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A NIRS Study of Violinists and Pianists Employing Motor and Music Imageries to Assess Neural Differences in Music Perception

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A NIRS STUDY OF VIOLINISTS AND PIANISTS EMPLOYING MOTOR AND MUSIC IMAGERIES TO ASSESS NEURAL DIFFERENCES IN MUSIC PERCEPTION

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ABSTRACT

A NIRS STUDY OF VIOLINISTS AND PIANISTS EMPLOYING MOTOR AND MUSIC IMAGERIES TO ASSESS NEURAL DIFFERENCES IN MUSIC PERCEPTION

Do musicians imagine movements differently? Are instrument-specific movements represented differently in the brain? The current study explores the perceptual differences in imagining music and movements. While attached to a near infrared spectroscopy (NIRS) device, violinists and pianists of diverse experience levels viewed a series of performance videos (piano, violin) and performed associated imagery tasks. It was hypothesized that musicians will show diverse levels of brain activity in the motor areas during imagery tasks, depending on their primary instrument and the movements within their repertoire. Results revealed that violinists and pianists significantly differ in imagining movements and music of their non-primary instrument. Violinists, in particular, found it difficult to imagine the piano music and the combination of piano movements and music, while they found ease in imagining piano movements alone. This suggests that the piano music suppresses the violinists' ability to imagine the piano movements and music together. Interestingly, this pattern was not present in the pianists, who easily imagined the movements and music of the violin. This further confirms that pianists and violinists imagine movements and music quite differently. The results from this study can be used to further investigate neural differences among musicians of various instruments, confirm the advantages of using near infrared spectroscopy techniques for music perception studies, and explore how people perceive music and movements differently.

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INTRODUCTION

To play an instrument, a musician must coordinate several intricate movements in order to execute a desired sound. Musical instruments require precise control of finger, wrist, arm, foot, tongue, or mouth movements, and the relationship of physical movement to sound production is unique to each instrument (Palmer, 2007). Movements from multiple limbs must be correctly prepared and timed for the execution to be accurate and precise. For example, during a violin performance, finger movements control various aspects of sound depending on which hand is considered. The left hand primarily controls pitch, timing, and rhythm while the right hand controls the movement, weight, and speed of the bow as well as sound production, timing, and rhythm. Small movements from each hand, even from specific fingers, must be coordinated synchronously. Finger and hand movements specifically required for violin playing are distinct from movements required for other instruments, demonstrating the unique biomechanical skills necessary for music production (Palmer, 2007). This thesis will primarily make reference to studies on violin performance because it is the experimenter's instrument of expertise.

One particularly interesting way of studying music and the brain is through music imagery - the imagination of music. Researchers have investigated the neural underpinnings involved in music cognition and perception, music performance, and music imagery. This thesis will consider the cognitive realm of action, observation, and imagination in violinists and pianists, predominantly investigating differences in motor imagery and music imagery.

CHAPTER ONE: MOVEMENT AND MOTOR IMAGERY

1. INTRODUCTION

In this chapter, the role of movement in music performance will be examined. The first part of the chapter will consider the psychological aspects of movement, establishing a description of movement, and the types of movements utilized in musical performance. Differences in movements among beginner, amateur, and professional musicians are discussed to identify the various levels in musical ability and movement execution. Such diverse abilities are often attributed to differences in practicing techniques and the number of total hours practiced. Deliberate practice, in particular, as well as the concept of expertise will be discussed near the end of the first section.

The second section of the chapter explores the neuroscience of movements involved in music performance. The motor regions of the frontal lobe of the brain, specifically the primary motor area, secondary motor area, and premotor area consistently reveal significant changes in activation in several music perception and performance studies. Each of these areas and their specific role in music-related movement will be described. Other areas of the frontal lobe also reveal changes in activation prior to the onset of a voluntary action; several studies using finger tapping tasks confirm the existence a movement preparation stage. The chapter concludes with a discussion of motor imagery and its use in music performance, action observation and the mirror neuron network, and the neural structures involved in movement imagination.

2. MOVEMENT IN MUSIC

Human physical movement is essential for a musical instrument to produce sound. Movements can be categorized into those initiated by either internal or external factors. Internally initiated movements are self-initiated in that one chooses to perform a movement without an external cue (Deecke, 1996), such as walking or singing. Externally initiated movements are reactions triggered by environmental stimuli, such as applauding in response to a musical performance. As a performer, one must make self-initiated movements and choices in the moment based on the musical composition, the instrument, and the external environment. These movements are usually generated internally prior to the onset of the movement (Deecke, 1996).

Often people do not perform one movement at a time, instead movements are combined into a series or sequence. Choosing a movement or sequence of movements is voluntary, intentional, and often associated with a prospective goal (Bouisset, 2008). For instance, the general goal of playing an instrument at a beginning level is to produce the correct sound with proper movements. Beginning musicians carefully choose each movement, learn how to make the correct sound after producing a certain movement, and then must figure out how to string together the movements into cohesive sequences. The objective at a more advanced level is to produce the correct sound, portray the correct emotion, and tell a story. Experienced players still choose specific voluntary movements, however, their end goal is more abstract, such as interpreting and expressing the emotions and feelings of the piece (Kazennikov, 2009). Regardless of expertise level, all movements and movement sequences of musicians must synchronized and well-rehearsed to be performed efficiently (Ericsson et al., 1993).

2.1. Development of Musical Movement

Musicians can be divided into subgroups by general skill level: beginners, amateurs (intermediates), and professionals. Beginning musicians primarily choose specific movements to control their sound because they are in the process of learning new motor skills. Such skills may include how to produce small finger movements to change pitch, such as the case with string instruments. These skills involve making the correct choice of movement for a desired sound, which can often be quite difficult for beginners. New motor skills can only be acquired with extensive motor practice involving minute physical changes of novel movement patterns (Ericsson et al., 1993). In the case of music performance, selecting and adjusting the correct placement of the fingers is vital to producing the correct sound, especially for string instrument players. Such actions begin as voluntary: a beginning musician must consciously think about where to place their fingers. These actions are not involuntary or automatic, in fact, they often require focus and careful concentration to produce the correct movement and sound. After consistent repetition of accurate movements, voluntary movements can become automatic over time. With musicians, finger sequences or breathing patterns can become automatic over time with deliberate practice (Ericsson et al., 1993).

Musicians develop different fine finger and hand movements that are particular to the instrument they chose to learn. For example, Bangert & Schlaug (2006) stated that musicians who play the violin or piano focus more on the development of one hand over the other: string players develop their left hand motor skills while pianists develop motor skills for both hands, or perhaps more so in the right hand, given that the left hand often serves an accompaniment role.[1] Due to the diverse functions of each hand, the researchers demonstrated that piano players display a left hemisphere advantage in activation levels, while string players show a right hemisphere advantage (Bangert & Schlaug, 2006).

Violinists learn to asymmetrically coordinate movements of the left and right hands, both of which control different elements of sound production (Baader, 2005). Sounds are produced by manipulating the bow, controlled by the right hand, and the left hand fingers choose the tones that will sound. The right hand and arm specifically control the pressure, speed, and direction of the bow on the string to set it into vibration. Left hand finger placement, however, proves to be one of the most difficult challenges of violin and other related string instruments. Individual left hand fingers must be dexterous as they determine the intended pitch with minute changes in pressure and tactile input (Elbert et al., 1995).

An additional and very important requirement for professional musicians must be considered. Professional violinists, during their musical training at a university level, are required to become proficient on multiple instruments, including the piano. Of course, their main focus and study is the violin; however, music teachers in particular must also be able to demonstrate general skills on other instruments. The piano is a main instrument of study for musicians because of its versatility and multi-functionality. For example, the piano can be played as a solo instrument, used to accompany other music, incorporated into ensemble with groups of other instruments, used in large orchestras, and utilized in music teaching settings at schools or in lessons, among many other reasons. Because of the versatility of

[1] Although some styles (ie. Bach's Fugues or New Orleans Boogie) have an active left hand

the instrument, pianists tend to only focus on their piano training during their studies, and less on other instruments.

Professional musicians use a variety of techniques to aid their performances. Not only are their motor skills developed quickly and efficiently over time, but their auditory (or aural) skills are developed by listening to an expansive variety of music and comprehending particular musical sounds and structures (Altenmüller, 2003). Importantly, professional musicians can efficiently use their aural skills to continuously monitor the auditory feedback produced by their complex physical movements. Complex motor skills and cognitive auditory skills are learned through experience and training, which consequently change the developing brain and its networks (Parncutt & McPherson, 2002). The effects of music listening, action observation, and music imagery will be discussed in Chapter 2.

Much more can be said about the differences between beginner and professional musicians. However, the most pertinent differences lie in the automaticity of movements and anticipatory behavior. Beginning violinists need to direct attention toward each note, finger and arm movement, and bow stroke before producing the correct sound. As they progress, amateurs can anticipate what they need to do in order to make the correct sound. Anticipatory behavior increases with skill level and practice, which reflects future-oriented behavior (Palmer & Drake, 1997; Drake & Palmer, 2000). Over time, amateurs become aware of their sound and recognize what they can do to fix any incorrect sounds or inefficient movements. As musicians develop additional technical skills, concentrated attention is given to producing the correct sound and series of sounds. As these skills become internalized and automatic after long-term practice, as is the case for professional musicians, less attention is given to how to produce the sound and more attention is directed toward the perception of the sound.

2.2. Automatic Movements

While watching a music performance, an audience member can perceive the ease and fluency of a professional musician. Clearly, a professional's movements of the fingers, arms, and body are automatic and seemingly effortless. The musician does not need to think about how to perform each movement or which movement to perform next. Finger movement sequences are automatized quite quickly while learning a new instrument, after hours of deliberate practice (Ericsson et al., 1993). Other elements, such as fluctuation in tempo (speed), variations in vibrato, and emotional expression become more important to a professional than the practice of specific movements.

A distinctive element of automatic movements is that one's direct attention is not given to the details of the movement, as is revealed in performing common movements (Bernstein, 1967). For example, professional musicians only use movements that they frequently use during practice to prepare for the final performance. During a performance, they do not need to continuously think about which movements to make. The movements, after hours and hours of practice, have been automatized. On the other hand, beginner musicians generally do not perform automatic movements because they must think about how to perform the movement and then react to the consequence of the movement – the sound it produces. Amateur musicians have learned the movements well enough as to not direct as much attention towards them, but are often still in the process of learning and practicing new techniques that will require close attention to complex movements.

Although a musician may improve after extended practice, it does not mean that they have achieved an automatic state (Ericsson et al., 1993; Hambrick et al., 2014). It can be difficult to distinguish between tasks that have been extensively practiced and improved, and tasks that have become automatic.

2.3. Deliberate Practice

Of course, a musician does not go directly from a beginner to a professional. A beginner must put in many hours on their instrument before movements become automatic. Although there is not a specific magic number of hours a musician needs to practice, in general, the more a musician practices, the better she will become over time. Ericsson et al. (1993) argued that it takes 10 years, or approximately 10,000 hours of focused, deliberate practice in order to achieve the highest levels of performance. However, not only are the hours of committed practice necessary, but also the quality of practice is very important.

Deliberate practice seems to be a distinguishing trait that differs between amateur and professional musicians (Ericsson et al., 1993). What exactly is deliberate practice? Ericsson and colleagues (1993) define deliberate practice as when a performer has the "motivation to attend to the task and exert[s] effort to improve their performance" (pp. 367). Musicians must be focused on the task at hand and willing to find ways to improve over their practice sessions, including strategies of practicing to ensure the correct movements, movement patterns, sequences of notes and sounds, and so on, to be the most efficient. Students learn such practice strategies from their music teachers, who give them the tools to modify their own playing (fixing mistakes and improving their performance) when the teacher is not present. If inadequate feedback is given to the performer, further practicing is not efficient to learning and only little improvement may occur. When deliberate practice is employed several times with slightly differing tasks, it improves the accuracy and speed of performance. However, mere repetition is not sufficient to lead to automaticity of movements for performance (Ericsson et al., 1993).

Hambrick et al. (2014) recently proposed that deliberate practice is not sufficient in explaining individual differences in performance, as maintained by Ericsson et al. (1993). Hambrick et al. (2014) pointed out that deliberate practice alone does not account for the variance of expertise in music performance. They suggest several other factors that may influence why some people become experts while others do not, including starting age, intelligence, personality, and genetics. Yet, some normal people attempt to become expert performers and simply cannot, regardless of the amount of time they deliberately practice; many performers remain at an intermediate level (Hambrick et al., 2014).

Current research remains inconclusive on the exact amount of time it takes to become a professional of a specific trained skill. Given the various factors that may influence potential skill acquisition and expertise, it is almost unreasonable to determine the amount of practice time as the most important distinguishing factor among beginners, amateurs, and professionals. However, in the current thesis, it is expected that general levels of brain activation will correlate with the experience level of each musician. Less experienced players will display similar activation patterns amongst themselves (at higher levels than more experienced musicians), while amateurs and professionals will reveal different levels of activation (lower in comparison to the less experienced musicians). Musical training is a unique and individualized process, resulting in different practice habits and methods of learning, accompanied by changes in brain plasticity.

3. THE DYNAMIC MUSICAL BRAIN

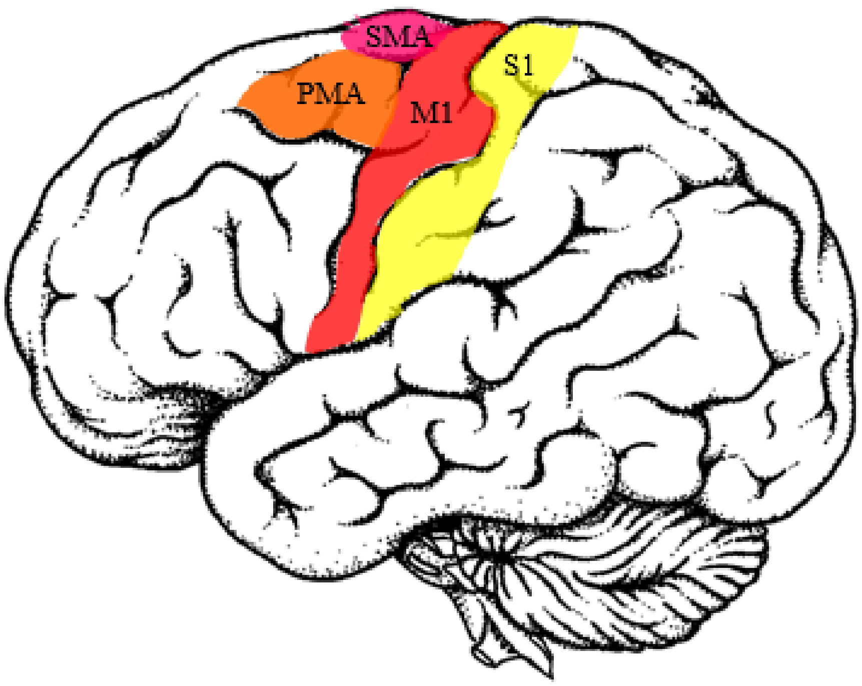


FIGURE 1 ACTIVE NEURAL AREAS DURING MOVEMENT

The primary motor area (M1) has a role in simple movements; shows increased activation during simple movement execution, and decreased response during movement preparation. The premotor area (PMA) is responsible for movement selection and initiation; reveals increased activation during movement preparation period and action observation. The supplementary motor area (SMA) plays a role in movement preparation, including the timing and sequencing of movements; has an increased response during the movement preparation period. The primary somatosensory cortex (S1) is stimulated while touching objects and sensing the environment, including haptic feedback from the instrument; shows increased activation during movement preparation and execution. The cingulate motor area (CMA) is within the medial cortex, thus not shown in this view; it surrounds the limbic system and has a role in emotional and reward responses to movement, and reveals increased activation during movement preparation and observation.

Music performance involves multiple brain regions that work together to allow for the coordination and proper execution of complex movements and movement sequences (Lotze et al., 2003; Zatorre et al., 2007; Altenmüeller, 2008). Various studies have discovered the activation of a large network of brain regions during numerous motor and cognitive skill performances; therefore, indicating one function per structure is unreasonable. Often, one function will activate numerous related structures, as is the case with music performance. Performing music excites joint activation of motor, temporal, visual, and somatosensory cortices, processed through the frontal areas and the limbic system (Lotze et al., 2003; Altenmüller, 2008).

Voluntary limb movements in skilled music production employ four critical regions of the brain: the primary motor area, the supplementary motor area, the cingulate motor area, and the premotor cortex. In general, the primary motor area (M1) controls the execution of simple movements, from its complex arrangement of body parts along the motor cortex. The supplementary motor area (SMA) manages the coordination of the two hands and sequencing of complex movements. Movements chosen on the base of reward are controlled by the cingulate motor area (CMA), which closely connects to the cingulate gyrus and limbic system, allowing the CMA to participate in cognitive and emotional functions related to action. The premotor cortex (PMC) is activated during movement planning as well as during the learning, execution, and recognition of limb movements (Parncutt & McPherson, 2002). Each of these areas mediate specific motor functions that are necessary for music performance, which will be discussed in the next paragraphs in more detail. Refer to Figure 1 for a depiction of these brain areas.

The motor areas are located at the rear portion of the frontal lobe and can be divided into distinct anatomical and functional roles for motor execution (Rizzolatti et al., 1998). Within the motor regions of the brain, the primary motor area (M1) largely manages simple voluntary movements, participates in learning and other cognitive activities (Sanes & Donoghue, 2000), and is directly connected to the spinal cord (Altenmüller, 2003). The primary motor area controls the required muscles for movement with assistance from secondary areas: supplementary motor area (SMA), pre-supplementary motor area (pre-SMA), cingulate motor area (CMA), and premotor cortex (PMC) (Altenmüller, 2003).

The SMA, CMA, and PMC, as secondary motor areas adjacent to M1, process patterns of movement rather than simple movements (Altenmüller, 2003). The SMA plays a vital role in movement preparation and planning (Cunnington et al., 1996), including movement timing and sequencing preparation (Kennerley et al., 2004; Bortoletto & Cunnington, 2010). Indeed, music performance requires control over basic motor functions for the timing and sequencing of movements (Zatorre et al., 2007). Serial order and event timing are indicated by the rhythmic and metrical structures of the music (for review see Palmer, 1997; Drake & Palmer, 2000). The ability to time movements has often been attributed to an "internal clock" (Treisman, 1963; Ivry & Schlerf, 2008) which is controlled by a network of regions specific to the movement demands, including the SMA. Movements that depend on timing of the rhythmic sequence (Zatorre et al., 2007) also recruit the cerebellum (Penhune, Zatorre, & Evans, 1998) and basal ganglia (Ivry & Spencer, 2004). The inner basal ganglia contribute to selection of motor actions (Altenmüller, 2003), movement timing for intervals longer than 1 second (Zatorre et al., 2007), and the learning and execution of motor sequences (Rizzolatti et al., 1998). The cerebellum controls accurate movement timing, fine corrections of individual movements, and the learning and execution of motor skills (Altenmüller, 2003).

Rhythmic sequencing involves combining specific movements within a temporal constraint, such as coordinating multiple limb movements at certain points in time (Drake & Palmer, 2000). These sequences are specifically shown by the contour of the notes, that is, the rising and falling of pitches in relation to one another, as indicated by the musical notation. The SMA and pre-SMA are involved in the organization, chunking, and execution of such complex movement sequences (Kennerley et al., 2004; Sakai et al., 2004; Zatorre et al., 2007), including the coordination of the two hands, especially in piano performance (Altenmüller, 2003).

The CMA seems to play a role in “movement selection based on reward”, and facilitating other cognitive and limbic functions in relation to movement; while the PMC is responsible for the selection and initiation of planned movements, particularly within the medial and lateral cortical areas. The PMC is also activated during the learning, recognition, and execution of complex limb movements (Altenmüller, 2003), and is possibly relevant in motor prediction (Janata & Grafton, 2003; Schubotz & Cramon, 2003).

Overall, the frontal lobes are responsible for planning future actions and controlling movement. Planning and deciding on actions take place in the prefrontal areas, while the control of movement is monitored by the motor areas in the posterior frontal lobe (Altenmüller, 2003). The motor areas, in conjunction with the parietal regions, are activated during simple and complex motor movements necessary for music production. The parietal lobes and the motor regions of the frontal lobes are physically connected and work in parallel to transform incoming sensory information into motor actions (Rizzolatti et al., 1998). The parietal lobe is also involved in movement processing, and its posterior area is specifically activated during sight-reading (reading through music for the first time) and while performing a complex piece of music (Altenmüller, 2003).

3.1. Preparing for Action

The preparation stage of a motor activity involves a sort of priming for the movement. In music performance, this involves holding the instrument in the correct position with the correct posture and setting the fingers on the right notes before beginning. This stage usually involves some sort of mental preparation, where questions such as “Will I begin in tune?” or “Will I have a good tone?” easily arise. This mental preparation, however, is not always an internal verbal check. Researchers have shown that a mental preparation time, prior to the execution of any complex motor skill, is accompanied by changes in regional activation (Deecke, 1969, 1996; Bortoletto & Cunnington, 2010; Shibasaki, 2012).

Deecke (1969, 1996) has shown that there is a brain preparation stage for the execution of voluntary movements. The EEG study in 1969 indicated that direct current waves from the cerebral cortex create a negative shift in the potential of the motor regions, occurring 1 to 2 seconds before muscle activity. The negative potential shift indirectly relates to the activation of the motor areas, known as the Bereitschaftspotential (BP) or the readiness potential. The readiness potential is primarily observed in actions that are initiated voluntarily (Deecke, 1969).

Other studies have confirmed that prior to the execution of a self-initiated voluntary movement, cortical activity increases, compared to movements cued by external factors (Deecke, 1996; Shibasaki, 2012). This increased cortical activity represents a preparation period during which the brain forms the groundwork from which a movement is initiated: the planning stage.

Bortoletto & Cunnington (2010) presented a notable experiment on movement preparation involving simple and complex finger movement tasks. EEG and fMRI imaging techniques were used to image brain activity prior to movement execution. The tasks involved movement sequences of four right-hand fingers (2-index, 3-middle, 4-ring, 5-little), each of which pressed a corresponding key. Three different movement tasks were employed: the simple condition had adjacent finger movements in a scale sequence (2-3-4-5-4-3); the timing condition used the simple scale sequence (2-3-4-5-4-3) within a time range of 3-6 seconds or 7-10 seconds between each sequence onset; and the sequencing condition used two complex sequences (2-4-3-5-3-4 and 2-5-3-4-3-5) that alternated between trials, following a 5-12 second pause at the end of each sequence. The participants had to attend to finger movement timing and complex sequencing patterns (Bortoletto & Cunnington, 2010).

