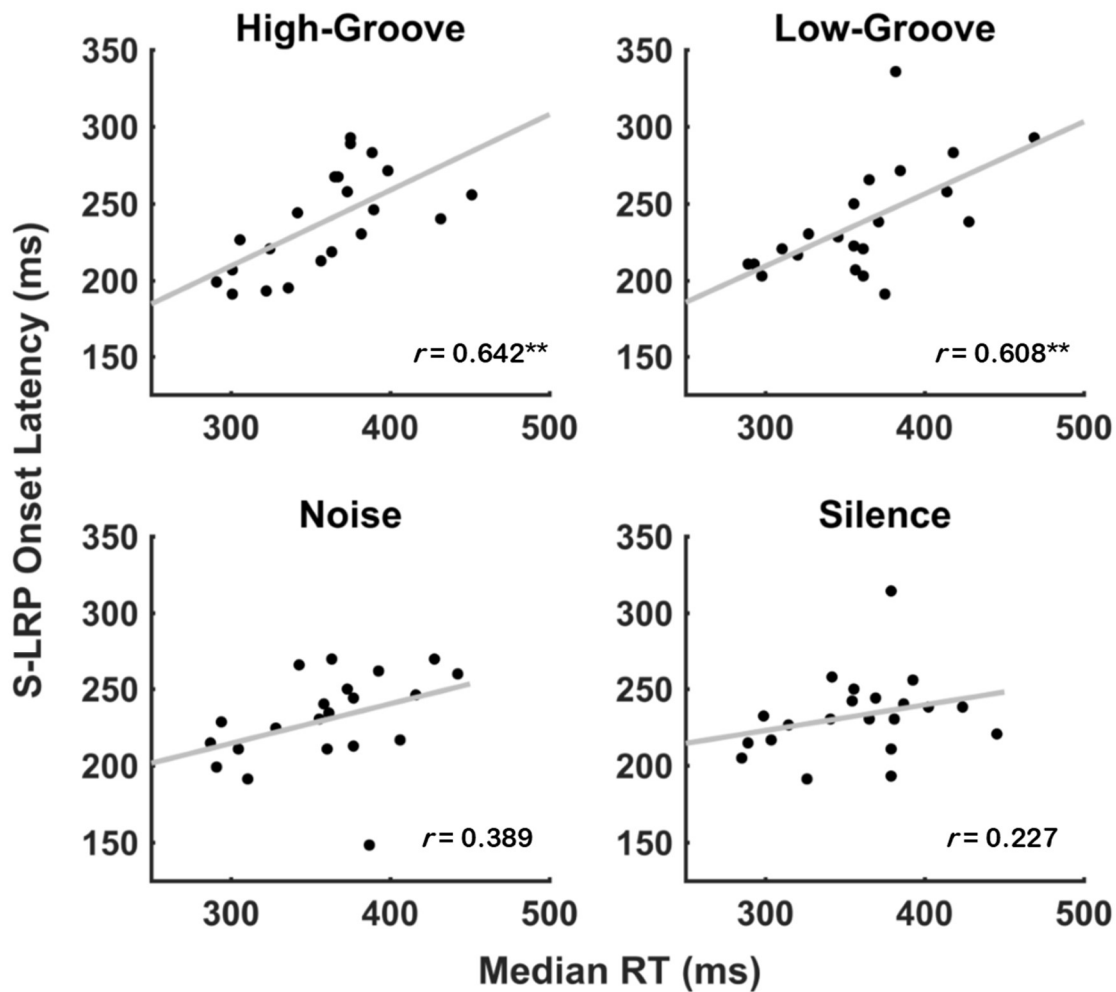


Figure 7. Relationships between S-LRP onset latency and median RT for HG (top left), LG (top right), noise (bottom left), and silence (bottom right) conditions. Faster S-LRP onset latencies relate to faster median RTs for all conditions, though only correlations for HG and LG conditions reached statistical significance. The relationship in noise is trending toward significance due to one extreme participant; however, this participant's mean S-LRP onset latency value in noise did not pass the Dixon's Test for Outliers (Dixon, 1953) and therefore is not a significant outlier (** $p < 0.005$).

Correlations between mean neural measures and mean subjective song rating are listed in Table 4. Results show no statistically significant correlations between any of the ERP measures and their corresponding subjective groove ratings.