The timing condition revealed brain activity that occurred before movement execution in the lateral prefrontal areas, while the sequencing condition activated premotor and parietal cortices. With increasing movement complexity, the researchers found heightened bilateral activity in the medial premotor cortices, including the cingulate motor area, supplementary motor area, lateral premotor cortex, and inferior and superior parietal lobe. All of these areas were activated immediately before movement execution.

Bortoletto & Cunnington (2010) concluded that the co-activation of the frontal and parietal lobes represents an active network before movement execution. This finding further supports the concept of the readiness potential as well as the importance of the frontal and parietal areas in movement planning and motor imagery, which will be explained in the next section.

3.2. Motor Imagery

A musician can prepare for a music performance using motor imagery. Motor imagery is the mental rehearsal of motor movements without actual movement execution (Jeannerod, 1995; Mulder, 2007). Motor imagery falls under the scope of mental imagery. On a larger scale, mental imagery or mental rehearsal can engage all of the senses to produce a vivid imagination of a performance. In fact, Altenmüeller (2008) stated that practicing through listening and/or observation can be considered a type of mental rehearsal. During a mental imagery, a musician can choose to internally focus on an ideal performance or change their mental perspective to that of an audience member observing the performance (Parncutt & McPherson, 2002). Imagining the movements necessary for music performance provides a performer with important information such as to what to expect during an actual performance.

Motor imagery involves the internal representation of an intentional movement (Jeannerod, 1995). The intentional movement can be either voluntary or automatic, and the representation of the movement takes the form of a motor image. This image is a self-initiated, internal representation of a movement generated during the movement preparation stage. Motor imagery ends upon execution of the intended movement; therefore, as Jeannerod (1995) argued, the movement preparation stage is where motor imagery must occur.

Jeannerod (1995) also demonstrated that movement execution and motor imagery share similar networks. For example, several studies have confirmed that the PMA and SMA are active during both execution and imagery, while M1 activation is still debatable (Kasess et al., 2008). It has also been shown that movement preparation and motor imagery share similar processes and functions in that both depend on motor processing mechanisms rather than the action of the movement itself (Decety, 1996). This is feasible because these processes are preparing the person to perform an action, without actual movement execution. Physical movements are overseen by the primary motor area, and secondary motor areas process movements; therefore during motor imagery, activation of the primary motor area decreases because of its role in movement execution rather than preparation, while secondary motor areas show increased activation (Decety, 1996).

As shown by Decety (1996), M1 activity can decrease during motor imagery. Kasess et al. (2008) also found a decrease in M1 activity and suggested that the change is caused by the SMA suppressing M1 activity during motor imagery. Why would the SMA suppress M1 activity? The researchers suggested that SMA may inhibit M1 activity in order to prevent actual movement execution. Specifically, the SMA is active for several seconds prior to a movement, forming a motor plan, which validates its role in action preparation (Kasess et al., 2008). However, this finding is controversial, as several others have reported that M1 increases during motor imagery (Porro et al., 1996; Dechent et al., 2004).

Although these studies show that activation of the primary motor area generally decreases, it is also important to consider the role of the contralateral M1 during movement imagination. Lotze et al. (2003) revealed that professional musicians who mentally practice and habitually employ imagery techniques show no contralateral M1 activation during motor imagery, while amateurs (who employ fewer imagery techniques) activate more of the primary motor cortex. During music performance, amateur musicians also tend to engage M1 and additional motor areas, while professional musicians activate only the secondary and tertiary areas. This suggests that frequent, long-term practice of imagery congregates fewer brain areas in professionals compared to a more wide-spread activation shown in amateur musicians (Lotze et al., 2003). Furthermore, Lotze & Halsband (2006) proposed that long-term practice and experience with motor imagery results in transformed activation sites that are more focused and shift to secondary and tertiary areas, supporting a more abstract internal representation. Therefore, professionals should show less activation in primary motor areas than beginner and amateur musicians during motor imagery, and show more activation in secondary areas, including the SMA and PMA.

Aside from participation of the primary motor cortex, the posterior supplementary motor area and premotor cortex are fundamental to motor imagery of movement (Stephan et al., 1995; Lotze & Halsband, 2006; Zatorre et al., 2007). The next section will explain the importance of the PMA in motor imagery and its role in the mirror neuron network.

3.2.1. THE MIRROR NEURON NETWORK

Mirror neurons are claimed to have a central role in action, observation, imagery, music, and variety of other action-related behaviors (Fadiga et al., 2009). This network is comprised of various frontal and parietal areas that respond during action execution, observation, and imagination. A classic study by Rizzolatti et al. (1996) used macaque monkeys to reveal that area F5 of the premotor cortex (PMC) is active during action observation.[2] Specifically, neurons discharge in the PMC when a monkey both performs an action and when it observes the same action being performed by another monkey or the experimenter. Kohler et al. (2002) further found that neurons discharge in the same area of the premotor cortex when a monkey performs a specific action and when it hears a related sound.

Using a music performance example, when a musician observes an action that belongs to their repertoire of movements, such as a violinist watching another violinist perform, the movements are automatically retrieved and prepared. The violinist observes a pattern of

[2] Area F5 is homologous to Broca's area in the human brain and is related to hand and mouth movements (Rizzolatti, 1996).

known, learned actions, yet does not perform them herself. Instead, the actions are mentally represented in the motor system by mirror neurons. Mirror neurons represent internal actions and play a role in our understanding of motor events (Rizzolatti, 1996). This system provides individuals with a unique means of communication, where one can understand the meaning and intention of individual's actions through observation or imagination. In an extensive review, Rizzolatti (2004) wrote more on the significant findings of a human mirror-neuron system. Several brain imaging and neurophysiological studies indirectly point toward a mirror-neuron system in humans (Rizzolatti, 2004), one of which will be discussed below.

3.2.2. OBSERVING ACTION

Calvo-Merino et al. (2005) presented a study exploring action observation and acquired motor skills in expert dancers. Ten professional ballet dancers, 9 capoeira dancers, and 10 non-expert control subjects watched 3 second video recordings of ballet and capoeira movements. Using fMRI, the researchers aimed to look into brain activity differences between observing learned and unlearned actions. It was hypothesized that the subjects who had learned to perform the observed actions will show stronger premotor and parietal cortex activation compared to the controls (Calvo-Merino et al., 2005).

The results revealed that the premotor cortex, parietal cortex, and superior temporal sulcus displayed stronger BOLD responses while dancers observed movements that were part of their motor repertoire compared to unfamiliar, unlearned dance movements (Calvo-Merino et al., 2005). These regions are specifically linked to the mirror neuron system. For example, the premotor cortex (PMC) may encode plans of action for complex movements, such as dancing or music-making. The researchers proposed that if a subject has learned the specific motor skills to perform an action, observation of that action should recruit such "mirror areas." They concluded that "action observation involves an internal motor simulation of the observed movement" seen in such areas inhabited by mirror neurons (Calvo-Merino et al., 2005).

This study is vital to the current thesis in providing further evidence of premotor activation during motor imagery and movement observation. Specifically, activation of the premotor cortex is correlated with the effect of expertise, which further supports the notion that the mirror-neuron system is activated during the observation of learned, skilled movements (Calvo-Merino et al., 2005). When participants observe the performance of an instrument that they have learned, it is expected that their PMC will increase in activity, due to its link with motor neurons. Similarly, when the participants engage in motor imagery, imagining the finger and hand movements of the performances, this should result in increased activity of the premotor cortex.

4. CONCLUSION

Musicians learn to control precise movements in order to generate sound from their instrument. Certain movements of the hands, arms, mouth, or tongue influence the quality of sound. Multiple movements are combined into sequences to create memorable melodies and harmonies. These movements are unique to each instrument. For example, violinists focus on training the left hand, while pianists focus more so on both hands, resulting in unique hemispherical advantages. The type of movements used and the focused training on one hand in particular demonstrate the wide range of differences among musicians and their instrument choice.

In addition to the different movements required for each instrument, musicians reveal great variety in skill, adding another level of individuality and complexity to the mix. Musicians display diverse skills and abilities depending on their level of training. Differences among beginners, amateurs, and professionals have been researched, commonly comparing the musicians to non-musician counterparts. The greatest difference between professionals and less experienced musicians is their use of automatic movements and anticipatory behavior. As movements become automatic and anticipation for certain events develop, musicians can more easily learn to imagine the movements. Professionals often report using imagery techniques to assist in learning, memorizing, or practicing a piece of music. Beginners, however, do not yet have the skills to imagine the movements in the same way as professionals, and this is reflected in brain activation differences. Beginners congregate additional brain structures while engaging in musical behavior (performance, observation, and imagery), while professionals exhibit more refined areas of activation, as they have accurately developed movements that require less direct attention to produce. In general, beginner and amateur musicians reveal higher levels of activation of primary frontal motor areas compared to professionals.

Music performance engages the motor, visual, temporal, and somatosensory cortices, revealing a large network of activation. Breaking down these brain areas into their specific functions in music allows researchers to find the “magic” in music-making. Movement in music highlights the motor areas of the frontal lobe, including the primary motor area, supplementary motor area, cingulate motor area, and premotor cortex. In general, the primary motor area is activated during simple musical movements, and is active more so in beginners and amateurs than professionals. The secondary motor areas are active during complex movements and sequences, and are generally more active in professionals than beginners or amateurs.

Motor imagery occurs during the stage of movement preparation, as defined by the readiness potential, and ends before the production of the movement. Importantly, motor imagery, movement preparation, and movement execution all share similar networks of activation. Motor imagery depends on the mechanisms that process movements rather than producing the actual movement. The SMA, CMA, and PMC process movements, while M1 supports the execution of simple movements. Studies have not yet confirmed the exact role of the primary motor area in motor imagery; however, it is reasonable to expect that a motor imagery task will activate the secondary motor areas more so than the primary areas.

Learning a musical instrument is clearly an individualized, complex process for all musicians. The large variation in skill, experience, and practice habits alone cannot be overlooked. Musical behavior reflects great individual differences and provides a means of studying the variance of complex, learned skills.

CHAPTER 2: MUSIC AND MUSIC IMAGERY

1. INTRODUCTION

Musicians use auditory feedback to constantly monitor their performance (Altenmüller, 2008). Professionals specifically are very aware of their sound, can anticipate future sounds and potential mistakes, and can quickly correct any mistakes based on feedback. Listening is an imperative aspect to learning and performing music. It is fundamental to being "in tune" – that is, to play accurate pitches. For example, string players slightly change a movement or angle of their left hand fingers to adjust a pitch upon hearing it. The ability to correctly adjust a pitch depends on careful listening and long-term practice.

Listening is also required for producing a clear tone. Tone relates to the clarity, quality, or color of a produced sound. For string instruments, the bow controls the sound and tone of the instrument. More or less pressure with the bow, its placement on the string, and its speed can influence the tone. Learning to distinguish changes in tone and how to fix and adjust the tone is important for a progressing student. Such small changes in tone or pitch depend on the careful listening, demonstrating that listening is a key skill for successful music learning and training.

2. MUSIC LISTENING AND OBSERVATION

Several music cognition studies, frequently comparing musicians to non-musicians, have shown that listening to music primarily engages the auditory regions of the brain (Zatorre et al., 1992; Ohnishi et al., 2001; Seung et al., 2005). The auditory areas, consisting of the primary and secondary auditory cortices, are located in the temporal lobe. The auditory cortices are responsible for processing auditory information related to speech and music (Zatorre et al., 1992; Zatorre et al., 2007). Specifically, listening to instrumental music (music without lyrics) activates the right auditory cortex (Halpern et al., 2004), which has been shown to have a role in processing pitch information (Zatorre et al., 2002). Listening to music with lyrics largely activates the left auditory cortex, due to the processing of speech in the left hemisphere (Zatorre et al., 2007). Several studies have shown that the auditory cortex can be activated even without the presence of sound (Zatorre & Halpern, 1993; Halpern & Zatorre, 1999; Halpern et al., 2004) and this likely facilitates music imagination (Zatorre & Halpern, 2005).

Recent brain imaging studies have revealed that listening to music engages not only the auditory cortex, but a large bilateral network comprising of the temporal, frontal, parietal, and subcortical areas (Peretz & Zatorre, 2005). These areas are specifically related to attention, memory, motor functions, and music processing during music listening (Janata et al., 2002; Peretz & Zatorre, 2005).

A study by Bangert et al. (2006) demonstrates musicians' brain substrates during music listening and motor observation. Two groups of participants were created in the study: 7 professional pianists and graduate piano students, and 7 control students who did not have any instrumental training. The participants were assessed using fMRI while performing an acoustic task and a motion-related task. The acoustic task had participants passively listen to 3 seconds of randomized sequences produced by a synthesized piano. For the motion-related task, participants were instructed to press random keys on a silent piano keyboard for 3 seconds. The participants were only instructed to relax and pay attention to the fixation point; they were not explicitly told to imagine any sounds or movements, nor suppress imagery (Bangert et al., 2006).

During the passive listening acoustic task, the bilateral primary and secondary auditory cortices, superior temporal gyri, and areas of the frontal and parietal lobes were activated in both groups (Bangert et al., 2006). The pianists, in contrast with the controls, showed additional frontal, parietal, and temporal cortical activity. Within the frontal cortex of pianists, M1 and PMA were bilaterally active, while the right frontal gyrus and the left frontal paracentral lobe were unilaterally active. Parts of the temporal gyrus and inferior parietal lobe were also activated. The researchers further found an activated strip in the left hemisphere that stretched from the left primary motor cortex to the PMA to the superior region of Broca's area in only the pianists (Bangert et al., 2006).

More specifically, Bangert et al. (2006) found that SMA and PMA activity increased during the motor-related tasks in musicians but not in the non-musicians. The researchers noted that this finding is distinct from other common results – there is typically a decrease in SMA and PMA activity in musicians compared to non-musicians. These motor areas, in combination with other frontal and auditory regions, make up a coactive auditory-motor network in musicians (Bangert et al., 2006). The main areas of this network, particularly in the left hemisphere of pianists, include the inferior frontal cortex/posterior frontal operculum, middle temporal gyrus, posterior superior temporal gyrus, and supramarginal gyrus. Non-musicians show a right hemisphere bias and do not seem to activate an auditory-motor network that is detected in musicians.

Overall, this study revealed that professional pianists show increased cortical activity compared to non-musicians during listening and finger movement tasks (Bangert et al., 2006), however this finding is controversial. Typically, a decrease in cortical activity is found in professional musicians compared to non-musicians.

3. MUSIC IMAGERY

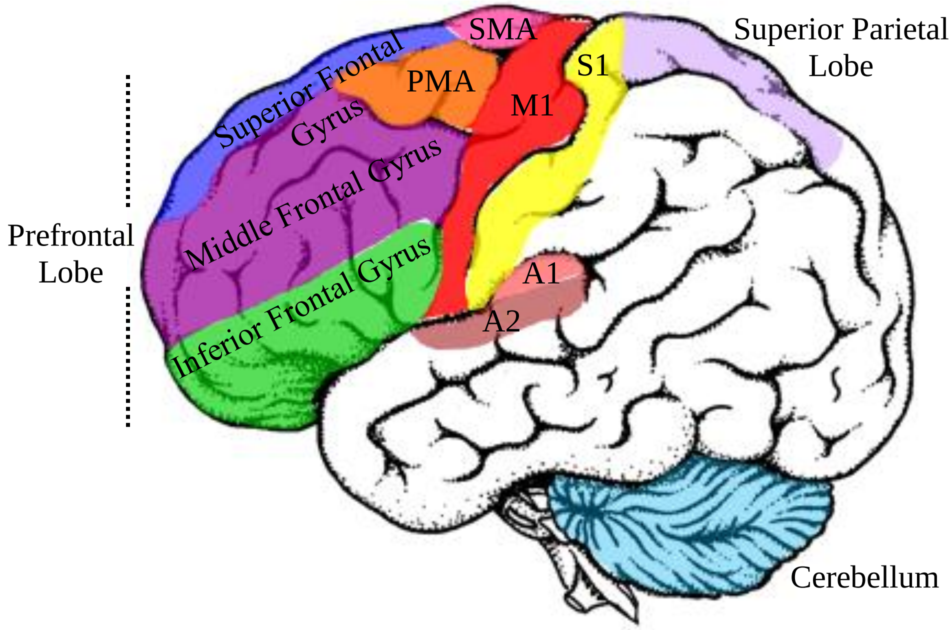


FIGURE 2 ACTIVE NEURAL AREAS DURING MUSIC PERFORMANCE AND IMAGERY

Music performance and music imagery share common sites of activation; nearly all areas of the frontal lobe are engaged. The frontal lobe is generally known for its role in planning, decision making, organizing, attention, and higher cognitive functions. Specifically, the superior and inferior frontal gyri within the prefrontal lobe respond during music imagery, while the middle frontal gyrus generally activates during music performance execution. Further back in the frontal lobe, the premotor area (PMA) and supplementary motor area (SMA) are active during music imagery due to their association with more complex musical tasks. The primary motor cortex (M1) is mainly responsive during music performance execution, although some researchers have also found it to be active during music imagery. The cerebellum and other areas in the parietal and temporal lobes, including the primary somatosensory cortex (S1), primary auditory cortex (A1), and secondary auditory cortex (A2) are also pertinent to the perception, execution, and imagination of music, however, they will not be examined in detail in this study

Music imagery is the ability to imagine music in one's mind (Zatorre & Halpern, 2005). Most people are able to think of a song without actually hearing it, thus partaking in music imagery. Music imagery specifically involves imagining the sounds of a musical piece, and is vitally distinct from motor imagery; music imagery involves the imagination of musical sounds, while motor imagery is the imagination of only movements. Likewise, music imagery is a type of auditory imagery, specifically imagining music rather than just sounds.

One can also imagine only hearing the music (music imagery) or only movements of the fingers (motor imagery), as separate imagined experiences. However, auditory and motor imageries often work together in an imaginative music performance – a mental rehearsal – to simulate a very similar experience to an actual live music performance (Tan, Pfordresher, & Harre, 2010). In fact, various researchers consider music imagery itself to be a combination of both auditory and motor imageries (Zatorre et al., 2005; Clark et al., 2012). Keller (2012) even defined music imagery as a multimodal process during which musical sounds, visuals, proprioceptive, kinesthetic, and tactile elements of music-related movements are imagined.

Music imagery has been shown to activate many of the same areas that are involved in music processing (for review, see Zatorre & Halpern, 2005). Zatorre et al. (2005) postulate that music imagery is produced by the interaction between frontal areas and the auditory cortex. Several studies have revealed differences in frontal lobe activation during music imagery (Zatorre et al, 1996; Langheim et al, 2002), which plays a role in generating an auditory image, while the auditory cortex sends feedback signals that assist in discerning a mental auditory image from an actual sound (Halpern & Zatorre, 1999). The auditory cortex plays an important role in music listening processes, music imagery, and music performance execution, however, there is some debate over which specific regions of the auditory cortex are active during music imagery. Many researchers have found activation of the secondary auditory cortex (Halpern et al., 2004), while others have observed activation changes in the primary auditory cortex (Zatorre & Halpern, 2005). A variable that may be responsible for the diverse findings is differences in task demands between investigations on music imagery and motor imagery (Zatorre & Halpern, 2005). With many different functional definitions of music imagery, it proves difficulty in detecting specific brain areas involved in only music imagery. Further research needs to be done to distinguish the interactions between the separate forms of imagery and their mental counterparts.

Although the auditory cortex has been shown to be activated during music imagery, the current thesis will only investigate changes in the frontal lobe, specifically within the motor cortex and prefrontal areas. Please refer to Figure 2 (pp. 26) for a description and image of the neural landmarks associated with music performance and imagery.

3.1. NON-MUSICIANS

First, let's consider at the neural correlates of music imagery in people who do not have much music training. Zatorre et al. (1996) used PET scans to investigate music imagery and perception in students with some music experience, but who did not consider themselves musicians. The experiment used a perceptual listening condition and an auditory imagery condition. For the perceptual task, participants viewed pairs of words from a familiar song while listening to the corresponding song, and then had to judge a change in pitch of two cued words from the song. The imagery task involved the same judgement as the perceptual condition, but without the auditory input. Participants were presented with two words and judged which word was longer for a baseline visual task. The researchers subtracted the baseline from the perception and imagery tasks, eliminating the shared neural activity between the two tasks (Zatorre et al., 1996).

Auditory (music) imagery for songs activated the secondary auditory cortices, located within the superior temporal gyri. The imagery task also engaged the left frontal lobe, the subcallosal and inferior areas of both frontal lobes, SMA, and left parietal lobe. The perceptual condition engaged the left frontal lobe, SMA, and the left parietal lobe, similar to the imagery task. These findings suggest that common neural components are involved in both perception and imagery (Zatorre et al., 1996).

Zatorre et al. (1996) noted that past research found that the SMA was activated only during imagined motor tasks and usually not engaged during motor execution. However, this study found that the SMA is also activated during the perceptual task (listening to the song). The researchers postulated that when participants listen to the stimulus, motor processes might be involved; concluding that the SMA may actually be active during both overt and covert vocalization of music (Zatorre et al., 1996).

An important difference between Zatorre's study and the current thesis is that Zatorre used a song – that is, music with lyrics – while the present thesis will use music without lyrics. Zatorre et al. (1996) suggested that the bilateral frontal areas, as well as the right hippocampus and thalamic areas, might be involved in the generation of nonverbal auditory representations. Music without lyrics, therefore, can be used as a nonverbal auditory stimulus in place of music with lyrics.[3] As stated previously, Zatorre et al. (1996) also proposed that songs without lyrics might activate more structures in the right hemisphere during a perceptual task, due to the contribution of the right hemisphere in pitch processing (Halpern, 2004). Due to these findings, the current thesis will focus on observing brain activity in the right frontal hemisphere and the motor areas specifically.

[3] Lyrics used in studies on music perception add yet another complex variable to the mix – verbal communication. Removing words from the current study, and other similar studies, will help eliminate the possible impact of some extraneous factors on nonverbal music perception.

3.2. AMATEUR MUSICIANS

Which neural substrates are engaged during music imagery in amateur musicians? A notable study by Langheim et al. (2002) used fMRI on musicians who performed, imagined, and listened to music to investigate the brain components of music imagery. There were 6 subjects, 2 violinists, 3 cellists, and 1 pianist, who all had at least 15 years of musical experience (instrumental lessons and performing) but did not perform professionally. Each musician selected their own piece based on familiarity, skill-level, and comfortability; all musicians performed different music selections. The selected pieces were used for each of the three conditions in the study.

The performance condition required the musicians to perform their piece of music for 60 seconds; the musicians tapped out the finger sequences rather than performing on an actual instrument (Langheim et al., 2002). After tapping, they were then instructed to close their eyes and imagine the finger sequences from where they had left off. This was repeated for 45, 30, and 15 sec intervals, alternating between actual finger movements and imagined finger movements. In the music imagery condition, the musicians closed their eyes and imagined performing their piece from beginning to end. A third listening condition was presented to five of the subjects, where they alternated between passively listening to their musical piece and bilateral finger-tapping (during resting blocks of no listening).

Langheim et al. (2002) concluded that the time taken to perform the selected piece and the time taken to imagine performing the same piece were highly correlated among all musicians. That is, the musicians were accurate in imagining the realistic amount of time needed to perform their selections. The music imagery condition activated several brain regions: the right inferior and superior frontal gyrus (premotor cortex area), SMA, right and left lateral cerebellum, and right superior parietal lobe. The right superior parietal lobe showed the greatest differences in increased activation during imagery compared to resting. Bilateral finger-tapping activated the bilateral primary motor cortices (M1), while the passive listening condition engaged the bilateral superior and medial temporal gyri (Langheim et al., 2002).

Essentially, this study reveals activation of the secondary motor areas (PMA, SMA) of the frontal lobes, cerebellum, and the superior parietal lobe during music imagery. In addition, M1 was not active during music performance imagination. This further suggests the activation of similar substrates during music performance and music imagery, and provides evidence for a frontal-parietal network active during music processing (Langheim et al., 2002). This frontal-parietal network assists in managing the timing, motor, and pitch aspects of a musical performance (pp. 30).

The researchers noted that their inclusion of different instruments and pieces allowed them to see if music imagery for different instruments activates a specific set of motor commands. For example, the right SMA was activated in violinists and cellists because their performances primarily relied on left hand movements. The pianist, however, showed increased left hemisphere activity due to using more right hand movements during the performance. The researchers concluded that there is not a significant difference in music imagery activation for motor commands for different instruments (Langheim et al., 2002).

The current thesis proposes that although different instruments (violin and piano) may not show significant differences in brain activation during music imagery, as supported by Langheim and colleagues, motor imagery tasks should expose activation differences due to the motor commands specific for the different instruments.

3.3. Skilled Musicians

In order to look into the neural areas connected to music imagery in skilled musicians, Lotze et al. (2003) examined professional and amateur violinists using fMRI. The violinists were asked to learn Mozart's Violin Concerto in G Major (KV216) prior to the study. The investigators scanned brain activity during execution and imagination tasks, and used electromyography (EMG) recordings to observe the firing of specific muscles. The execution task required the violinists to perform left-hand finger tapping movements on their chests, corresponding with the finger movements necessary to perform the piece. During the imagination task, the violinists had to vividly imagine performing the finger movements without making any actual finger movements. Training for the imagination task was given to the participants prior to the experiment, focusing on kinesthetic, visual, and auditory imagination of the musical performance; thus not solely focusing motor imagery, but a combination of imageries (Lotze et al., 2003).

The researchers hypothesized that musical experience and training may be related to transformations in neural activity. This included increased activation of contralateral M1 and decreased activation of ipsilateral M1, and changes in cerebellar activation due to training onset, both correlating with greater musical training; activation of fewer brain areas in professionals; and auditory co-activation during silent performances (Lotze et al., 2003).

Comparing amateurs and professionals, Lotze and colleagues (2003) found that the musicians demonstrate similar activation patterns during the movement execution task; however, amateurs used a more widely distributed set of brain areas, while professionals showed more concise areas of activation. Specifically within the motor cortex, professionals displayed contralateral primary motor cortex activation, while amateurs revealed bilateral primary motor cortex activations. Bilateral M1 activation in amateurs was also positively correlated with right-hand motor activity measured by EMG recordings. Both groups exhibited similar activations of the bilateral parietal areas, SMA, PMC, cerebellum, left temporal lobe, and some prefrontal areas during the finger-tapping task. Specifically within the prefrontal areas, amateurs showed increased BOLD signals in the bilateral orbitofrontal, right middle frontal, and left frontal operculum regions (located within the inferior frontal lobe), while professionals only activated the frontal operculum (Lotze et al., 2003).

During the imagination task, activity was more dispersed in amateurs, shown particularly within the bilateral lateral frontal lobe, inferior frontal lobe, and the primary and supplementary motor, temporal, parietal, and cerebellar regions (Lotze et al., 2003). The strongest BOLD activations occurred in the bilateral cerebellum, SMA, left inferior premotor cortex, and contralateral somatosensory cortex. Activity also increased in the inferior parietal lobes, left prefrontal areas, and the left temporal gyrus. Professionals, however, displayed greater BOLD signal clusters in the left M1, SMA, cerebellum, left parietal lobe, and inferior frontal gyrus than the amateurs (Lotze et al., 2003).

In general, for both executed and imagined tasks, amateurs displayed more widely distributed BOLD signals, while professionals exhibited fewer BOLD signal clusters. Particularly, amateurs have more dispersed activation within the sensorimotor areas and cerebellum of both hemispheres, greater prefrontal activation, and weaker auditory cortex activation. The researchers hypothesized that primary motor and auditory areas become closely associated during movement execution over years of musical training. Due to their strong connections, the areas will tend to co-activate during movement execution, which may help explain why the auditory areas are not as active during movement imagination (Lotze et al., 2003). The investigators concluded that greater musical training (observed in professionals) is linked to increased skill efficiency, spontaneity, and flexibility. The network contributing to efficiency and flexibility becomes more focused and refined with long-term practice (Lotze et al., 2003).

Therefore, in this thesis, it is expected that more experienced musicians should show a lesser amount of activity within the motor and frontal areas; players with less experience and the non-musicians, on the other hand, should show a greater amounts of activity within these regions compared to experienced musicians.

4. CONCLUSION

Researching music clearly shows an abundance of individual differences in ability, perception, and associated neural activity. Each person responds differently to music in physical, mental, emotional, and spiritual ways. Such variance is accompanied by changes in brain activity patterns, function, and structure as observed in studies of non-musicians and musicians of different skill levels.

The chapter began by looking into the importance of auditory feedback for musicians. The auditory aspects of music-making are vital to musicianship, as many aspects of playing an instrument rely on listening and adjusting movements based off of feedback from the instrument. Several studies brain imaging studies show a large network of many brain regions involved during music listening, chiefly monitored by the auditory cortex. During music imagination, it has been hypothesized that the prefrontal cortex forms an auditory image that is sent to the auditory cortex, where it is recognized as an internal auditory image rather than an actual sound. However, further research needs to be done to distinguish which specific areas of the auditory cortex are active during music imagination tasks.

Recent research suggests that the brains of performers respond differently to music than non-musicians. However, it is also imperative to study the variance in brain activity among people with different levels of musical experience. For example, when experienced musicians listen to a well-learned piece of music, they might automatically simulate a mental performance (Tan, Pfordresher, Harre, 2010). However, non-musicians are much more limited in their imagery abilities; often, music imagery actually happens involuntarily rather than voluntarily (Sacks, 2007). Nearly all people have had a song spontaneously pop into their head before, thus partaking in involuntarily music imagery. Music imagery seems to be a natural phenomenon, regardless of an individual's amount of musical experience.

This chapter also examined the differences between motor and music imagery. Several researchers have considered music imagery to be multimodal, often a combination of auditory and motor imageries. However, this thesis defines music imagery as imagining the sounds of a music performance, and motor imagery as imagining the finger and hand movements of a performance, in order to distinguish between the two types of imagery.

Studies on music perception and music imagery have revealed common neural components, including the SMA, PMA, parietal lobe, and cerebellum. Rather than primary motor regions functioning during music imagery, a network of secondary motor areas works together with the prefrontal cortex, parietal cortex, and cerebellum. These regions direct and control auditory information, such as the timing (rhythm) and pitch of a music performance.

During music imagery, similar to motor imagery, non-musicians generally show the highest amount of activation in primary motor areas (M1), and with increasing experience, musicians reveal lower amounts of activation in fewer primary areas and slightly more activation in secondary areas (SMA, PMA). Non-musicians, beginners, and amateurs should reveal higher levels of activation in the primary motor areas, including higher activation of the prefrontal cortex during motor and music imagery tasks; while professionals should display lower activity levels within the primary motor areas and prefrontal lobe, with higher activation of the secondary motor areas. Non-musicians and musicians possess various levels of experience and knowledge, which subsequently highlights great variance in brain activity while they engage in musical activities. Because of this, it is vital to record and correlate people's musical experience with the amount of brain activity revealed in their task performance.

Musicians often use music imagery to assist in practicing, memorizing music, silently reading written music, sight-reading, and composing new music (Aleman, 2000). Music imagery is an important skill for a musician to utilize, as many professional musicians disclose using music imagery to enhance their practices and performances (Hodges & Sebald, 2011). It has also been discovered that the combination of physical and mental imagery practice can be equally as effective (and perhaps more efficient) in improving performance as simple physical practicing, because of the musician's procedure of mentally assessing the cognitive aspects of movements (Ross, 1985). Other researchers have found that mental imagery practice may even be more effective when intermixed with physical practice, rather than simply utilizing physical practice alone (Tan, Pfordresher, and Harre, 2010). These studies show the importance of studying music perception, performance, and imagination to dive deeper into the cognitive realm of understanding music. The following thesis aims for analogous discoveries of the use of motor and music imagery in violinists, pianists, and non-musicians.

CHAPTER THREE: A NIRS STUDY OF VIOLINISTS AND PIANISTS EMPLOYING MOTOR AND MUSIC IMAGERIES TO ASSESS NEURAL DIFFERENCES IN MUSIC PERCEPTION

1. INTRODUCTION

Well-trained musicians frequently use motor imagery and music imagery, both of which provide useful information to enhance music learning and performances. These imagery techniques offer musicians ways to imagine movements and sounds, and anticipate and expect the possibilities of a live performance, without actually performing the necessary actions. Chapter 2 explained that musicians' brains are more highly activated and responsive while listening to music stimuli compared to non-musicians (Zatorre et al., 1992; Seung et al., 2005). When someone imagines hearing music, this is known as music imagery. It is also well documented that when an individual performs a specific action, the movements involved can also be imagined (Jeannerod, 1995). When musicians imagine the specific movements to perform their instrument, this is identified as motor imagery. Motor and music imagery often occur simultaneously when a musician envisions a performance or memorizes a piece of music. Because the two imageries can coexist, they share many of the same neural components. The aim of the current thesis is to measure the brain activation differences among violinists and pianists during tasks of motor imagery and music imagery.

2. METHODS AND MATERIALS

2.1. PARTICIPANTS

Three groups of participants were recruited for the study: non-musicians, pianists and violinists. All participants voluntarily participated in the experiment after reading and signing an informed consent statement about the procedures in the study. The Institutional Review Board at Northern Michigan University approved the experimental procedures.

Non-musician group: 4 participants, 1 female (mean age 20.75 ± 3.59 years). These control participants met the criteria that they have not had extensive musical training on an instrument beyond three years.

Pianist group: 4 participants, 3 females (mean age 24 ± 3.92 years). All pianists met the criteria of playing piano for at least three years; they had total lifetime practice experience of 10.75 ± 6.45 years. Therefore, the pianists were considered to be at an intermediate or amateur level.

Violin group: 4 participants, 3 females (mean age 35 ± 10.71 years). These participants met the criteria of playing the violin for at least three years; they had a considerable amount of practice experience over their lifetime, 26.25 ± 12.34 years. Therefore, the violinists were considered to be at a professional level. Furthermore, two of the violinists also studied piano as a secondary instrument during their musical training at the university level.

2.2. STIMULI

The stimuli for this experiment were video recordings of the composition *Meditation from Thais* by Jules Massenet. Recordings of two musicians (one violinist, one pianist) from Northern Michigan University were created preceding the experiment. The violin performance of *Meditation from Thais* was video recorded by the experimenter. The video focused on the left finger and hand movements because the left hand has a significant role in motor dexterity and control of fine finger movements. As shown below in Figure 3, the right hand movements of the bow were somewhat shown in the video, but they were not focused on because the bow does not require the same kind of movements as the left hand.

A piano professor from NMU recorded the piano part for *Meditation from Thais*; the video focused on the movements of both hands, angled directly above the hands because the coordination of movements between the left and right hands is vital to piano playing (Figure 4). Both recordings were filmed from these angles in order to enhance the first-person motor component during the motor imagery tasks. The video recordings were used for all sessions of the experiment.

FIGURE 3. VIOLIN PERFORMANCE VIDEO

FIGURE 4. PIANO PERFORMANCE VIDEO

2.3. APPARATUS

Near infrared spectroscopy (NIRS) was utilized in the experiment to record brain activity associated with motor and music imagery. NIRS uses near infrared light to measure oxygenated and deoxygenated hemoglobin by shining the light on the scalp, through the tissue, and to the brain. The light reflects off the brain and is sensed by a nearby detector.

The changes in the amount of light reaching the detector is then calculated, which corresponds with changes in absorption at the region immediately below the source and detector, indicating changes in blood volume or blood oxygenation. Both blood volume and blood oxygenation occur during functional activation (Boas, 2004).

The NIRS system employed in this experiment was the TechEn Continuous Wave6 (CW6), pictured in Figure 5 below. The CW6 system included 16 laser sources and 16 laser detectors. Two primary wavelengths modulated light at 690 nm (visible) and 830 nm (invisible). Each laser was paired with optical fibers that delivered light to the participant's head. The near infrared laser light used to make the measurements had very low power and the intensity used to monitor activity was completely harmless. The intensity was similar to the amount of light the brain would receive while outside on a sunny day (Boas, 2004). The optical power emitted on the participant's skin was P ~ 5 mW, while the optical fluence was P / A ~ 0.16 W/cm2. This value is below the maximum amount of exposure to skin with a laser beam at 690-850 nm, according to the American National Standards Institute (Boas, 2004).

FIGURE 5. TECHEN CONTINUOUS WAVE 6

Near infrared spectroscopy was utilized in this experiment rather than another imaging system for a few key reasons. First, NIRS allows for rapid data acquisition, an advantage over other imaging systems such as fMRI or PET (Boas, 2004). NIRS can also detect processes of longer time intervals with better localization than EEG paradigms (Wallois et al., 2012), which is suitable for experiments where participants are required to watch videos for longer than a few seconds. NIRS is also one of the few neuroimaging techniques that is less sensitive to head and body movements; movement sensitivity is a common drawback of other imaging systems such as fMRI (Boas, 2004; Cui et al., 2010). Furthermore, NIRS is non-invasive and safe. Utilizing NIRS in this experiment will provide further confirmation of its advantages in experimentation and data collection, as well as its use in studies investigating cognition and perception.

In terms of its drawbacks, NIRS has limited depth sensitivity and spatial resolution (Muehlschlegel et al., 2009). Depth sensitivity refers to how deep the light can penetrate the brain. For example, NIRS cannot go beyond a depth of 1 cm, or past the outer cortex of the brain. This limits the type of structures that NIRS can detect. Spatial resolution refers to the visual data produced by the hemoglobin levels. NIRS cannot produce 3D images of the brain, as the data is limited to a line graph of the hemoglobin responses throughout the tested time interval.

NIRS is also somewhat sensitive to large movements; head and body movements can result in increased noise. Small movements of the face (from blinking, coughing, yawning, etc.) can cause the optodes to shift on the head, changing the distance between the source, detector, and scalp (Cui et al., 2010). Participants' hair can also easily create problems if the head array is not securely fit, with hair completely clear from the area of contact between the optode and the scalp, which allows for proper transmission of the light signal. This proves to be a frustrating problem that requires meticulous practice and effort to gain an accurate, clean signal. However, overall, NIRS is a reliable and practical brain imaging system for the current experiment.

3. EXPERIMENTAL PROCEDURE

3.1. ARRAY PLACEMENT

Participants performed each session once with each head array (prefrontal and motor). The arrays were placed on the head based on the International 10-20 System for EEG placement (Figure 6). Participants' heads were measured to determine the center of the head on which the head array positions were based. Hair was parted to the side to ensure that the optodes have close contact with the scalp, and the array was fitted tightly against the head with Velcro straps and Ace bandages.

An array constructed of 12 optodes (Figure 7) was first placed over the forehead (Fp1–Fp2, centered on Fpz) to measure the activity of the prefrontal areas. Due to the ease and swiftness of attaching the prefrontal array, participants wore this array for the first experimental session. The second session of the experiment was conducted using a motor array, due to the more difficult nature in placing the array over the hair. The motor array, composed of 11 optodes (Figure 7), was placed over the motor regions in the right hemisphere (area covering C_2–C_6 and FC_2–FC_6, centered between C_4 and FC_4). C_2–C_6 roughly include the primary motor areas, while FC_2–FC_6 approximately include the secondary motor areas.

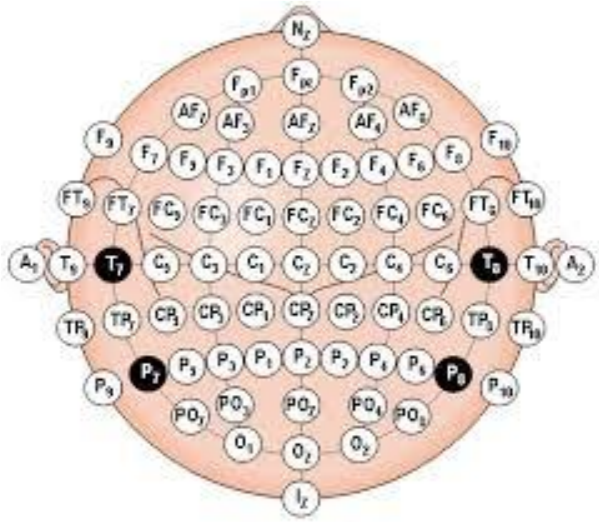


FIGURE 6. INTERNATIONAL 10-20 SYSTEM

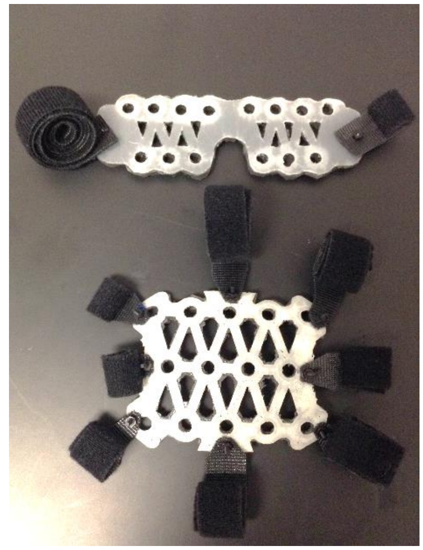


FIGURE 7. PREFRONTAL AND MOTOR ARRAYS

3.2. PROCEDURE

After placing the array on the prefrontal area, participants took part in the first experimental session, which lasted approximately 20 minutes. After taking a short break of 5 minutes, the motor array was placed over the motor areas, and participants began the second experimental session.

The videos for each experimental condition were viewed on an HP Compaq LA2306x computer, using EPrime 2.0 (2013) software in a dark laboratory room. The participants wore Panasonic ErgoFit earbuds while listening to the videos and performing the imagery tasks in order to block out any external sounds.

For each session, the participants ran two sets of instrument trials (violin and piano) presented in a random order. Participant 1 began with the violin set followed by the piano set, participant 2 began with the piano set then the violin set, and so on. Participants were exposed to three runs per set. Each run consisted of a group of conditions: a baseline, a motor imagery task, a music imagery task, and a combined motor imagery + music imagery task. The conditions, proceeding the baseline, were randomized within each run (Table 1). Constructed in an on-off block paradigm, the baseline and all conditions lasted for 35 seconds followed by 15 seconds of rest.

PIANO SET		
Run 1	**Run 2**	**Run 3**
Baseline	Baseline	Baseline
Motor Imagery	Music Imagery	Motor Imagery + Music Imagery
Music Imagery	Motor Imagery + Music Imagery	Motor Imagery
Motor Imagery + Music Imagery	Motor Imagery	Music Imagery
VIOLIN SET		
Run 1	**Run 2**	**Run 3**
Baseline	Baseline	Baseline
Motor Imagery	Music Imagery	Motor Imagery + Music Imagery
Music Imagery	Motor Imagery + Music Imagery	Motor Imagery
Motor Imagery + Music Imagery	Motor Imagery	Music Imagery

TABLE 1 PIANO AND VIOLIN RUN SETS

In the baseline condition, participants simply observed and listened to the performance video. The baseline was used to establish familiarity with the music and movements of the particular instrument in the video. Only after hearing the music and observing the specific movements for each instrument could participants then perform the associated imagery tasks. In the motor imagery condition, participants imagined the finger and hand movements of the particular instrument while listening to the accompanying music. In the music imagery condition, participants were instructed to imagine the sounds of the muted video of the instrument. The combined task of motor imagery and music imagery had participants imagine the movements and music of the instrument in the video, without any assistance from visual or auditory input.

In addition, during instruction for the imagery tasks, participants were not informed about how they should imagine the music or movements, that is, whether to imagine in the first-person (performing the movements themselves) or in the third-person (watching someone else performing the movement) perspective. Participants, instead, were free to choose how to imagine the movements and music on their own.

3.3. Questionnaires

Prior to the experimental trials, participants filled out an online version of the original Vividness of Movement Imagery Questionnaire (VMIQ) developed by Isaac, Marks, and Russell (1986). This 24 item questionnaire was used to assess each individual's experience in imagining movements prior to performing the imagery tasks and gave participants the opportunity to become familiar with imaging movements (Appendix A). Participants were instructed to imagine various movement tasks from first-person (performing movements) and a third-person (watching movements being performed) points of view. After imagining the tasks, participants rated their imagery clarity on a scale of 1-5 (1 indicated a clear image, and 5 indicated unclear/no image).

Immediately succeeding the experimental trials, participants took a Music and Movement Questionnaire to assess their musical behaviors (Appendix B). The first 20 questions were based off the Goldsmiths Musical Sophistication Index (Gold-MSI) developed by Müllensiefen et al. (2014). This comprehensive survey allows for self-reports of musical skills and behaviors. The current thesis did not used the entire Gold-MSI, only selected questions were used to assess relevant music experience.

The Music and Movement Questionnaire was divided into five sections: general music activities, music training experience, music perception abilities, imagery tasks ratings, and demographic information. The first section assessed general music activities, including daily time spent listening to music, monthly attendance of music events, amount of free time spent on musical activities, openness with listening to unfamiliar music, and whether the participant considers herself a musician. The second section evaluated music training experience: playing an instrument for more than 3 years (listing which instrument), total years spent learning instruments, primary instrument, type training experiences (school programs, classes, teaching, performing, composing, music degree, etc.), and weekly amount of hours practicing/performing on primary instrument. The third section had individuals estimate their music perception abilities, including their recognition of familiar songs, recognition of new songs, identifying different music genres, singing or playing from memory, comparing performances, noticing mistakes in performances, and their prior engagement with music imagery (including in which situations and how often it is used for practicing and performances).