Neural Measure	Music Type	Music Rating	<i>r</i>	<i>p</i>
S-LRP onset latency	high-groove	groove	-0.094	0.686
		likability	-0.039	0.867
		familiarity	0.035	0.881
	low-groove	groove	-0.112	0.629
		likability	-0.347	0.123
		familiarity	-0.29	0.202
S-LRP amplitude	high-groove	groove	0.223	0.31
		likability	-0.116	0.616
		familiarity	0.011	0.962
	low-groove	groove	-0.213	0.355
		likability	0	0.999
		familiarity	-0.085	0.715
R-LRP onset latency	high-groove	groove	-0.150	0.517
		likability	-0.363	0.106
		familiarity	-0.211	0.358
	low-groove	groove	0.026	0.991
		likability	-0.114	0.622
		familiarity	0.275	0.228
R-LRP amplitude	high-groove	groove	0.336	0.137
		likability	0.017	0.943
		familiarity	-0.135	0.559
	low-groove	groove	-0.068	0.77
		likability	0.045	0.847
		familiarity	-0.11	0.635

Table 4. Pearson *r* and associated *p* values for correlations between mean ERP and corresponding mean subjective rating measures (e.g., high-groove rating x high-groove S-LRP onset latency). There were no statistically significant relationships between any ERP measure and subjective groove ratings.

CHAPTER 4

Discussion

The present experiment studied the behavioral and neural indices of motor response processing in the presence of music, spectrally-matched noise, and silence. If HG music listening enhanced motor area activation, HG music would elicit greater LRP mean amplitudes, earlier LRP onset latencies, and/or faster RTs compared to LG, noise, and silence conditions. Additionally, there would be relationships between behavioral and neural indices with higher groove ratings and faster RTs relating to greater LRP mean amplitudes and earlier LRP onset latencies. Alternatively, if HG listening did not impact neural functioning in motor regions, there would be no mean differences among listening conditions for neural or behavioral indices and there would be no relationships between subjective music ratings and neural measures.

In line with the latter hypothesis, I found no mean differences among the listening conditions for S-LRP onset latency, S-LRP amplitude, R-LRP onset latency, or R-LRP amplitude, indicating no differences in neural response preparation, response execution, or response variability when listening to music, noise, or silence. Furthermore, there were no differences in median RT among conditions signifying similar behavioral response timing in all listening conditions. Contrary to this hypothesis, however, there are statistically significant relationships between median RT and S-LRP onset latency during HG and LG listening (trending in noise), but not in silence. Though earlier onset latencies related to faster RTs when listening to background sound, onset latencies remained somewhat constant (200-250ms) regardless of RT variability when responding in silence. Also, these data replicated some of the results from Janata et al. (2012), with statistically significant correlations between subjective

groove ratings and likeability ratings, but not between groove and familiarity ratings. While participants generally agreed that music with groove was more enjoyable, possibly due to a generational and/or regional difference compared to Janata et al. (2012)'s sample, the participants in the present study may not have been as familiar with the music, but still rated HG music as having more musical groove compared to LG music.

Previous work that utilized the LRP to investigate motor processing in schizophrenic populations often found that S-LRP onset latency did relate to median RT (Kappenman et al., 2012; Luck et al., 2009). Other than the authors attributing this relationship to variations in participant-to-participant individual stimulus evaluation time or to the nature of certain conditions (i.e. faster responses needed in speeded conditions), the mechanistic reasons for these correlations were never explored. In the present within-subject study, however, trial timing stayed consistent: all participants performed the same number of trials of the same timing distribution with only changes to what was heard. Therefore, even without the support of mean differences among neural and behavioral measures, significant relationships between S-LRP onset latency and median RT in only some music listening conditions is worth understanding.

The basal ganglia play an important role in how we move, decide, and perceive a beat. While it is well-studied that cortico-striato-thalamocortical (CST) loops from the basal ganglia to the motor system help regulate motor actions and may help participants perceive musical beat (Grahn & Brett, 2007; Grahn & Rowe, 2009; Leow, Parrott, & Grahn, 2014), separate CST loops also form a pathway from the basal ganglia to the dorsolateral prefrontal cortex (DLPFC), an area responsible for decision making and executive function (Lapidus, Stern, Berlin, & Goodman, 2014). Thus, the basal ganglia not only aid in simple movement execution, but also helps us make decisions on when to move and which part of the body.