The fourth section required participants to rate their level of difficulty of the imagery tasks. This included their difficulty in imagining specific musical elements such as pitches, rhythm, loudness, duration, and timbre; the finger and hand movements and duration of these movements; and the combination of both imageries to imagine the music and movements of each performance. The fifth section ended with basic demographic information including name, age, sex, handedness, and education level.

4. HYPOTHESES

The current thesis predicts the following two hypotheses concerning motor imagery and music imagery. The first hypothesis predicts that motor imagery tasks will reveal different levels of activation of the prefrontal and motor regions while violinists and pianists imagine movements particular to violin and piano playing. Specifically, violinists should respond differently while imagining violin movements compared to imagining piano movements, as they are more familiar with the movements that are specific to violin playing. Pianists should parallel this pattern by responding differently to familiar piano movements and unfamiliar violin movements. Overall, the general pattern of motor region activation should be comparable among violinists and pianists when compared to the non-musician control group. With diverse levels of experience, non-musicians and amateur musicians should show increased activation of the prefrontal and motor areas compared to professional musicians.

The second hypothesis expects that while musicians imagine only the sounds of the music from both instruments, the prefrontal and motor regions related to music imagery, will be highly active. As previously mentioned in Chapter 2, music imagery does not solely depend which instrument produces the music, rather, it depends on imagining the sounds of the music. In particular, violinists should show increased activation during the imagination conditions of both instruments compared to the perceptual baseline condition. Likewise, pianists should reveal areas of heightened activation in the motor and prefrontal areas for music imagery while imagining the musical sounds of both instruments. Non-musicians should show great differences in activation between the music and motor imagery tasks compared to the pianists and violinists. The music imagery tasks are expected to reveal less variation in brain activity among the violinists and pianists, but greater variation in activity in non-musicians.

Naturally, individual differences in specific activation levels will arise, particularly when analyzing differences in the motor imagery tasks. This variation will be even more apparent when correlated with the number of years playing a primary instrument and the total amount of musical experience.

5. DATA ANALYSIS

5.1. PREPROCESSING

All NIRS data was pre-processed through Homer2 software (Huppert, 2009). Each condition provided raw data of hemoglobin concentration changes throughout the course of the experiment. The data was processed into three groups through Homer2: individual data from single runs, session data from multiple runs of one individual, and group data between various individuals.

The raw data was first segmented with stimulus marks in Homer2 to distinguish the conditions within each run. The data was then processed with a low bandpass filter (LPF) of 0.5. This filter was employed in order to eliminate noise from environmental, physiological, physical, or instrumental elements (such as cardiac signals) resulting in a smoother depiction of the hemodynamic response (Huppert, 2009). After applying the filter, the data was processed as a hemodynamic response function (HRF) session, which averaged the data of multiple runs from one individual. The third type of data processing involved group data, which was produced by averaging multiple individual data of the represented group.

The overall HbO and HbR averages were calculated for all sources for the three groups, as displayed on the following graphs in the results section. Then, the HbO and HbR data were averaged together, to produce a mean of each group's total activity response in each pair of sources. The results show the changes of oxygenated (HbO) and deoxygenated (HbR) hemoglobin in the motor cortex for the three groups (non-musicians, pianists, and violinists) while participants were exposed to the piano and violin runs for the four conditions: baseline, motor imagery (MOI), music imagery (MUI), and motor and music imagery (MMI).

The data was then analyzed using the Statistical Package for Psychological Sciences (SPSS). A one-way analysis of variance (ANOVA) was conducted to compare the effects of imagery type on each group (non-musicians, pianists, and violinists). The ANOVA results will be provided in tables after the HbO and HbR figures in the subsequent sections.

5.2. MOTOR AREAS

Figure 8 shows the motor array source locations. Sources were recorded two by two: 5-21, 6-7, 6-22, 7-8, 7-23, 8-23.

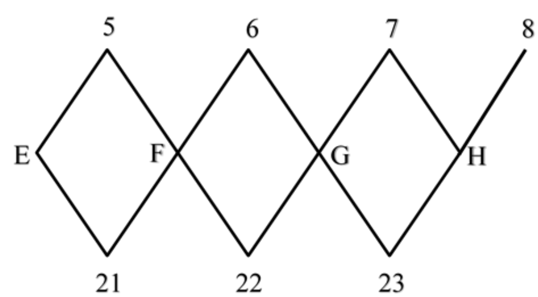


FIGURE 8. MOTOR ARRAY SOURCES

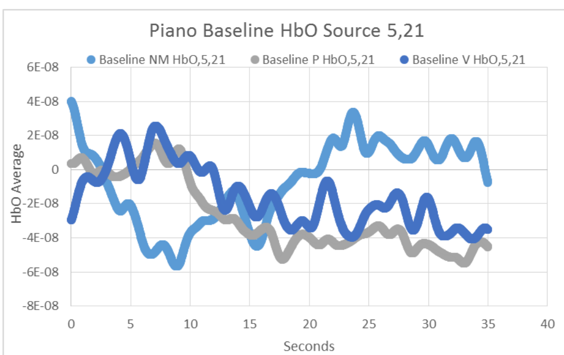
The source pairs covered the motor areas of the right hemisphere. The detectors (E, F, G, H) sensed the signals sent from the sources. Sources 5-21 and 6-22 covered the primary motor areas, while the other sources, 6-7, 7-8, 7-23, and 8-23 covered the secondary motor areas. The HbO and HbR results for all pairs of sources in all groups are presented in the following section.

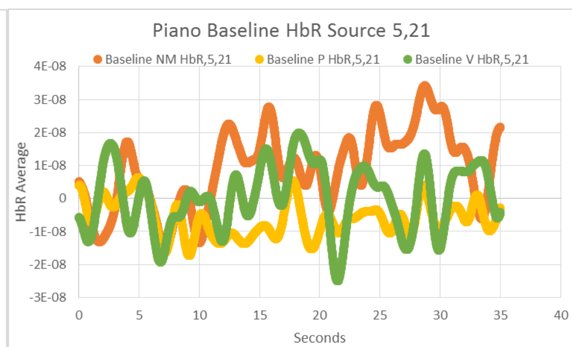
6. RESULTS

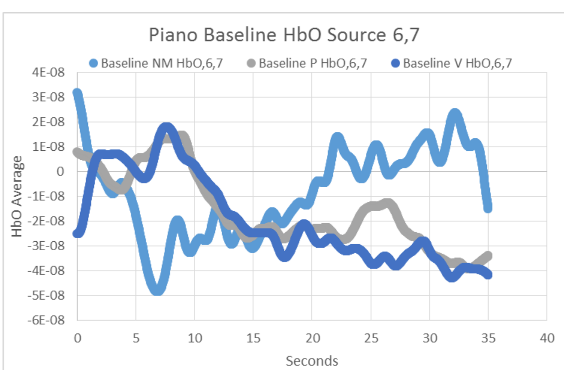
6.1. PIANO RUNS

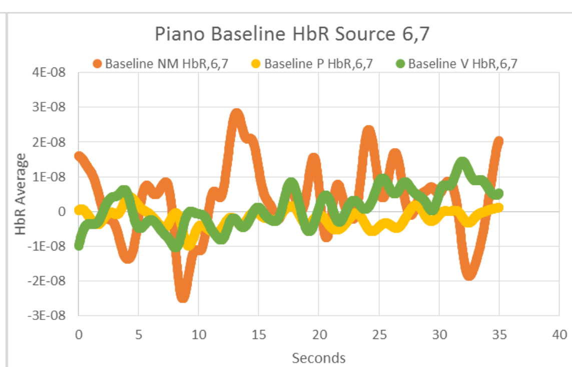
The piano runs were compared for each pair of sources for HbO and HbR over the motor area for the three groups and the four conditions. A one-way analysis of variance (ANOVA) was conducted to compare the effects of piano imagery type on each group (non-musicians, pianists, and violinists).

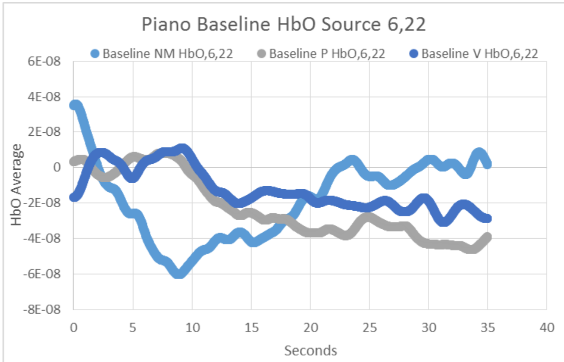
6.1.1. Baseline



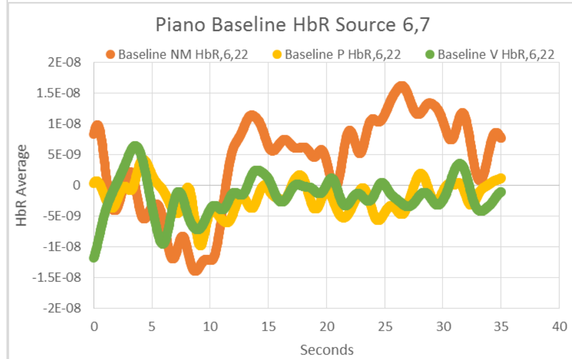




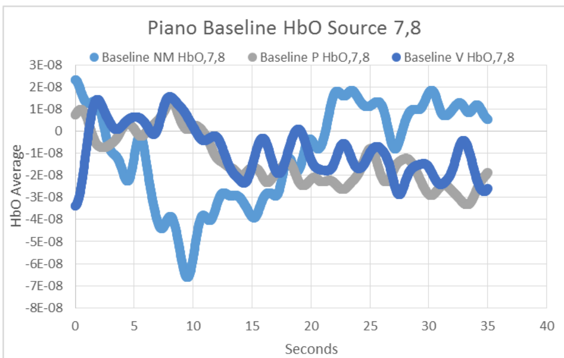




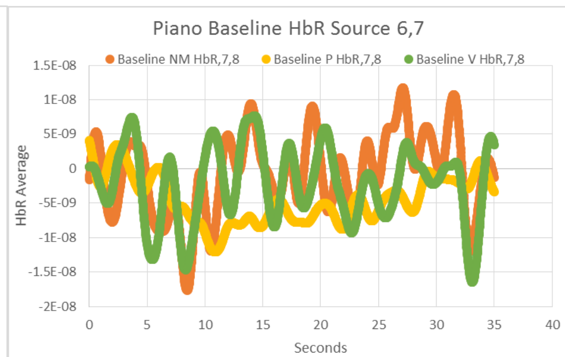
Piano Baseline HbO Source 6,22
Baseline NM HbO,6,22
Baseline P HbO,6,22
Baseline V HbO,6,22
HbO Average
Seconds



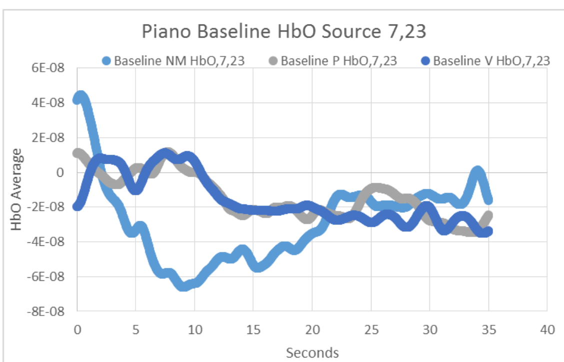
Piano Baseline HbR Source 6,7
Baseline NM HbR,6,22
Baseline P HbR,6,22
Baseline V HbR,6,22
HbR Average
Seconds



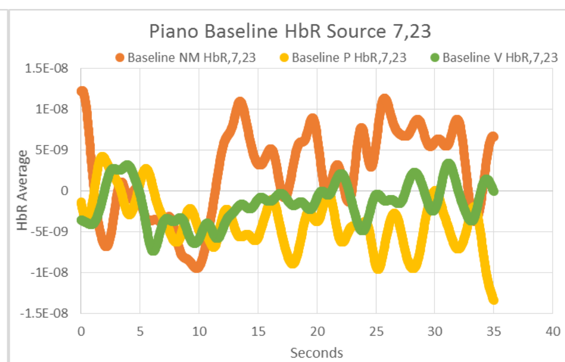
Piano Baseline HbO Source 7,8
Baseline NM HbO,7,8
Baseline P HbO,7,8
Baseline V HbO,7,8
HbO Average
Seconds



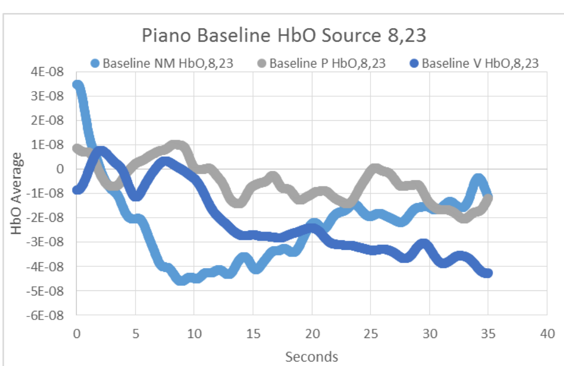
Piano Baseline HbR Source 6,7
Baseline NM HbR,7,8
Baseline P HbR,7,8
Baseline V HbR,7,8
HbR Average
Seconds



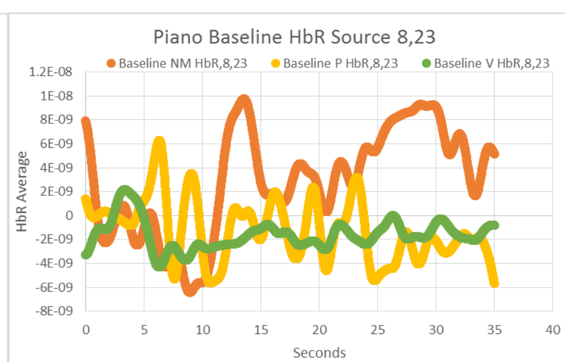
Piano Baseline HbO Source 7,23
Baseline NM HbO,7,23
Baseline P HbO,7,23
Baseline V HbO,7,23
HbO Average
Seconds



Piano Baseline HbR Source 7,23
Baseline NM HbR,7,23
Baseline P HbR,7,23
Baseline V HbR,7,23
HbR Average
Seconds



Piano Baseline HbO Source 8,23
Baseline NM HbO,8,23
Baseline P HbO,8,23
Baseline V HbO,8,23
HbO Average
Seconds



Piano Baseline HbR Source 8,23
Baseline NM HbR,8,23
Baseline P HbR,8,23
Baseline V HbR,8,23
HbR Average
Seconds

FIGURE 9. BASELINE CONDITIONS FOR BOTH HBO (LEFT) AND HBR (RIGHT) FOR THE THREE GROUPS: NON-MUSICIANS (NM), VIOLINISTS (V), AND PIANISTS (P) FOR SOURCES 5-21, 6-7, 6-22, 7-23, AND 8-23

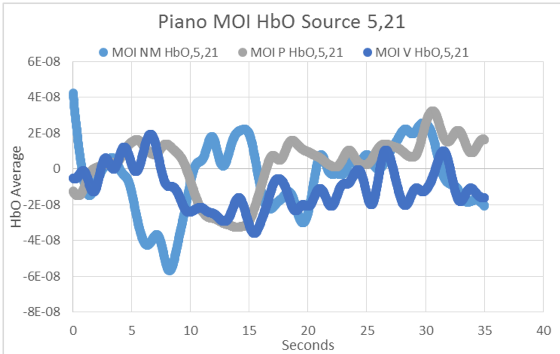
Figure 9 shows that for the baseline condition, there was an increase in HbO for both P and V groups, and a decrease for the NM group in the first 15 seconds. This trend was reversed for the last 15 seconds, with a decrease in HbO for both V and P, and an increase for NM. HbR responses are steady for both P and V and varies for NM.

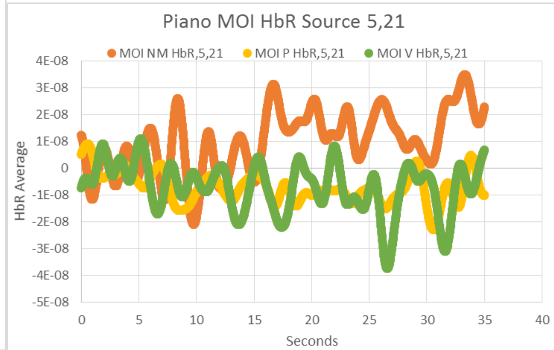
Table 2 below displays the one-way ANOVA results as performed on each pair of sources. The one-way ANOVA revealed significant differences among all groups at five source pairs during the 5 to 15 second interval, and the Bonferroni post-hoc tests also showed that all groups were significantly different from one another. The ANOVA also revealed significant differences among specific groups in source 6-7, with pairwise comparisons revealing significant differences between the non-musicians and pianists, and non-musicians and violinists, but not between the pianists and violinists.

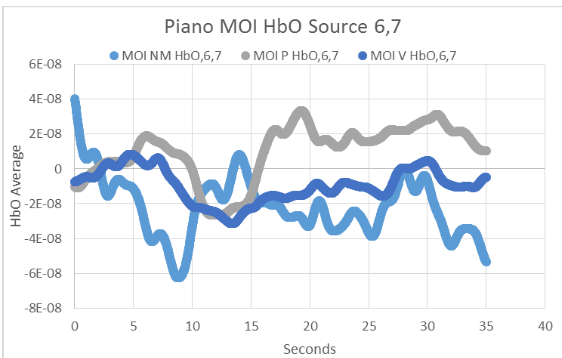
Source	**ANOVA Results**	**Pairwise Comparisons**
5-21	$F(2, 1000) = 242$, $p < .001$, $\eta^2 = .33$	All groups ($p < .001$)
6-7	$F(2, 1000) = 203$, $p < .001$, $\eta^2 = .29$	NM + P ($p < .001$) NM + V ($p < .001$) P + V (no significant difference)
6-22	$F(2, 1000) = 62.8$, $p < .001$, $\eta^2 = .11$	All groups ($p < .001$)
7-8	$F(2, 1000) = 269$, $p < .001$, $\eta^2 = .35$	All groups ($p < .001$)
7-23	$F(2, 1000) = 27.9$, $p < .001$, $\eta^2 = .05$	All groups ($p < .001$)
8-23	$F(2, 1000) = 571$, $p < .001$, $\eta^2 = .52$	All groups ($p < .001$)

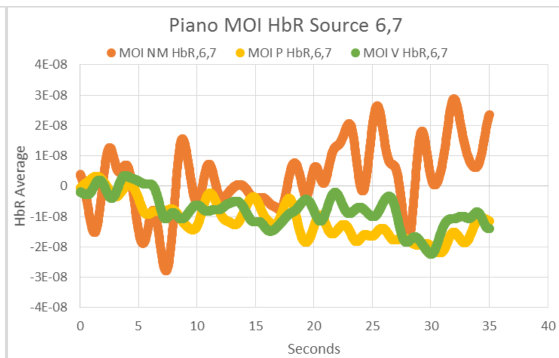
TABLE 2 ANOVA RESULTS FOR PIANO BASELINE

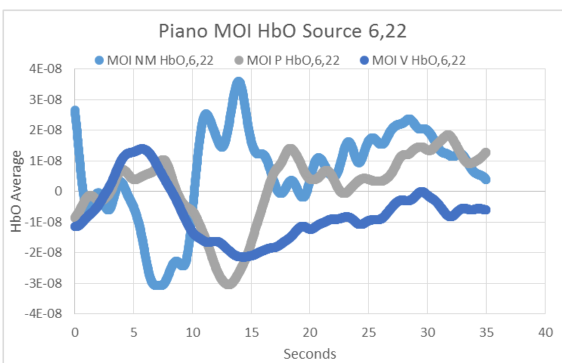
6.1.2. Motor Imagery (MOI)

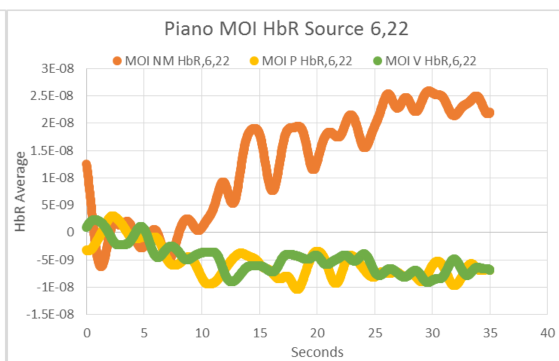


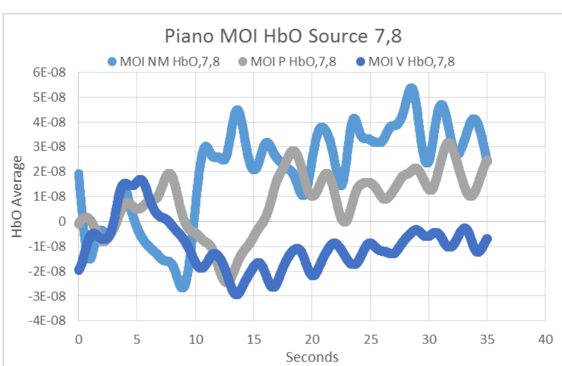


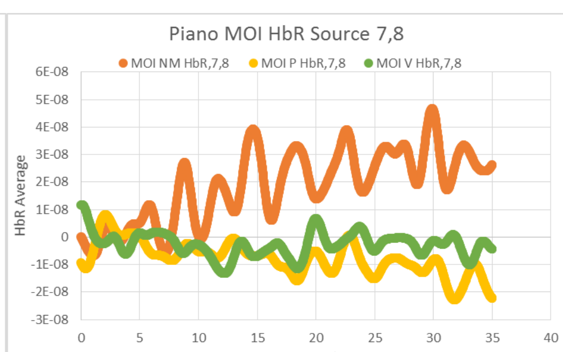












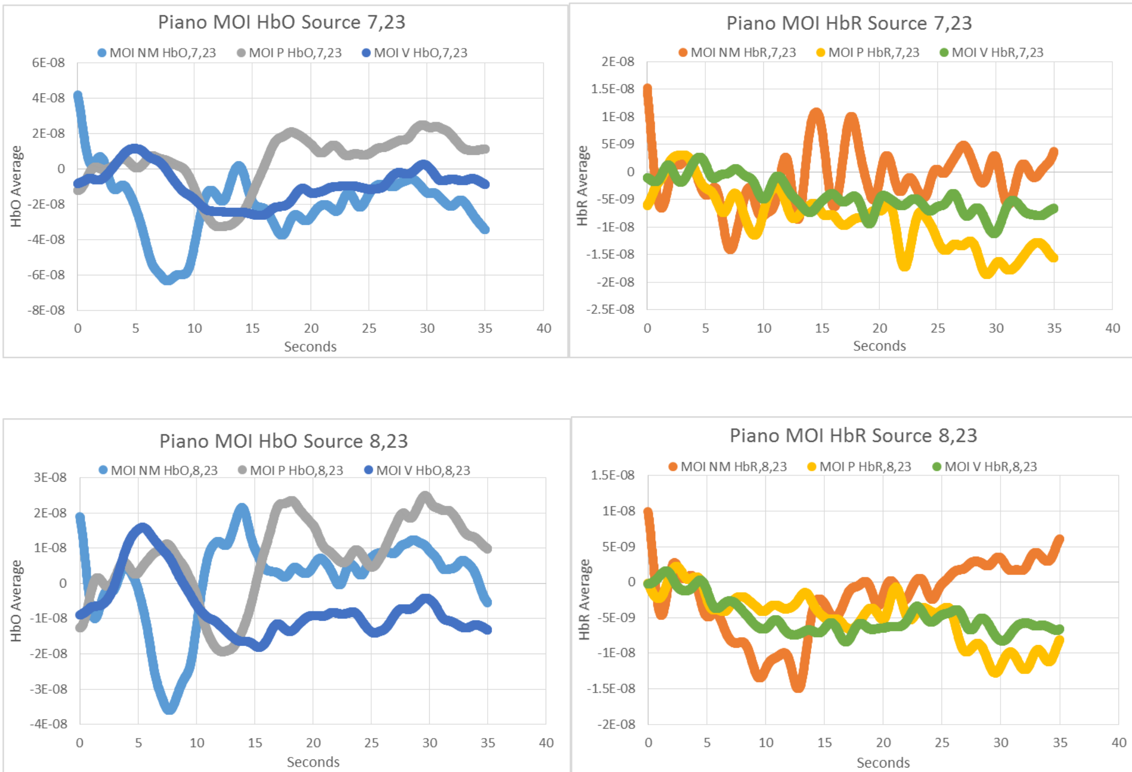


Figure 10. Piano motor imagery conditions for both HbO (left) and HbR (right) for the three groups: non-musicians (NM), violinists (V), and pianists (P) for sources 5-21, 6-7, 6-22, 7-23, and 8-23

Figure 10 reveals that in the motor imagery conditions, P and V groups show a positive peak around 5 seconds followed by a negative peak around 12 seconds in HbO. There is a continued increase in HbO for group V with a positive peak around 15 seconds, the HbO response then becomes relatively steady for the remaining period. A similar trend is seen in the P group, where there in an increase in HbO with a positive peak around 18 seconds, followed by generally stable activity. The NM group displays an opposite trend with a negative peak around 5 seconds, followed by a positive peak around 12 seconds, and varied activity for the remainder of the condition. HbR activity parallel HbO levels, as tested over the full condition period of 35 seconds for both P and V groups, while HbR levels vary for NM.

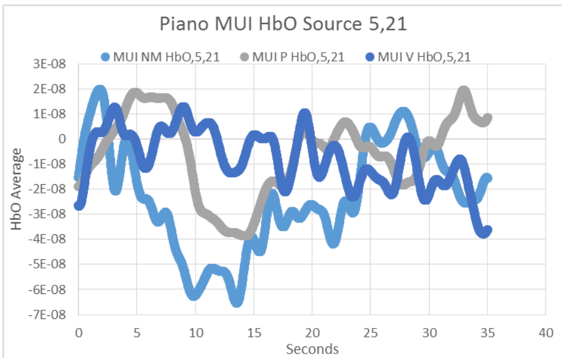
The data also show that violinists and pianists begi imagining piano movements in a similar fashion, but the trend changes halfway through the condition. A possible explanation for this is that violinists could no longer accurately imagine the piano movements after 15 seconds, likely due to the synchronous nature of the two hands, and found this imagery task to be more difficult than the pianists. Pianists, however, easily imagined the movements of their instrument, as illustrated by the trends in data.

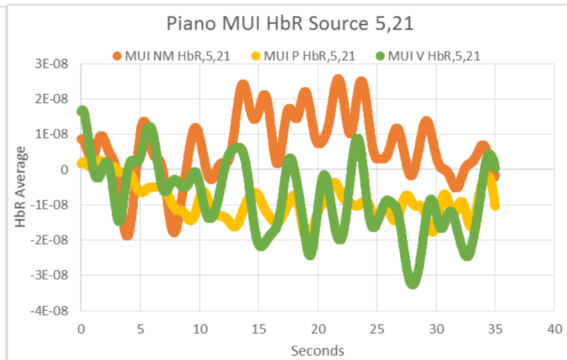
Source	**ANOVA Results**	**Pairwise Comparisons**
5-21	$F(2, 1000) = 17.1, p < .001, \eta^2 = .03$	NM + P ($p = .034$) NM + V ($p < .001$) P + V ($p < .001$)
6-7	$F(2, 1000) = 352, p < .001, \eta^2 = .41$	All groups ($p < .001$)
6-22	$F(2, 1000) = 79.8, p < .001, \eta^2 = .14$	All groups ($p < .001$)
7-8	$F(2, 1000) = 288, p < .001, \eta^2 = .37$	All groups ($p < .001$)
7-23	$F(2, 1000) = 273, p < .001, \eta^2 = .35$	All groups ($p < .001$)
8-23	$F(2, 1000) = 123, p < .001, \eta^2 = .20$	All groups ($p < .001$)

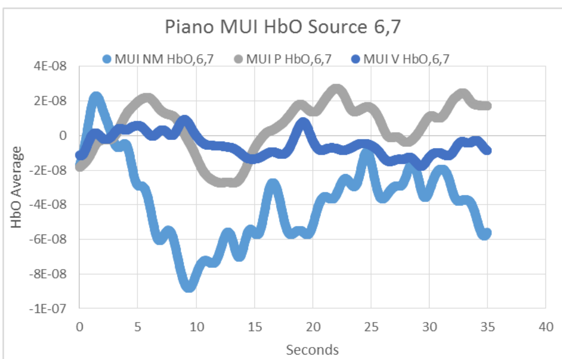
TABLE 3 ANOVA RESULTS FOR PIANO MOTOR IMAGERY

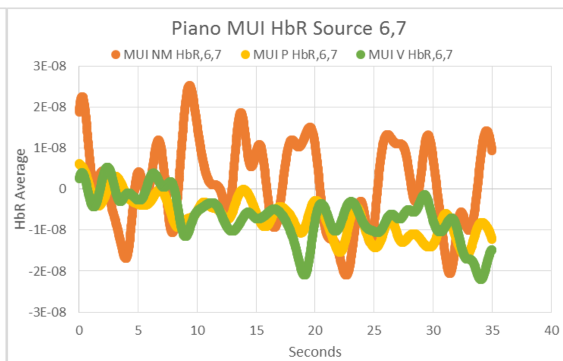
Table 3 displays the one-way ANOVA results as performed on each pair of sources among the three groups (non-musicians, pianists, and violinists) during the piano motor imagery condition from the 5 to 15 second interval. The ANOVA revealed significant differences among all groups at each pair of sources. In addition, source 5-22 showed the most variation, as pairwise comparisons revealed slight differences in significance levels between non-musicians and pianists ($p = .034$), non-musicians and violinists ($p < .001$), and pianists and violinists ($p < .001$).

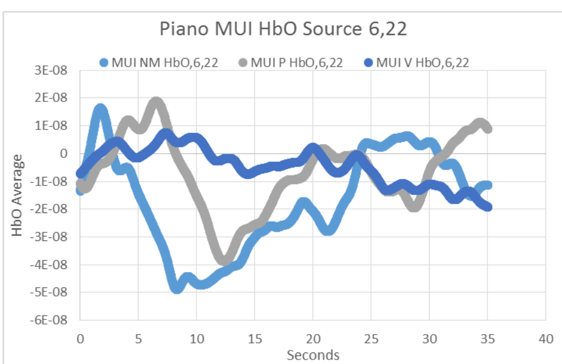
6.1.3. Music Imagery (MUI)

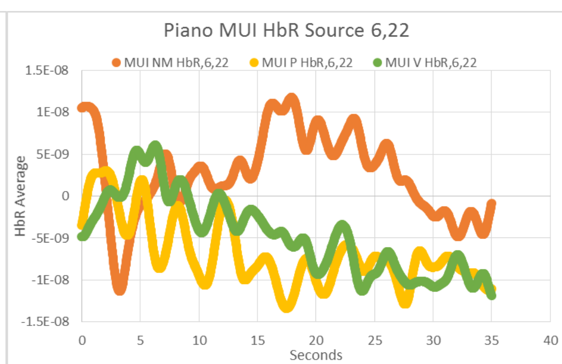












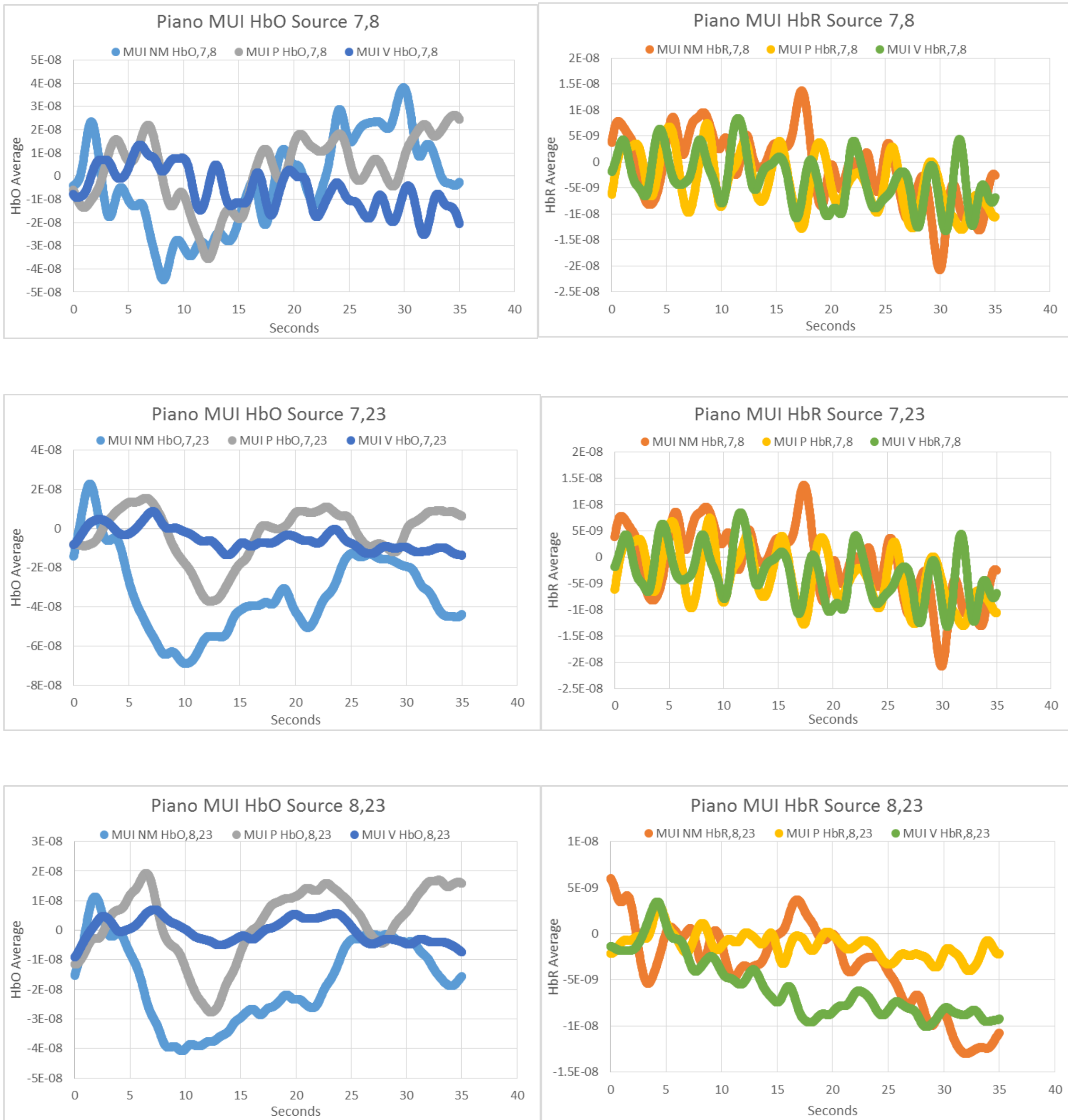


FIGURE 11. PIANO MUSIC IMAGERY CONDITIONS FOR BOTH HBO (LEFT) AND HBR (RIGHT) FOR THE THREE GROUPS: NON-MUSICIANS (NM), VIOLINISTS (V), AND PIANISTS (P) FOR SOURCES 5-21, 6-7, 6-22, 7-23, AND 8-23

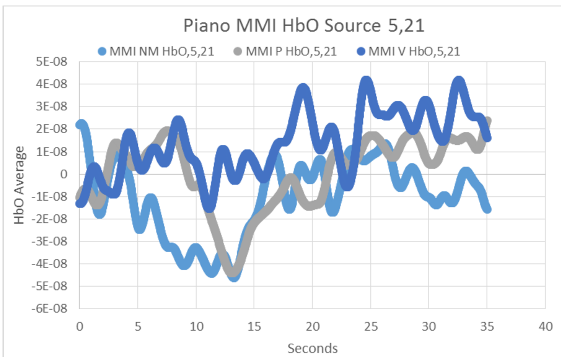
Figure 11 shows that in the music imagery conditions, both P and NM groups HbO responses follow the same trend. Group P shows a sinusoidal response with a positive peak of higher amplitude and frequency around 7 seconds, as opposed to group NM which has a narrower peak at around 2 seconds. This response is followed by a negative peak of lower amplitude around 12 seconds for group P, and a larger negative peak around 10 seconds for group NM. A third positive period with a peak around 22 seconds is observed in group P, while this peak arrives much later, around 27 seconds, for group NM. HbO response in group V is constant and steady for the tested period, while NM and P groups have similar HbO variations. HbR levels show an opposite trend as HbO, revealing the most fluctuation in group NM and more stabilized activity in groups V and P.

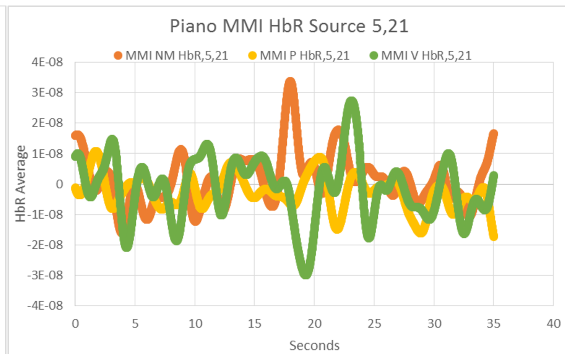
Source	**ANOVA Results**	**Pairwise Comparisons**
5-21	$F(2, 1000) = 39.5, p < .001, \eta^2 = .07$	All groups ($p < .001$)
6-7	$F(2, 1000) = 31.7, p < .001, \eta^2 = .06$	NM + P ($p < .001$) NM + V (no significant difference) P + V ($p < .001$)
6-22	$F(2, 1000) = 1607, p < .001, \eta^2 = .76$	All groups ($p < .001$)
7-8	$F(2, 1000) = 1113, p < .001, \eta^2 = .69$	All groups ($p < .001$)
7-23	$F(2, 1000) = 199, p < .001, \eta^2 = .29$	All groups ($p < .001$)
8-23	$F(2, 1000) = 174, p < .001, \eta^2 = .25$	NM + P ($p < .001$) NM +V (no significant difference) P + V ($p < .001$)

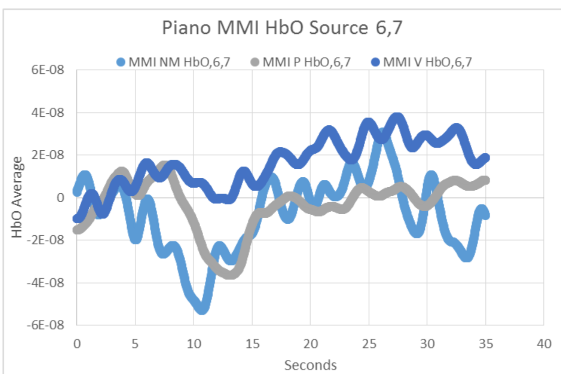
TABLE 4 ANOVA RESULTS FOR PIANO MUSIC IMAGERY

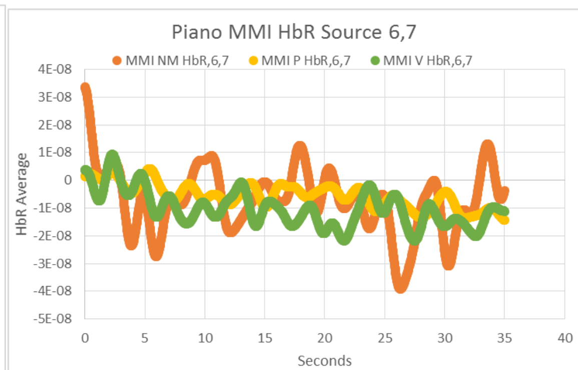
Table 4 displays the one-way ANOVA results as performed on each pair of sources for the three groups (non-musicians, pianists, and violinists) during the piano music imagery condition from the 5 to 15 second interval. The ANOVA illustrates significant differences among all groups in several pairs of sources: 5-22, 6-22, 7-8, and 7-23. The ANOVA also indicated significant differences among specific groups in source 6-7; pairwise comparisons revealed significant differences between the non-musicians and pianists, and pianists and violinists, but not between the non-musicians and violinists. The ANOVA also showed significant differences among different groups in sources 8-23; pairwise comparisons again showed significant differences between the non-musicians and pianists, and pianists and violinists, but not between the non-musicians and violinists.

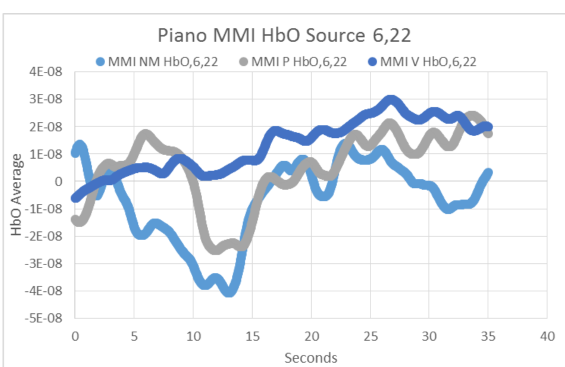
6.1.4. Motor Imagery and Music Imagery (MMI)

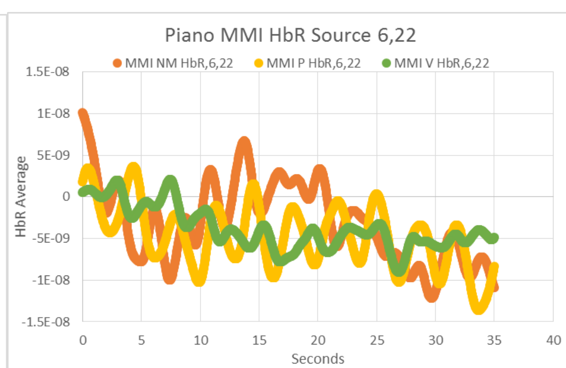












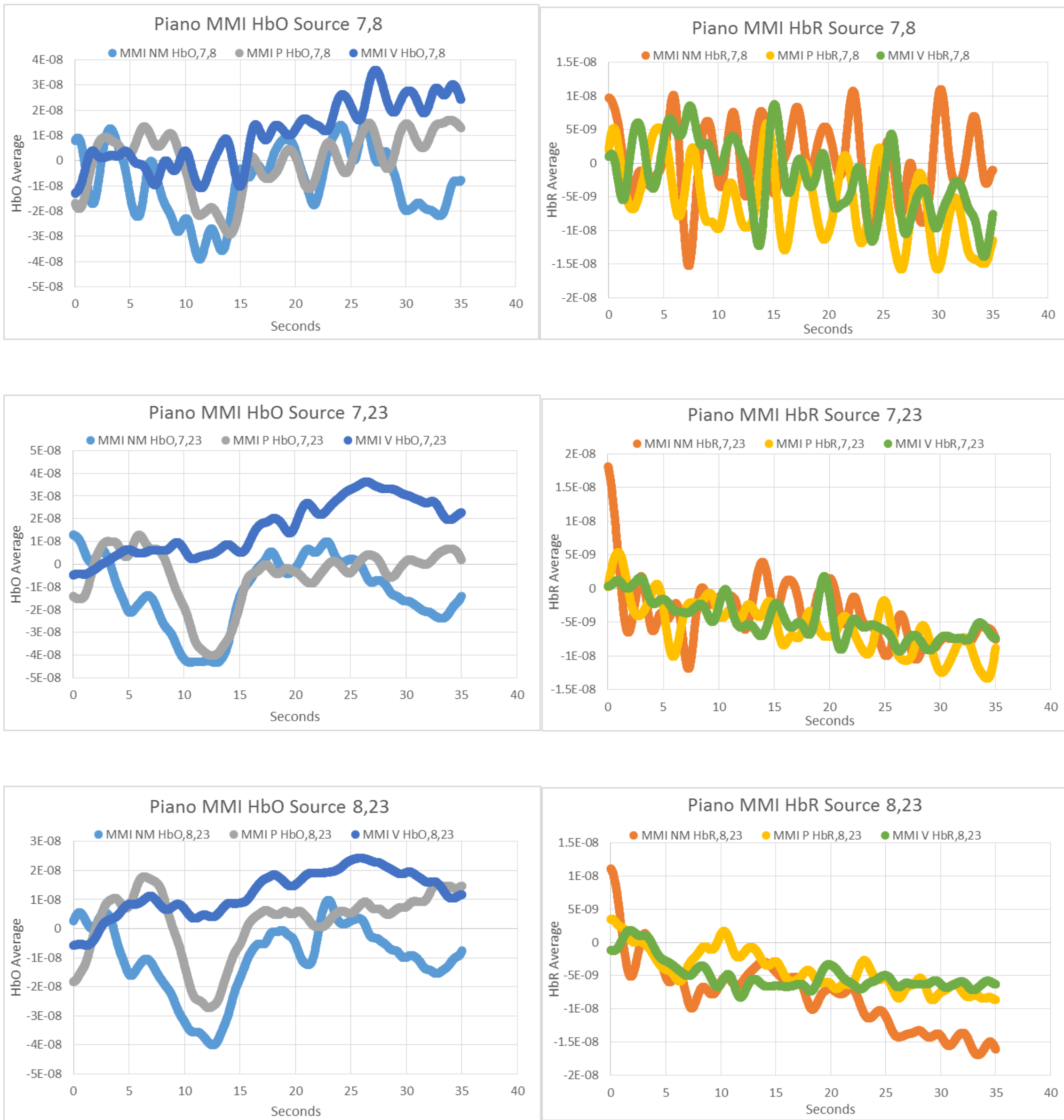


Figure 12. Piano motor and music imagery conditions for both HbO (left) and HbR (right) for the three groups: non-musicians (NM), violinists (V), and pianists (P) for sources 5-21, 6-7, 6-22, 7-23, and 8-23

Figure 12 shows that the motor imagery and music imagery condition is similar to the motor imagery condition in P and NM groups, and follows the same trend; while the V group displays a more stabilized and constant response for HbO. NM and P groups have similar HbO patterns compared to group V. HbR responses are steady for the three groups with no apparent significant differences.