Dopamine is a key neurotransmitter in the basal ganglia. Without it, motor-related functions deteriorate resulting in debilitating conditions such as Parkinson's disease (Bernatzky, Bernatzky, Hesse, Staffen, & Ladurner, 2004; L. A. Brown, de Bruin, Doan, Suchowersky, & Hu, 2009; Hayashi, Nagaoka, & Mizuno, 2006; Nombela, Hughes, Owen, & Grahn, 2013). Enjoyable music listening induces dopamine release into the striatum with resulting activations in motor and frontal areas (Popescu, Otsuka, & Ioannides, 2004; Salimpoor et al., 2011). Increases in dopamine has also been shown to quicken neural response preparation via earlier S-LRP onset latencies (Rammsayer & Stahl, 2006). Taking this into consideration, enjoyment experienced in music listening conditions could induce more dopamine production allowing the basal ganglia to better regulate timing between the motor and DLFPC. Therefore, preparing to respond (S-LRP onset latency) and deciding to move (RT) become significantly related only during music listening conditions.

Correlations between groove rating and likeability rating indicated that participants found HG music more enjoyable than LG music. Therefore, when considering results from previous musical groove investigations, I would expect to see faster motor preparation and execution in HG conditions (Ross et al., 2016; Stupacher et al., 2013). When asked about their personal music tastes, however, some participants preferred LG to HG music. Individual music preferences could contribute to the lack of mean differences seen in neural and behavioral LRP measures as well as similar significant neural-behavioral response correlations. Though the HG correlation is slightly stronger than the LG correlation, without the support of mean neural or behavioral differences, it cannot be assumed that HG had better response-response timing compared to LG.

Heightened basal ganglia function during beat perception (Grahn & Brett, 2007; Grahn & Rowe, 2009; Kung et al., 2013) and enjoyable music listening (Salimpoor et al., 2011), both

components that define musical groove (Janata et al., 2012), support the neural-behavioral response correlations between the S-LRP onset latency and median RT exhibited during music listening; however, it is less understood why trending response-response relationships were found in noise. Stochastic resonance (SR) is a phenomenon where a moderate amount of noise can facilitate cognitive performance. The Moderate Brain Arousal model explains that noise in the environment can introduce noise internally via the perceptual system (Sikström & Söderlund, 2007). This noise can in turn induce SR in the neurotransmitter systems. Previous data indicate that moderate noise can improve memory performance in children diagnosed with attention deficit hyperactivity disorder (ADHD) (G. Söderlund, Sikström, & Smart, 2007) and benefit motor learning in spontaneously hypertensive rats (G. B. W. Söderlund, Eckernäs, Holmblad, & Bergquist, 2015) while hindering performance in healthy controls. Because those diagnosed with ADHD have reduced neural background activity and decreased functioning in their dopamine systems, they require more noise than healthy controls to reach optimal cognitive performance (Solanto, 2002). Here, noise may have had a similar effect. While only one participant self-reported an ADHD diagnosis, this 45-minute experiment could have taxed attention, and consequently, these participants may have performed at sub-optimal cognitive levels that may have been comparable to those with a mild ADHD diagnosis. Listening to noise could have introduced noise internally into the neurotransmitter system, encouraging dopamine production, and accordingly, resulted in similar timing regulation within the motor- and DLFPC-basal ganglion CST loops as seen in music listening.

Executive function, which includes mental processes such as selective attention, working memory, and inhibitory control (Zelazo, Craik, & Booth, 2004), could explain the lack of mean differences found for neural and behavioral measures. The hope of this experiment was to see

how passive music and/or noise listening could influence overall motor activation. Because participants were asked to respond to visual targets as quickly and accurately as possible, they could have been consciously ignoring the background music or noise though asked to listen to it passively. This would corroborate the paucity of differences between conditions for mean correct responses: participants performed similarly for all conditions regardless of what was playing in the background. Music and/or noise did not distract or aid in responding. In a future iteration of this study, I would like to use auditory targets, such as two differently-pitched pure tones, embedded within the music, to see if recruiting more attention to the auditory stimulus would result in differences among listening conditions.

Additionally, the use of a button press could have disrupted the predicted neural motor activity. In previous investigations of musical groove, impacts of motor function in the presence of music listening were done without an accompanying motor task (Ross et al., 2016; Stupacher et al., 2013). In this study, however, participants were asked to listen to the music or noise passively while performing a button-pressing task to the best of their ability. The need to make correct responses likely resulted in the recruitment of both motor and executive function networks. Therefore, rather than music and/or noise facilitating faster neural response preparation, the concentration needed to perform the motor task may have recruited more cognitive efforts toward executive function attenuating the effects that music or noise would have on the motor system.