Table 5 below displays the one-way ANOVA results as performed on each source pair for the three groups (non-musicians, pianists, and violinists) during the piano motor and music imagery condition from the 5 to 15 second interval. The ANOVA revealed significant differences among all groups for all pairs of sources. Bonferroni post-hoc tests confirmed the significant differences among each of the groups.

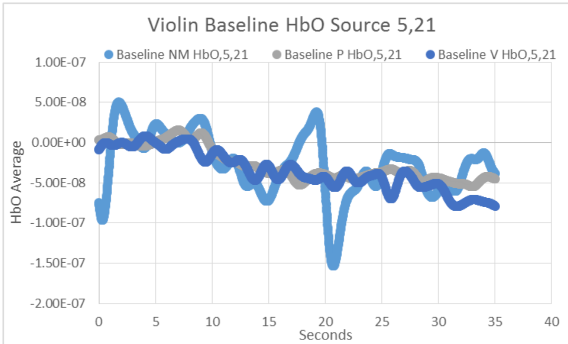
Source	**ANOVA Results**	**Pairwise Comparisons**
5-21	$F(2, 1000) = 1165, p < .001, \eta^2 = .70$	All groups ($p < .001$)
6-7	$F(2, 1000) = 282, p < .001, \eta^2 = .36$	All groups ($p < .001$)
6-22	$F(2, 1000) = 222, p < .001, \eta^2 = .31$	All groups ($p < .001$)
7-8	$F(2, 1000) = 884, p < .001, \eta^2 = .64$	All groups ($p < .001$)
7-23	$F(2, 1000) = 531, p < .001, \eta^2 = .52$	All groups ($p < .001$)
8-23	$F(2, 1000) = 172, p < .001, \eta^2 = .26$	All groups ($p < .001$)

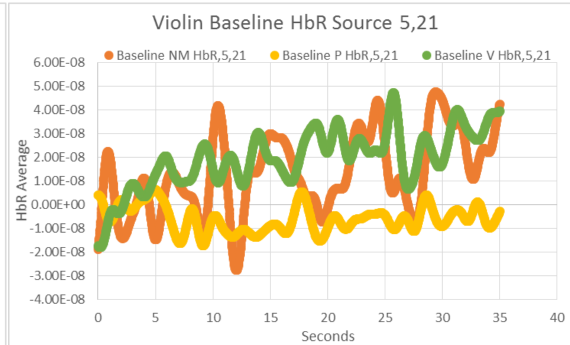
TABLE 5 ANOVA RESULTS FOR PIANO MOTOR AND MUSIC IMAGERY

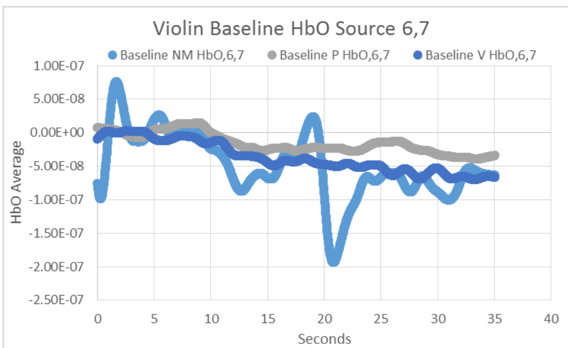
6.2. VIOLIN RUNS

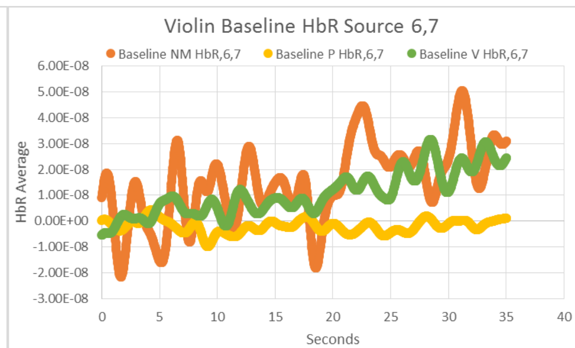
The violin runs were also compared among the three groups (non-musicians, pianists, and violinists) for HbO and HbR in each pair of sources over the motor areas for the conditions (baseline, motor imagery, music imagery, motor and music imagery). A one-way analysis of variance (ANOVA) was conducted to compare the effects of violin imagery type on each group (non-musicians, pianists, and violinists).

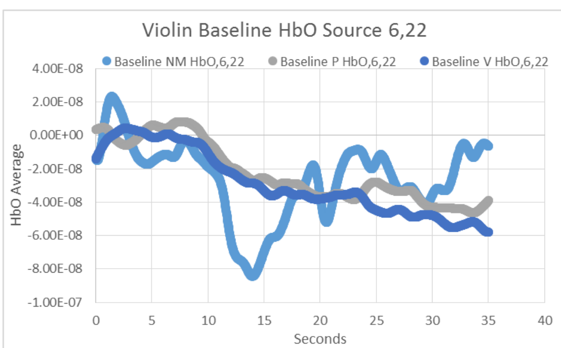
6.2.1. Baseline

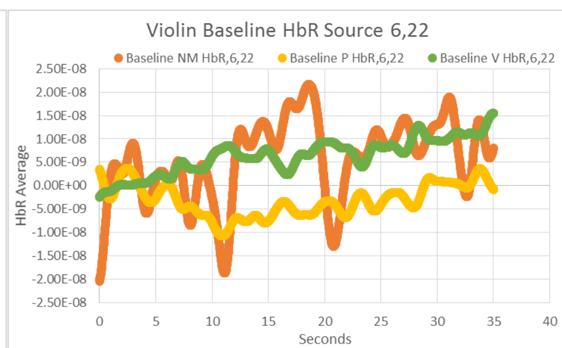


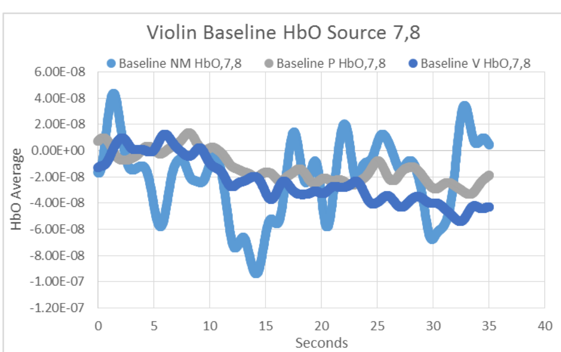


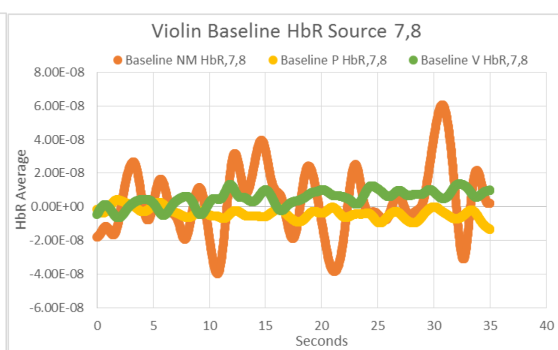












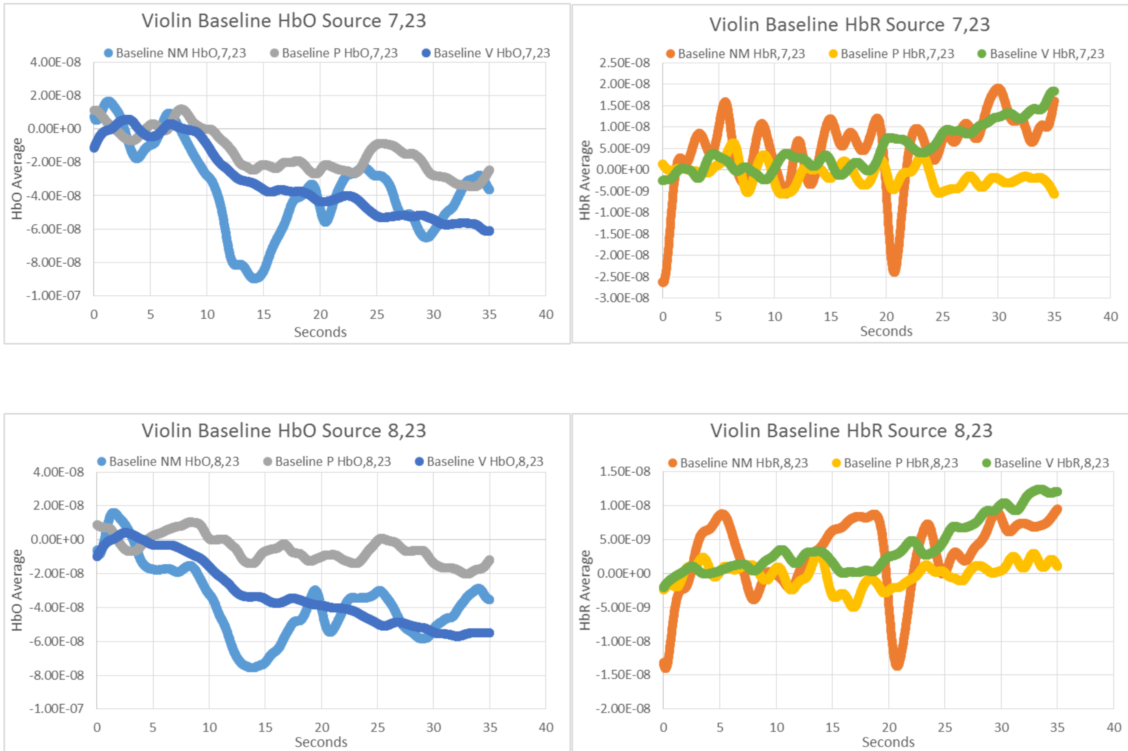


FIGURE 13. VIOLIN BASELINE CONDITIONS FOR BOTH HBO (LEFT) AND HBR (RIGHT) FOR THE THREE GROUPS: NON-MUSICIANS (NM), VIOLINISTS (V), AND PIANISTS (P) FOR SOURCES 5-21, 6-7, 6-22, 7-23, AND 8-23

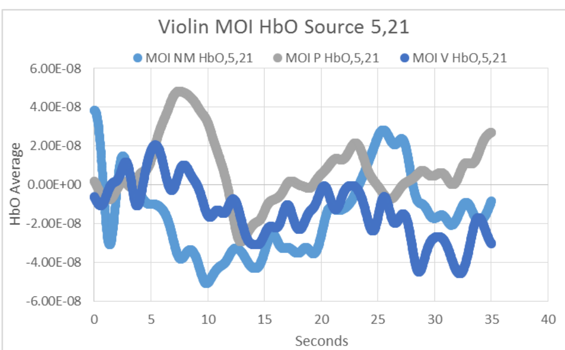
Figure 13 shows that for the violin baseline conditions, HbO was stable for the first 10 seconds in the P and V groups, decreased until 15 seconds, and then stabilized for the remainder of the condition. The NM group showed an opposite trend, with a positive peak at 2 seconds, followed by a sharp decrease in HbO until the 15 second mark. At 15 seconds, there is an increase in HbO activity in the NM group until it peaks at 19 seconds, and sharply decreases at 20 seconds. There is another increase in HbO activity until 25 seconds, with a decrease at 30 seconds, followed by an increase until 35 seconds. The HbR responses for both P and V groups were steady over the 35 seconds, while the NM group varied.

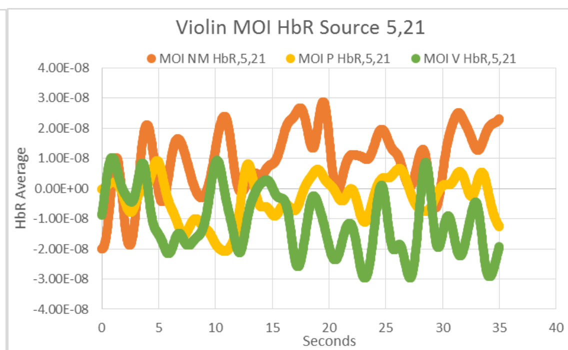
Table 6 below depicts the one-way ANOVA results as performed on each pair of sources for all groups (non-musicians, pianists, violinists) in the violin baseline condition during the 5 to 15 second interval. The ANOVA revealed significant differences among all groups for all pairs of sources, confirmed by Bonferroni post-hoc tests.

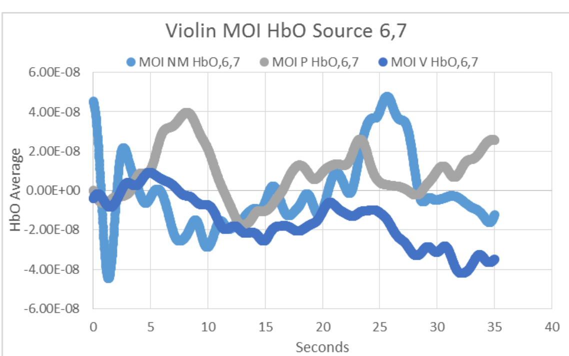
Source	ANOVA Results	Pairwise Comparisons
5-22	$F(2, 1000) = 433, p < .001, \eta^2 = .46$	All groups ($p < .001$)
6-7	$F(2, 1000) = 106, p < .001, \eta^2 = .18$	All groups ($p < .001$)
6-22	$F(2, 1000) = 1368, p < .001, \eta^2 = .73$	All groups ($p < .001$)
7-8	$F(2, 1000) = 49.7, p < .001, \eta^2 = .09$	All groups ($p < .001$)
7-23	$F(2, 1000) = 532, p < .001, \eta^2 = .52$	All groups ($p < .001$)
8-23	$F(2, 1000) = 2678, p < .001, \eta^2 = .84$	All groups ($p < .001$)

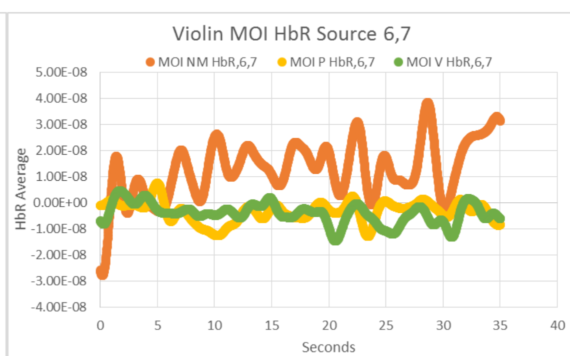
TABLE 6 ANOVA RESULTS FOR VIOLIN BASELINE

6.2.2. Motor Imagery (MOI)









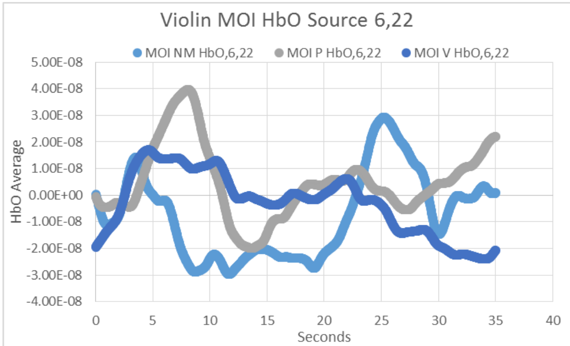
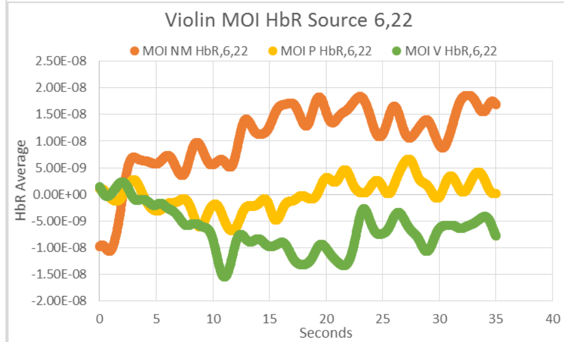
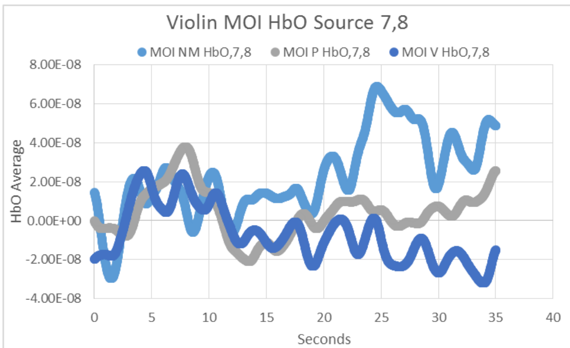
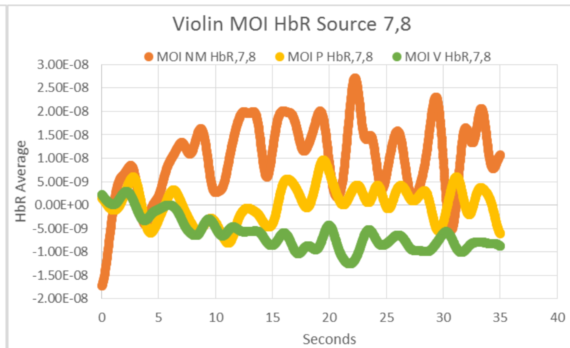
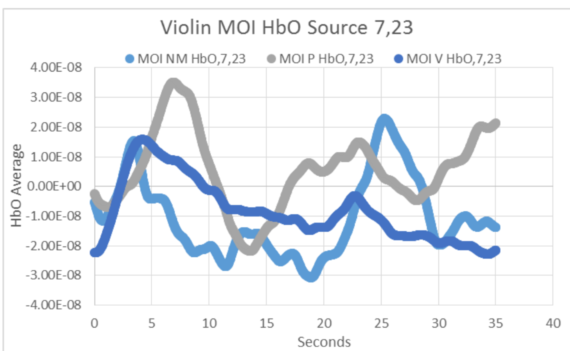
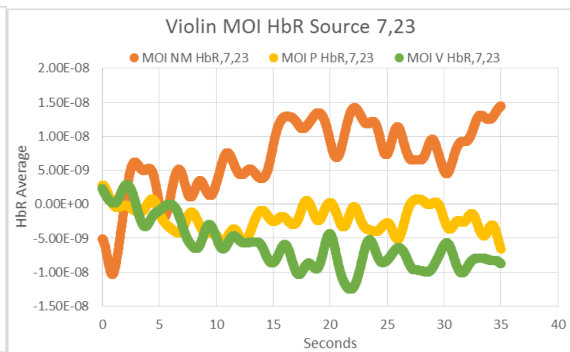
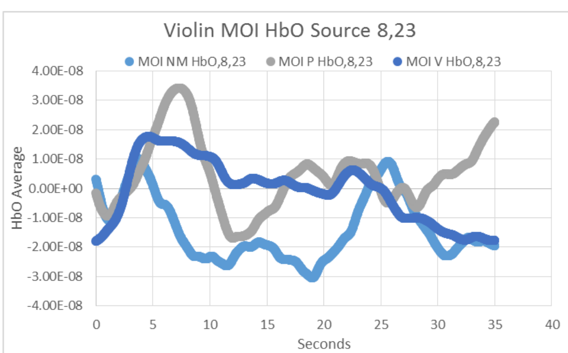
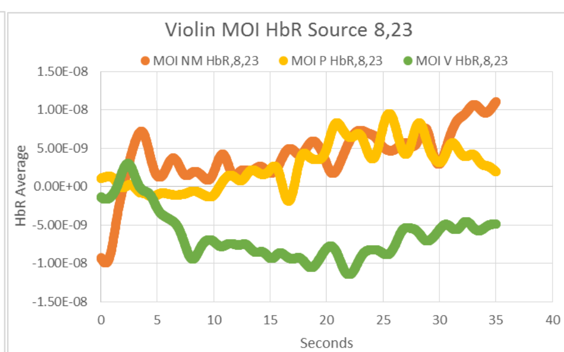

Violin MOI HbO Source 6,22
MOI NM HbO,6,22
MOI P HbO,6,22
MOI V HbO,6,22
5.00E-08 4.00E-08 3.00E-08 2.00E-08 1.00E-08 0.00E+00 -1.00E-08 -2.00E-08 -3.00E-08 -4.00E-08
HbO Average
0 5 10 15 20 25 30 35 40
Seconds

Violin MOI HbR Source 6,22
MOI NM HbR,6,22
MOI P HbR,6,22
MOI V HbR,6,22
2.50E-08 2.00E-08 1.50E-08 1.00E-08 5.00E-09 0.00E+00 -5.00E-09 -1.00E-08 -1.50E-08 -2.00E-08
HbR Average
0 5 10 15 20 25 30 35 40
Seconds

Violin MOI HbO Source 7,8
MOI NM HbO,7,8
MOI P HbO,7,8
MOI V HbO,7,8
8.00E-08 6.00E-08 4.00E-08 2.00E-08 0.00E+00 -2.00E-08 -4.00E-08
HbO Average
0 5 10 15 20 25 30 35 40
Seconds

Violin MOI HbR Source 7,8
MOI NM HbR,7,8
MOI P HbR,7,8
MOI V HbR,7,8
3.00E-08 2.50E-08 2.00E-08 1.50E-08 1.00E-08 5.00E-09 0.00E+00 -5.00E-09 -1.00E-08 -1.50E-08 -2.00E-08
HbR Average
0 5 10 15 20 25 30 35 40
Seconds

Violin MOI HbO Source 7,23
MOI NM HbO,7,23
MOI P HbO,7,23
MOI V HbO,7,23
4.00E-08 3.00E-08 2.00E-08 1.00E-08 0.00E+00 -1.00E-08 -2.00E-08 -3.00E-08 -4.00E-08
HbO Average
0 5 10 15 20 25 30 35 40
Seconds

Violin MOI HbR Source 7,23
MOI NM HbR,7,23
MOI P HbR,7,23
MOI V HbR,7,23
2.00E-08 1.50E-08 1.00E-08 5.00E-09 0.00E+00 -5.00E-09 -1.00E-08 -1.50E-08
HbR Average
0 5 10 15 20 25 30 35 40
Seconds

Violin MOI HbO Source 8,23
MOI NM HbO,8,23
MOI P HbO,8,23
MOI V HbO,8,23
4.00E-08 3.00E-08 2.00E-08 1.00E-08 0.00E+00 -1.00E-08 -2.00E-08 -3.00E-08 -4.00E-08
HbO Average
0 5 10 15 20 25 30 35 40
Seconds

Violin MOI HbR Source 8,23
MOI NM HbR,8,23
MOI P HbR,8,23
MOI V HbR,8,23
1.50E-08 1.00E-08 5.00E-09 0.00E+00 -5.00E-09 -1.00E-08 -1.50E-08
HbR Average
0 5 10 15 20 25 30 35 40
Seconds

FIGURE 14. VIOLIN MOTOR IMAGERY CONDITIONS FOR BOTH HBO (LEFT) AND HBR (RIGHT) FOR THE THREE GROUPS: NON-MUSICIANS (NM), VIOLINISTS (V), AND PIANISTS (P) FOR SOURCES 5-21, 6-7, 6-22, 7-23, AND 8-23

Figure 14 illustrates that in the violin motor imagery conditions, NM and V groups show a positive peak around 5 seconds for HbO activity, and a positive peak around 8 seconds for the P group. These activity peaks are followed by a decrease in HbO until about 12 seconds for group NM, 13 seconds for group P, and 20 seconds for group V, followed by varied activity. At 28 seconds, P and V groups show inverse HbO activity, where activity in P is increases and activity in V is decreases. Group NM HbO activity fluctuates increases until a positive peak at 25 seconds, then decreases until the end of the condition. HbR activity parallels HbO levels for all groups, as tested over the full condition period of 35 seconds.

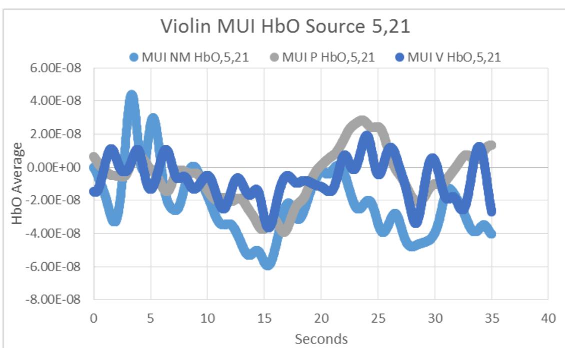
The data also show that violinists and pianists begin imagining the violin movements in a similar fashion, but the trend changes 5 seconds into the condition. From 5 seconds onward, violinists' activity stabilizes, while pianists' activity further increases and fluctuates, but continues to mirror the violinists' patterns. Interestingly, this suggests that pianists seem to have a slightly more difficult time imagining violin movements than the violinists.

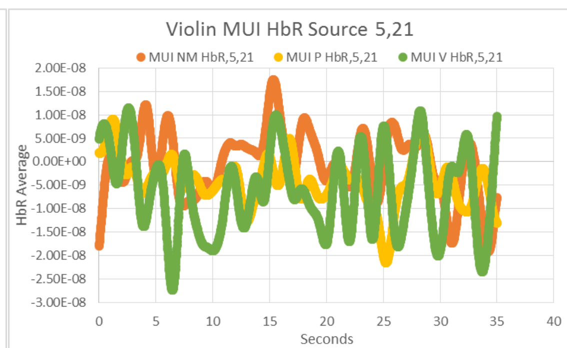
Table 7 below displays the one-way ANOVA results as performed on each source pair for the three groups (non-musicians, pianists, and violinists) during the violin motor imagery condition from the 5 to 15 second interval. The ANOVA showed significant differences among all groups for all pairs of sources, as confirmed by Bonferroni post-hoc tests.

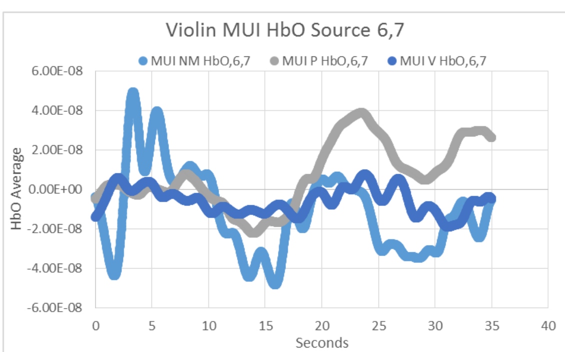
Source	ANOVA Results	Pairwise Comparisons
5-21	$F(2, 1000) = 2996$, $p < .001$, $\eta^2 = .86$	All groups ($p < .001$)
6-7	$F(2, 1000) = 278$, $p < .001$, $\eta^2 = .36$	All groups ($p < .001$)
6-22	$F(2, 1000) = 317$, $p < .001$, $\eta^2 = .39$	All groups ($p < .001$)
7-8	$F(2, 1000) = 597$, $p < .001$, $\eta^2 = .54$	All groups ($p < .001$)
7-23	$F(2, 1000) = 308$, $p < .001$, $\eta^2 = .38$	All groups ($p < .001$)
8-23	$F(2, 1000) = 1008$, $p < .001$, $\eta^2 = .67$	All groups ($p < .001$)

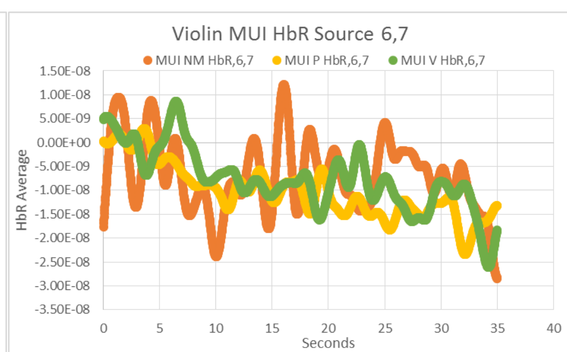
TABLE 7 ANOVA RESULTS FOR VIOLIN MOTOR IMAGERY

6.2.3. Music Imagery (MUI)









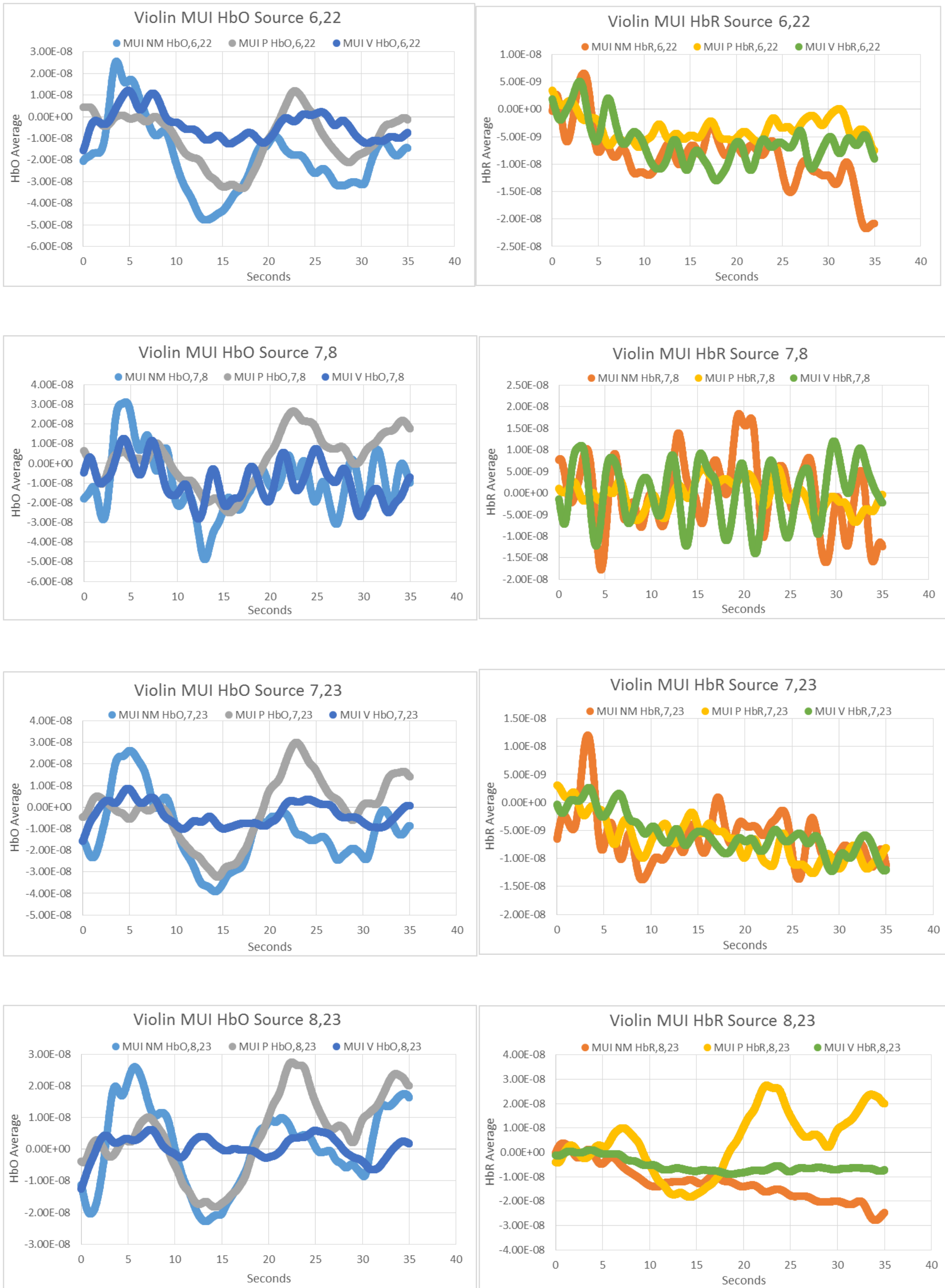


FIGURE 15. VIOLIN MUSIC IMAGERY CONDITIONS FOR BOTH HBO (LEFT) AND HBR (RIGHT) FOR THE THREE GROUPS: NON-MUSICIANS (NM), VIOLINISTS (V), AND PIANISTS (P) FOR SOURCES 5-21, 6-7, 6-22, 7-23, AND 8-23

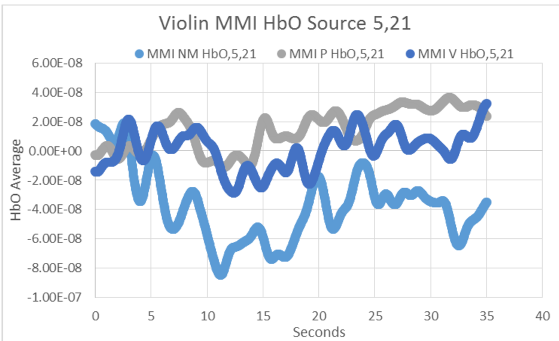
Figure 15 shows that in the violin music imagery conditions, both P and NM groups HbO responses follow a similar trend, but at different amplitudes. The NM group HbO responses fluctuate over the condition: peaking between 4-6 seconds, followed by a steep decrease in activity with a negative peak at 13-15 seconds, slight increase in activity up to 22 seconds, followed by a decrease in activity to 30 seconds, and an increase in activity for the last 5 seconds. Group P follows a similar trend in positive and negative peaks, but is less varied in activity level. Group V, on the other hand, remains quite stable throughout the condition. HbR levels show a general similar trend of varying activity for all groups, so it is difficult to draw a concrete conclusion.

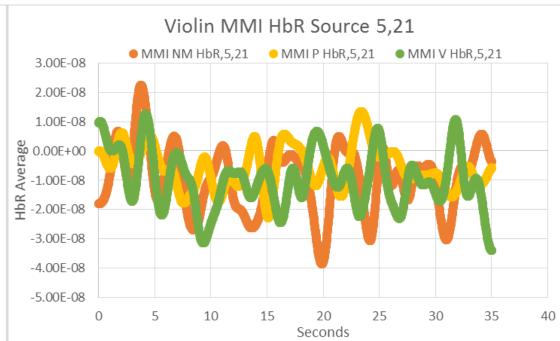
Source	**ANOVA Results**	**Pairwise Comparisons**
5-21	$F(2, 1000) = 29.3, p < .001, \eta^2 = .06$	All groups ($p < .001$)
6-7	$F(2, 1000) = 867, p < .001, \eta^2 = .63$	All groups ($p < .001$)
6-22	$F(2, 1000) = 1221, p < .001, \eta^2 = .71$	All groups ($p < .001$)
7-8	$F(2, 1000) = 123, p < .001, \eta^2 = .20$	All groups ($p < .001$)
7-23	$F(2, 1000) = 286, p < .001, \eta^2 = .36$	All groups ($p < .001$)
8-23	$F(2, 1000) = 80, p < .001, \eta^2 = .14$	NM + P (no significant difference) NM + V ($p < .001$) P + V ($p < .001$)

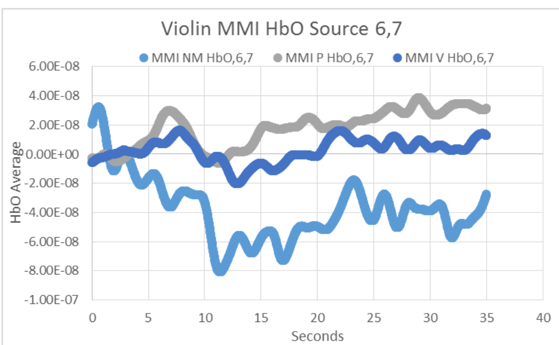
TABLE 8 ANOVA RESULTS FOR VIOLIN MUSIC IMAGERY

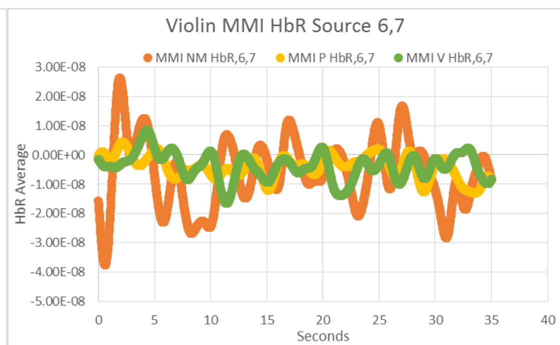
Table 8 displays the one-way ANOVA results as performed on each source pair for the three groups (non-musicians, pianists, and violinists) during the violin music imagery from the 5 to 15 second interval. The ANOVA indicated significant differences among all groups for 6 of the 7 source pairs: 5-21, 6-7, 6-22, 7-8, and 7-23. Source 8-23, in particular, revealed significant differences ($F(2, 1000) = 80$, $p < .001$, $\eta 2 = .14$) between the non-musicians and violinists, and pianists and violinists, but not between the non-musicians and pianists, as revealed by the pairwise comparisons.

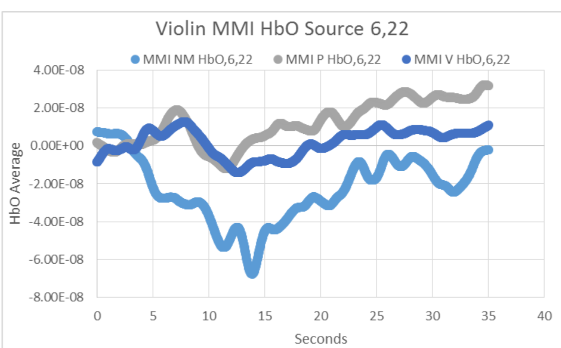
6.2.4. Motor and Music Imagery (MMI)

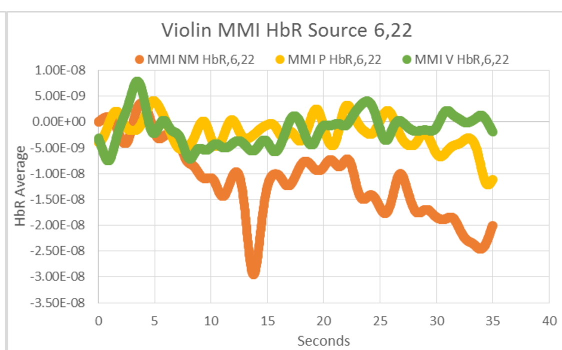












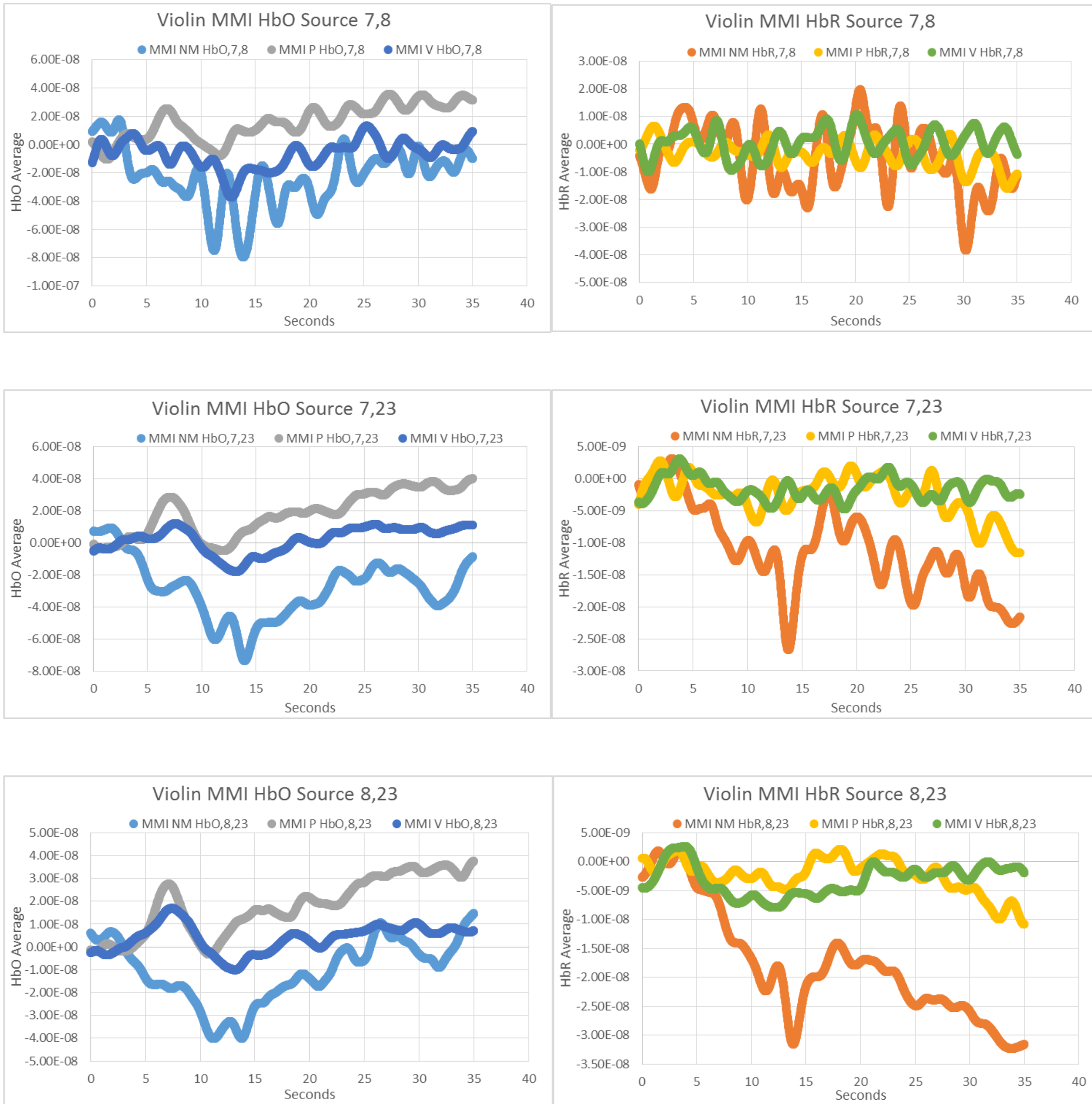


FIGURE 16. VIOLIN MOTOR AND MUSIC IMAGERY CONDITIONS FOR BOTH HBO (LEFT) AND HBR (RIGHT) FOR THE THREE GROUPS: NON-MUSICIANS (NM), VIOLINISTS (V), AND PIANISTS (P) FOR SOURCES 5-21, 6-7, 6-22, 7-23, AND 8-23

Figure 16 displays the violin motor imagery and music imagery conditions, revealing a similar trend of P and V groups for the motor imagery conditions. The violinists and pianists show a stabilized and constant HbO response. P and V groups have similar HbO activity compared to group NM. HbR responses fluctuate between sources, making it more difficult to draw a conclusion from that data.

Table 9 below displays the one-way ANOVA results as performed on each source pair for the three groups (non-musicians, pianists, and violinists) during the violin music imagery from the 5 to 15 second interval. The ANOVA revealed significant differences among all groups in only three of the source pairs: 5-21, 7-8, 8-23, as confirmed by the Bonferroni post-hoc tests. The other three sources revealed significant differences among specific groups. Bonferroni post-hoc tests showed significant differences in sources 6-7, 6-22, and 8-23 among the non-musicians and pianists, and pianists and violinists, but not between the non-musicians and violinists.

Source	**ANOVA Results**	**Pairwise Comparisons**
5-21	$F(2, 1000) = 361, p < .001, \eta^2 = .42$	All groups ($p < .001$)
6-7	$F(2, 1000) = 354, p < .001, \eta^2 = .42$	NM + P ($p < .001$) NM + V (no significant difference) P + V ($p < .001$)
6-22	$F(2, 1000) = 173, p < .001, \eta^2 = .26$	NM + P ($p < .001$) NM + V (no significant difference) P + V ($p < .001$)
7-8	$F(2, 1000) = 1781, p < .001, \eta^2 = .78$	All groups ($p < .001$)
7-23	$F(2, 1000) = 545, p < .001, \eta^2 = .52$	NM + P ($p < .001$) NM + V (no significant difference) P + V ($p < .001$)
8-23	$F(2, 1000) = 717, p < .001, \eta^2 = .69$	All groups ($p < .001$)

TABLE 9 ANOVA RESULTS FOR VIOLIN MOTOR AND MUSIC IMAGERY

6.3. VIVIDNESS OF MOVEMENT IMAGERY QUESTIONNAIRE (VMIQ)

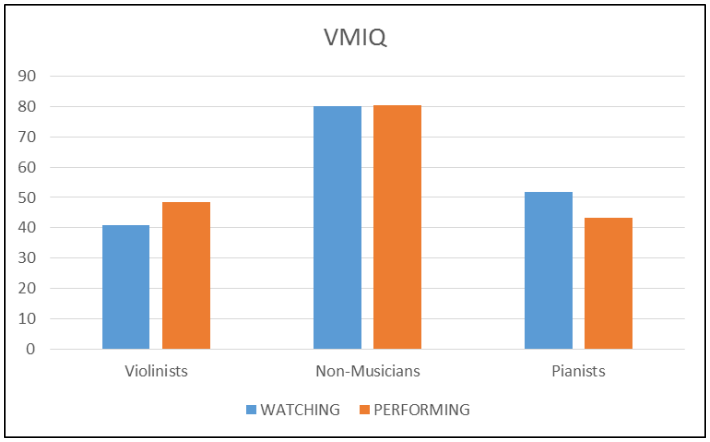


FIGURE 17. VIVIDNESS OF MOVEMENT IMAGERY QUESTIONNAIRE (VMIQ) RESULTS: CLARITY RATINGS OF IMAGERY TASKS IN FIRST-PERSON VS. THIRD-PERSON PERSPECTIVE

Figure 17 displays the Vividness of Movement Imagery Questionnaire results. Each group rated the clarity of each imagery task, comparing third-person (watching someone else perform a movement) vs. first-person (performing the movement oneself) perspectives, based on a 1-5 scale. Lower ratings corresponded with greater clarity of the task. The responses for all groups were analyzed using the Chi-Square method in SPSS.