On the other hand, music conditions may have had no impact on executive function, but the consecutive trial study design could have manipulated attention alone. Sridharan et al. (2007) conducted a study in which non-musicians listened to entire symphonies while in an fMRI scanner. In the break between movements where no music was played, they found right-

lateralized peak activity in the ventral fronto-temporal and dorsal fronto-parietal networks, the areas responsible for event detection and attention regulation, respectively (Sridharan, Levitin, Chafe, Berger, & Menon, 2007). Though Sridharan et al. (2017)'s listening paradigm was more natural compared to the current one, the feeling of anticipation for the upcoming movement or trial may have been similar. Therefore, in this experiment, most of the recruited attention needed for the button-pressing task may have been at the beginning of trials after the five second break; however, without supporting evidence that the fastest RTs and the most number of correct responses occurred at the beginning of trials, I can only speculate.

For the remaining neural and behavioral measures, I believe methodology attributed to the dearth of statistically significant differences among stimulus conditions. First, the length of the sound trials could have attenuated predicted effects of condition on neural measures. It is unusual for people to listen to a song for only 45 seconds. When listening and moving to music, it is more natural to listen to a song in its entirety. In the context of this experiment, the shortened music trials may have not been long enough to activate the motor system enough to see statistically significant differences in HG compared to LG, noise, and silence. Feeling the groove in music often does not happen immediately, especially with unfamiliar music. In a future study, it would be useful to construct trials spanning the song's length to see if more naturalistic music listening can tease apart neural motor differences between groove and non-groove conditions.

Moreover, EEG may have not been the right tool to investigate these questions. There are very few experiments that investigate how auditory stimuli can manipulate the LRP (Gong et al., 2012; Miller et al., 1999). Both of these studies controlled the timbre and intensity, respectively, of the LRP-producing targets. This is the first investigation that uses continuous sound listening

while concurrently performing a motor task to elicit the LRP. While there is strong evidence indicating that the LRP is generated from M1 (Smulders & Miller, 2012), dipole orientation and dopaminergic contributions make it difficult to use EEG alone to pinpoint the true source(s) of the LRP. It is possible that dipole projections from frontal and auditory regions could contribute to activations seen at C3 and C4. Additionally, because the prefrontal cortex, a decision-making and executive function center of the brain, is also regulated by dopamine, it is hard to discern whether the LRP is a purely motor cortex-modulated response, or if larger premotor and prefrontal networks also contribute to this brain response. To further investigate the effects of musical groove listening on the motor system alone, it would be advantageous to use TMS, a technology that can stimulate specific motor areas with relatively high temporal precision, but higher spatial precision compared to EEG. In future studies, I wish to investigate the role of the motor system on musical groove perception by down-regulating M1 using repetitive TMS.

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Curriculum Vitae

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EDUCATION

- Ph.D. in Experimental Psychology** expected May 2020
University of Nevada, Las Vegas
Concentration: Cognitive Psychology
- M.A. in Experimental Psychology** December 2018
University of Nevada, Las Vegas
Concentration: Cognitive Psychology
- B.A. in Psychology** June 2011
Northwestern University
- B.Mus. in Music Performance** June 2011
Northwestern University
Concentration: Violin

PUBLICATIONS

- Lenartowicz, A., Simpson, G.V., **O'Connell, S.R.**, & Cohen, M.S. (2015). Measurement of neurophysiological signals of ignoring and attending processes in attention control. *JoVE (Journal of Visualized Experiments)*, (101), e52958.
- Slater, J., Skoe, E., Strait, D. L., **O'Connell, S.**, Thompson, E. C., & Kraus, N. (2015). Longitudinal evidence of improved speech-in-noise perception with group music training. *Behavioral Brain Research*, 291, 244-252.
- Strait, D. L., Slater, J., **O'Connell, S.**, & Kraus, N. (2015). Music training relates to the development of neural mechanisms of selective auditory attention. *Developmental Cognitive Neuroscience*, 12, 94-104.
- Slater, J., Strait, D. L., Skoe, E., **O'Connell, S.**, Thompson, E. C., & Kraus, N. (2014). Longitudinal effects of group music instruction on literacy skills in low-income children. *Plos One*, 9(11), e113383.

- Strait, D. L., **O'Connell, S.**, Parbery-Clark, A., & Kraus, N. (2014). Musicians' enhanced neural differentiation of speech sounds arises early in life: developmental evidence from ages three to thirty. *Cerebral Cortex*, 24(9), 2512-2521.
- Strait, D. L., Parbery-Clark, A., **O'Connell, S.**, & Kraus, N. (2013). Biological impact of preschool music classes on processing speech in noise. *Developmental Cognitive Neuroscience*, 6, 51-60.
- Tierney, A., Strait, D. L., **O'Connell, S.**, & Kraus, N. (2013). Developmental changes in resting gamma power from age three to adulthood. *Clinical Neurophysiology*, 124(5), 1040-1042.

HONORS AND AWARDS

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|--|-----------------------|
| Summer Doctoral Scholarship
University of Nevada, Las Vegas | Summer 2018 |
| Patricia Sastaunik Scholarship
University of Nevada, Las Vegas | Fall 2017-Spring 2019 |
| Lovinger Award
University of Nevada, Las Vegas | Summer 2017 |
| Graduate Recruitment Scholarship
University of Nevada, Las Vegas | Fall 2015-Spring 2016 |

CONFERENCE PRESENTATIONS

- Lenartowicz, A., Simpson, G.V., **O'Connell, S.R.***, Noah, S.L.M., Head, A.L., Bilder, R.M., McCracken, J.T., Bookheimer, S.Y., Reid, R., Cohen, M.S. (2015). *New EEG measures reveal infra-slow fluctuations in both attending and ignoring in adults with ADHD that provide high accuracy in discriminating ADHD from control.* Society for Neuroscience. McCormick Place, Chicago, IL.
- Strait, D.L., **O'Connell, S.**, Kraus, N. (2012). *Neural discrimination of stop consonants in musician and nonmusician children.* MidWinter Meeting of the Association for Research in Otolaryngology. San Diego, CA.
- O'Connell, S.**, Strait, D.L., Parbery-Clark, A., Kraus, N. (2011). *Musical training promotes development of attention abilities: evidence in children and adults.* Music, Science and Medicine: Frontiers in Biomedical Research and Clinical Applications, New York Academy of Sciences, New York, NY.

O'Connell, S., Strait, D.L., Parbery-Clark, A., Kraus, N. (2011). *Musical training promotes development of attention abilities: evidence in children and adults*. Chicago Area Undergraduate Research Symposium. Museum of Science and Industry, Chicago, IL.

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DEPARTMENTAL TALKS

Why Musical Groove Makes Us Move: An Electroencephalographic Investigation. Master's Thesis Defense, Department of Psychology, University of Nevada, Las Vegas, July 31, 2018.

Why Musical Groove Makes Us Move: An Electroencephalographic Investigation. Departmental Data Blitz, Department of Psychology, University of Nevada, Las Vegas. April 18, 2018

Why Music Makes Us Dance: An EEG Investigation. Department of Psychology, University of Nevada, Las Vegas, November 15, 2016.

Investigating the Influence of Groove on Motor Excitation and Arousal. Department of Psychology, University of Nevada, Las Vegas, April 20, 2016

TEACHING EXPERIENCE

Course Instructor Fall 2018-present
General Psychology (Undergraduate)
University of Nevada, Las Vegas

Teaching Assistant Spring 2017
Introduction to Cognitive Neuroscience (Undergraduate)
University of Nevada, Las Vegas

Teaching Assistant Spring 2016
Introduction to Cognitive Neuroscience (Undergraduate)
University of Nevada, Las Vegas

Teaching Assistant Fall 2016
Sensation and Perception (Undergraduate)
University of Nevada, Las Vegas

ADDITIONAL TRAINING

Certification in Responsible Conduct of Research Spring 2017
University of Nevada, Las Vegas

Certification in Non-Invasive Brain Stimulation Methods Summer 2016
University of Southern California

ERPLAB Boot Camp Summer 2016
University of California, Davis

ASSOCIATIONS

American Psychological Association: Society for Teaching of Psychology 2018-2019

Association for Psychological Science 2017-2018

Society for Music Cognition and Perception 2016-2018

OUTREACH

Instructor Summer 2018
Dawson Bound Project Summer Camp, Las Vegas, Nevada

Science Fair Judge Spring 2017
UNLV College of Sciences High School Science Fair, Las Vegas, Nevada

Secretary Fall 2017
500 Women of Science Las Vegas, Las Vegas, Nevada

Mentor Fall 2016-present
Outreach Undergraduate Mentoring Program, University of Nevada, Las Vegas

Secretary Fall 2016
Experimental Student Committee, University of Nevada, Las Vegas