The results showed that violinists rated the imagination task of watching someone else perform the movement to be clearer than imagining performing the movements themselves. Pianists, conversely, rated the imagination task of performing the movement themselves to be clearer than imagining someone else perform the movement. Non-musicians revealed no differences between watching vs. performing the imagined movements. The ANOVA revealed that there was an effect of group (non-musicians, pianists, violinists) on response ($F(2, 9) = 3.69$, $p < .05$, $\chi^2 = .45$). There was not a difference between the imagination types (watching vs. performing). Pairwise comparisons through Bonferroni post-hoc tests showed that violinists and pianists were significantly different from non-musicians, and that there was no difference between the pianists and violinists.

6.4. Music and Movement Questionnaire

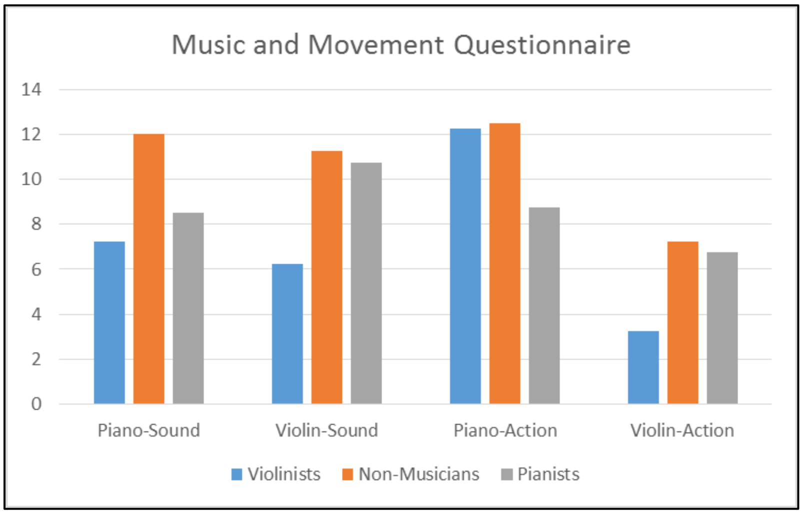


Figure 18. Music and Movement Questionnaire Results: Piano-Sound and Violin-Sound indicate music imagery conditions, Piano-Action and Violin-Action indicate motor imagery conditions

The Music and Movement Questionnaire, given to participants post-experiment, had a section designed to assess clarity for all imagery conditions. The ratings (1-5) were given to assess clarity in the specific imagery conditions; lower ratings corresponded with greater clarity. Within Figure 18 above, the piano-sound and violin-sound columns represent music imagery conditions, while the piano-action and violin-action columns represent the motor imagery conditions. The questionnaire was analyzed using an analysis of variance (ANOVA) in SPSS.

The music imagery (piano-sound vs. violin-sound) ratings were almost significant between the three groups ($F(1, 2) = 3.22$, $p = .08$)), with the violinists and non-musicians showing the greatest difference ($p = .07$). Motor imagery ratings were next assessed (piano-action vs. violin-action), revealing a significant effect of instrument ($F(1, 2) = 44.79$, $p < .001$), and an interaction between instrument and group ($F(2, 9) = 6.24$, $p = .02$). Group alone, however, did not reveal a significant effect on motor imagery ratings. Bonferroni post-hoc comparisons revealed that when the violin movements were imagined, motor imagery was perceived to be easier than when imagining piano movements.

6.5. SUMMARY OF RESULTS

Overall, the results reveal that non-musicians, pianists, and violinists all show significant differences in motor area activation during imagery tasks particular to the piano and violin. Each of the conditions (baseline, motor imagery, music imagery, and motor and music imagery) in both the piano and violin sets achieved significant findings among all groups in the one-way ANOVA.

The graphs provided visual representations of the HbO and HbR variance among the groups, revealing interesting patterns and trends from which to draw further conclusions. Often, the musicians exhibited similar response trends, although always at significantly different levels. The non-musicians and musicians appeared to respond in different ways while partaking in imagery tasks specific to a particular instrument. For example, during the violin imagery tasks, pianists and non-musicians appeared to act more similarly, although at significantly different levels. Likewise, during the piano imagery tasks, violinists and non-musicians appeared to act more similarly compared to the pianists. In general, the non-musicians showed the greatest variability and fluctuation in response, while the violinists revealed the least amount of variability, with stable patterns of activity, and the pianists' activity was somewhere in between the other groups.

Furthermore, the questionnaires provided results that aligned with the NIRS data. The Movement and Music Questionnaire, specifically, showed that the non-musicians found it more difficult to imagine piano movements than violin movements, which was also observed in their variation in HbO and HbR responses. Similarly, the violinists found it much more difficult to imagine the piano movements compared to the piano music; however, their HbO and HbR data reflect more stable patterns of activity. Pianists, on the other hand, found it more difficult to imagine the violin music than the violin movements, as confirmed by their considerable variation in activity throughout the violin imagery tasks.

CHAPTER FOUR: DISCUSSION AND CONCLUSION

In the current study, the hypothesis that musicians (pianists and violinists) would perform imagery tasks (motor imagery, music imagery, motor and music imagery) differently depending on the imagined instrument (piano and violin) was tested. The results suggest significant differences among pianists and violinists when they partake in motor and music imagery tasks related to piano and violin playing.

Within the piano set, the pianists easily imagined the movements, music, and the combination of the two, confirming that musicians can easily imagine movements and music of their primary instrument compared to a non-primary instrument. The data also suggested that violinists and pianists were nearly identical in imagining the piano movements, but revealed differences when violinists imagined the piano music and the combination of movements and music. During the motor and music imagery condition, violinists had a more difficult time imagining the entire piano performance, further suggesting that the sound of the music inhibited their motor imagery ability.

As a group, the musicians (violinists and pianists) performed the piano imagery tasks more easily than the non-musicians. As expected, the non-musicians exhibited the most difficulty in imagining the movements of the piano alone. Interestingly, the non-musicians acted similar to the pianists while partaking in music imagery task and the combined motor and music imagery task for the violin; they did not appear to behave the same way as the violinists. This finding implies that the non-musicians were not suppressed by the music of violin, rather, it actually assisted them in the motor and music imagery task.

Within the violin set, the results revealed various patterns to what was found in the piano runs. As expected, the violinists were easily able to imagine all aspects of the violin performance, whereas the pianists had more difficulty imagining the movements, music, and combination of the two. The pianists presented the most variance in activity during the separate violin motor imagery condition and music imagery conditions, however, they were similar to the violinists during the motor and music imagery condition. What does this finding suggest? We can conclude that instrument type had an effect on the pianists' ability to imagine violin movements and music separately. However, when the violin movements and music were imagined together, the pianists had an easier time partaking in the combined imagery task and did not show a suppression of imagery ability.

As a group, the non-musicians again demonstrated greater difficulty in the violin motor and music imagery tasks compared to the violinists and pianists. In fact, the non-musicians seemed to find the violin imagery tasks to be more difficult than the piano imagery tasks, similar to what was found in the pianists for the violin imagery tasks; yet again revealing an effect of instrument type. This finding implies that due to the difficult nature of violin movements and an unfamiliarity with violin movements and music, the non-musicians could not easily integrate and perform the imagery tasks.

Further data analysis will consider the prefrontal areas during all imagery tasks. Although the prefrontal areas are not expected to reveal significant differences among imagery tasks between the violinists and pianists, it may bring to light other possibilities. Perhaps it will encourage further ideas regarding correlations between brain activity of the prefrontal area and how internal images are formed and represented.

A few potential caveats and confounding variables of the current study must be addressed. First, due to the limited population of violinists and pianists in Marquette, Michigan it was very difficult to find participants for the experiment. Those that participated were personal acquaintances and colleagues of the experimenter, thus reducing true random selection and the potential power of the experiment.

Second, the head arrays that were utilized caused a significant amount of pressure and stress on participant's heads. Two participants in particular developed headaches and asked to continue to the second half of the experiment on a different day. Due to the stress caused by the head arrays, it is likely that the participant's attention was not completely given to the task at hand, thus creating additional factors within the data.

A third variable to consider is that the pianists and violinists had varied levels of experience with their primary instrument. The pianists were considered amateur musicians and the violinists were considered professionals. This classification was not intentional prior to the experiment, rather, it presented itself upon analyzing the data, likely due to the small sample of participants. This factor noticeably influenced the general data trends, as we observed that the pianists and non-musicians often acted more similarly to each other compared to the violinists, while the violinists exhibited stable trends.

Fourth, we cannot know for sure whether the participants were truly imagining the movements and music particular to the instruments; especially the non-musicians, who likely did not have much experience with music imagery prior to the experiment. It is assumed that the musicians had no problem performing the tasks due to their prior experience with imagery, however, the non-musicians' unfamiliarity with using imagery may have led to their notable variation in activity throughout the conditions.

Future studies on music and motor imageries could consider the ways other opposing instruments are imagined. The current work looked into only the violin and piano, but perhaps exploring different instruments, such as percussion, wind, or brass, may reveal further interesting differences in the ways particular movements and sounds are represented in the musician's brain. Other future work could investigate individual musicians who are skilled on multiple instruments in order to see how motor and music imageries differ among the various instruments, and comparing these individualized differences with other musicians of a similar nature.

Overall, the results confirm that musicians imagine movements and music differently depending on the imagined instrument and the associated imagery tasks. Calvo-Merino and colleague's (2004) study on motor observation of learned vs. unfamiliar movements in expert dancers inspired the current study with its applicable findings: the influence of motor expertise on movement-related tasks. Extending this idea to the current work, music imagery also appears to be affected by motor expertise: pianists could easily imagine well-learned, familiar movements and sounds, but struggled when asked to imagine unfamiliar movements and sounds of the violin. The violinists, however, showed no apparent difficulty in imagining the movements or sounds of either instrument, as influenced by their expertise level and individual training experiences.

As we continue to learn about how music and movements are represented in the brain, we can discover more about the beauty and magic of music. Movements are essential to a musician's instrument and are just as much a part of their repertoire as any musical piece. Not only do musicians use small, precise movements every time they play, they also develop imagery techniques to practice movements and music as well. The use of imagery is vital to an advanced musician, and is an efficient way to gather the senses to generate imaginative performances. Motor imagery and music imagery are necessary in learning, practicing, and ultimately, performing music.

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APPENDIX A

Vividness of Movement Imagery Questionnaire

Isaac, A.; Marks, David F.; Russel, David G. (1986).

Movement imagery refers to the ability to imagine a movement. The aim of this test is to determine the vividness of your movement imagery. The items of the test are designed to bring certain images to your mind. You are asked to rate the vividness of each item by reference to the 5-point scale. After each item, choose the appropriate number rating. The first column is for an image obtained by watching somebody else and the second column is for an image obtained by doing it yourself. First, complete all tasks as if watching somebody else perform them, then return to the beginning of the questionnaire and rate the tasks as if completed by doing them yourself. Try to do each item separately, independently of how you may have done other items. The two ratings for a given item may not in all cases be the same. For all items please have your eyes CLOSED.

RATING SCALE - The image aroused by each item might be:
1 - Perfectly clear and as vivid as normal vision
2 - Clear and reasonably vivid
3 - Moderately clear and vivid
4 - Vague and dim
5 - No image at all, you only "know" you are thinking of the skill

Think of each of the following acts and classify the images according to the degree of clearness and vividness as shown on the rating scale. Please close your eyes to imagine each item.

	Watching somebody else perform movement					Performing movement yourself				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Standing	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Walking	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Running	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Jumping	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Reaching for something on tiptoe	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Drawing a circle on paper	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Kicking a stone	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Bending to pick up a coin	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Falling forwards	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Running up stairs	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Jumping sideways	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Slipping over backwards	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Catching a ball with two hands	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Throwing a stone into water	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Kicking a ball in the air	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Hitting a ball along the ground	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Running downhill	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Climbing over a high wall	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Sliding on ice	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Riding a bike	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Jumping into water	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Swinging on a rope	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Balancing on one leg	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Jumping off a high wall	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

APPENDIX B

Music Experience Questionnaire

GENERAL MUSIC EXPERIENCE

Q1 Approximately how much time per day do you spend listening to music?
- ❍ 0-1 hour
- ❍ 2-3 hours
- ❍ 4-5 hours
- ❍ 6-7 hours
- ❍ 8 hours+

Q2 Approximately how many music events do you attend per month?
- ❍ 0-1
- ❍ 2-3
- ❍ 4-5
- ❍ 6-7
- ❍ 8+

Q3 Approximately how much of your free time do you spend on music activities?
- ❍ A great deal
- ❍ A lot
- ❍ A moderate amount
- ❍ A little
- ❍ None at all

Q4 How open are you to listening to unfamiliar music?
- ❍ Always willing to listen
- ❍ Most of the time willing to listen
- ❍ About half the time willing to listen
- ❍ Sometimes willing to listen
- ❍ Never willing to listen

Q5 Do you consider yourself a musician?
- ❍ Yes
- ❍ No

MUSIC TRAINING EXPERIENCE

Q6 Do you have experience playing any musical instruments?
- ❍ Yes
- ❍ No

Q7 Do you have experience playing any instruments for 3+ years?
- ❍ Yes
- ❍ No

Q8 Which instrument(s) do you have 3+ years' experience playing? Please list.

Q9 How many total years have you spent learning musical instruments? Please list.

Q10 What is your primary instrument? Please list.

Q11 Please list any secondary instruments:

Q12 What kind of music training have you had?
- ❑ School program (beyond elementary school)
- ❑ Private lessons
- ❑ Teaching
- ❑ Solo performing
- ❑ Ensemble performing
- ❑ Composing
- ❑ Music theory classes
- ❑ Music degree
- ❑ No music training

Q13 Approximately how many hours do you practice and/or perform on your primary instrument per week?
- ❍ 0-4
- ❍ 5-9
- ❍ 10-14
- ❍ 15-19
- ❍ 20-24
- ❍ 25+ (please type amount) ____

PERCEPTUAL ABILITIES

Q14 Are you able to easily recognize familiar music?
- ❍ Yes
- ❍ Sometimes
- ❍ No

Q15 Are you able to recognize music that you have heard only a couple times before?
- ❍ Definitely yes
- ❍ Probably yes
- ❍ Might or might not
- ❍ Probably not
- ❍ Definitely not

Q16 Are you able to identify different music genres (ie. classical, pop, rock, jazz, rap, etc)?
- ❍ Definitely yes
- ❍ Probably yes
- ❍ Might or might not
- ❍ Probably not
- ❍ Definitely not

Q17 Are you able to sing/play an instrument from memory?
- ❍ Yes
- ❍ Maybe
- ❍ No

Q18 Do you judge others' singing ability?
- ❍ Yes
- ❍ Sometimes
- ❍ No

Q19 Do you compare people's musical performances?
- ❍ Yes
- ❍ Sometimes
- ❍ No

Q20 Can you spot mistakes in performances?
❍ Yes
❍ Sometimes
❍ No

IMAGERY EXPERIENCE

Q21 Have you ever used music imagery before this study?
❍ Definitely yes
❍ Probably yes
❍ Might or might not
❍ Probably not
❍ Definitely not

Q22 During which situations have you used music imagery before?
❑ Thinking about a song/piece
❑ Having a song stuck in your head
❑ Practicing an instrument
❑ Performing
❑ Other (please list) ____________________
❑ None

Q23 How often do you engage in imagery to assist with practicing/performing on your instrument?
❍ Very frequently
❍ Most of the time
❍ About half the time
❍ Sometimes
❍ Never

Q24 Have you ever used motor imagery before this study?
❍ Definitely yes
❍ Probably yes
❍ Might or might not
❍ Probably not
❍ Definitely not

Q25 During which situations have you used motor imagery before? Please list and describe.

MUSIC STIMULUS FAMILIARITY

Q26 Were you familiar with the music played in the videos?
- ❍ Yes
- ❍ Maybe
- ❍ No

Q27 Have you learned the piece of music played in the videos?
- ❍ Yes
- ❍ No

Q28 Have you performed the piece of music played in the videos?
- ❍ Yes
- ❍ No

IMAGERY RATINGS Please rate each item on a scale of very clear (easy to imagine) to very unclear (difficult to imagine)

Q29 Imagining the *music* of the **piano** performance video

	Very clear	Somewhat clear	Neither clear nor unclear	Somewhat unclear	Very unclear
Pitches (notes)	❍	❍	❍	❍	❍
Loudness	❍	❍	❍	❍	❍
Rhythm	❍	❍	❍	❍	❍
Speed	❍	❍	❍	❍	❍
Duration (length of piece)	❍	❍	❍	❍	❍
Timbre (sound quality difference between piano & violin)	❍	❍	❍	❍	❍

Q30 Imagining the *movements* of the **piano** performance video

	Very clear	Somewhat clear	Neither clear nor unclear	Somewhat unclear	Very unclear
Finger movements	❍	❍	❍	❍	❍
Left hand movements	❍	❍	❍	❍	❍
Right hand movements	❍	❍	❍	❍	❍
Movements of both hands	❍	❍	❍	❍	❍
Speed of movements	❍	❍	❍	❍	❍

Q31 Imagining the *music and movements* of the **piano** performance video

	Very clear	Somewhat clear	Neither clear nor unclear	Somewhat unclear	Very unclear
All musical elements and finger/hand movements	❍	❍	❍	❍	❍

Q32 Imagining the *music* of the **violin** performance video

	Very clear	Somewhat clear	Neither clear nor unclear	Somewhat unclear	Very unclear
Pitches (notes)	❍	❍	❍	❍	❍
Loudness	❍	❍	❍	❍	❍
Rhythm	❍	❍	❍	❍	❍
Speed	❍	❍	❍	❍	❍
Duration (length of piece)	❍	❍	❍	❍	❍
Timbre (sound quality difference between piano & violin)	❍	❍	❍	❍	❍

Q33 Imagining the *movements* of the **violin** performance video

	Very clear	Somewhat clear	Neither clear nor unclear	Somewhat unclear	Very unclear
Finger movements	❍	❍	❍	❍	❍
Hand movements	❍	❍	❍	❍	❍
Speed of movements	❍	❍	❍	❍	❍

Q34 Imagining the *music and movements* of the **violin** performance video

	Very clear	Somewhat clear	Neither clear nor unclear	Somewhat unclear	Very unclear
All musical elements and finger/hand movements	❍	❍	❍	❍	❍

DEMOGRAPHIC INFORMATION

Q35 Name

Q36 Age

Q37 Gender

Q38 Handedness
❍ Right
❍ Left
❍ Ambidextrous

Q39 Education level
- ❍ High school student
- ❍ High school graduate
- ❍ Some college
- ❍ Associate's degree
- ❍ Bachelor's degree
- ❍ Master's degree
- ❍ Doctorate, PhD

APPENDIX C

Approval Notice for IRB Proposal HS14-580

TO: Sonja Prychitko
Mounia Ziat
Psychology Department

DATE: February 21, 2014

FROM: Brian Cherry, Ph.D.
Assistant Provost/IRB Administrator

SUBJECT: **IRB Proposal HS14-580**
IRB Approval Dates: 2/21/2014-2/21/2015**
Proposed Project Dates: 3/1/2014-3/31/2016

"Musical Imagery Using NIRS"

The Institutional Review Board (IRB) has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required.

A. You must include the statement "Approved by IRB: Project # HS14-580" on all research materials you distribute, as well as on any correspondence concerning this project.

B. If a subject suffers an injury during research, or if there is an incident of non-compliance with IRB policies and procedures, you must take immediate action to assist the subject and notify the IRB chair (dereande@nmu.edu) and NMU's IRB administrator (bcherry@nmu.edu) within 48 hours. Additionally, you must complete an Unanticipated Problem or Adverse Event Form for Research Involving Human Subjects

C. Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding. Informed consent must continue throughout the project via a dialogue between the researcher and research participant.

D. If you find that modifications of methods or procedures are necessary, you must submit a Project Modification Form for Research Involving Human Subjects before collecting data.

E. **If you complete your project within 12 months from the date of your approval notification, you must submit a Project Completion Form for Research Involving Human Subjects. If you do not complete your project within 12 months from the date of your approval notification, you must submit a Project Renewal Form for Research Involving Human Subjects. You may apply for a one-year project renewal up to four times.

NOTE: Failure to submit a Project Completion Form or Project Renewal Form within 12 months from the date of your approval notification will result in a suspension of Human Subjects Research privileges <u>for all investigators listed on the application</u>, until the form is submitted and approved.

APPENDIX D

Extension Approval for HS14-580

MEMORANDUM

TO: Sonja Prychitko
Psychology Department

CC: Mounia Ziat
Psychology Department

FROM: Robert Winn, Ph.D.
Assistant Provost/IRB Administrator

DATE: April 18, 2016

RE: Extension for IRB HS14-580
New Project Approval Dates: 2/17/2014-4/18/2017**
"Musical Imagery Using NIRS" / "Motor Imagery and Music Imagery Using NIRS"

Your project modification to extend "Motor Imagery and Music Imagery Using NIRS" has been approved under the administrative review process. Please include your proposal number (HS14-580) on all research materials and on any correspondence regarding this project.

Any changes or revisions to your approved research plan must be approved by the IRB prior to implementation.

Please submit a Project Completion Form for Research Involving Human Subjects at the conclusion of your study.

****If you do not complete your project within 12 months from the date of this approval notification, you must submit a Project Renewal Form for Research Involving Human Subjects. You may apply for a one-year project renewal a maximum of four times.**