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Electrophysiological Response to Classical Music in Instrumentalists, Vocalists, and Non-Musicians

Brielle McDonald
brielle.mcdonald@trincoll.edu

TRINITY COLLEGE

ELECTROPHYSIOLOGIC RESPONSE TO CLASSICAL MUSIC IN INSTRUMENTALISTS, VOCALISTS AND NON-MUSICIANS

BY

Brielle McDonald

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Brielle McDonald

Honors Thesis Committee

Approved:

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Sarah Raskin, Thesis Advisor

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Dan Lloyd, Thesis Advisor

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Sarah Raskin, Director, Neuroscience Program

Date: ____________________________________

Abstract

Musical experience has been shown to impact electrophysiological response in response to sudden changes in music. The purpose of this exploratory case study is to investigate responses to a variety of continuous classical music stimuli in individuals with varying musical backgrounds, through the use of electroencephalography (EEG). Individuals were categorized as instrumentalists (5+ years of instrumental training), vocalists (5+ years of vocal training), or non-musicians (<1 year of musical training). Participants were played a variety of classical vocal and instrumental music while an EEG was recorded. Data were then collected and analyzed using independent component analysis (ICA) and time/frequency analysis through EEGLAB. It was found that overall, both instrumentalists and vocalists had a greater electrophysiological response to musical stimuli, specifically in the frontal lobe than the non-musician. The vocalist also had a significantly greater electrophysiological response to the musical stimuli that were most similar to their experience and expertise. This indicates that expertise and familiarity with a genre of music may impact the electrophysiological response. While this only a case study with a small sample size, the results indicate that there is potential for impactful further research about how individuals of different musical backgrounds respond to a variety of continuous musical stimuli based on their experiences.

Introduction

The present study aimed to investigate responses to classical music in individuals with varying musical backgrounds through the use of electroencephalography (EEG). Previous longitudinal studies have revealed structural differences in brain development between individuals who have received musical training and those who have not (Hyde et al., 2009). The purpose of this study is to explore how these structural differences, differing backgrounds, and similarity of the stimulus to the expertise of the musician, will impact electrical activity within the brain.

Past findings with ERPs

It has been previously shown that musicians and non-musicians have significantly different electrical activity in response to sudden changes in music (Overman et al., 2003; Habibi et al., 2012). Sudden and unexpected changes in key, tempo or melody induce event related potentials (ERP), which caused a greater decrease in alpha waves in the left hemisphere of musicians compared to the non-musicians, with no significant change in the right hemisphere (Overman, et al., 2003). The decrease in alpha waves in the left hemisphere suggests that musicians have a greater cognitive response in their left hemisphere to ERPs induced by sudden changes in music than non-musicians. More specifically, rhythmic deviance and sudden changes or surprises in rhythm have also been shown to lead to a significant response in the amplitude of P200 (Habibi et al., 2014). This was also seen when dissonant or seemingly “wrong” or unexpected notes were played (Habibi et al., 2012), and generally dissonant music has been shown to increase synchronization, which is indicated by a higher density of delta and theta bands during consonant music in comparison to dissonant music (Varotto et al., 2012). Similarly, a sudden change in tempo has been shown to lead to an event-related desynchronization (ERD) in the alpha band, but pieces of music with a steady tempo, whether fast or slow, does not modulate ERD strength (Daly et al., 2014). This study intended to compare these previous findings of cognitive response from ERPs to potential cognitive responses induced by continuous stimuli from a variety of classical genres, which has not been previously studied. Therefore, the stimuli that were used avoided sudden changes in musical elements that have been previously shown to induce ERPs (Habibi et al., 2012; Varotto et al., 2012; Daley et al., 2014). The stimuli within this study have no significant tempo changes throughout the piece, but the tempos did vary piece to piece. The stimuli also have no surprising modulations or changes in key signature, and no unexpected or unusual dissonant notes. All musical stimuli chosen for this study were written between 1670-1890, followed the general rules of Western music theory and practices, and had an overall consonant and pleasant sound. By adhering to these rules while choosing musical stimuli, known superficial and sudden changes that have been previously noted to generate ERPs were controlled. This allowed for electrophysiological responses to each musical excerpt to be compared.

Previous Research on Musicians and Music

Musicians and music have been a popular topic of research ranging in a variety of areas including our neurological processing, emotional perception, and memory of music.
Research on our neurological response to listening to music has shown an increase of blood flow to the primary and secondary auditory cortices, primary motor cortex, frontal operculum (Broca's area), posterior cerebellum, and basal ganglia (Brown et al., 2004). Past research has also revealed connections between the processing of language and music, specifically in Broca's and Wernicke's areas which have been implicated in both musical imitation and vocal learning (Schön et al., 2010; Brown et al., 2004). A common cerebral network between lexical and phonological melodic processing has also been identified. Musical stimuli with and without

lyrics both increased activity in the middle and superior temporal gyri and inferior middle frontal gyri (Schön et al., 2010). Listening to music has also been shown to increase activity within areas associated with rewards and pleasure (Zatorre, 2003). An fMRI study found an increase in activity within the nucleus accumbens, dorsal midbrain, and insula in correlation with music-induced chills (Zatorre, 2003).

Previous studies exploring the emotional perception of music found tempo, mode (major or minor) and cultural backgrounds to be correlated with what emotion individuals view that music to be portraying (e.g. Happy or sad music) (Hunter & Schellenberg, 2010). It was also found that universally, both non-musicians and musicians prefer consonance over dissonance in music (Hunter & Schellenberg, 2010). Studies on music and emotion have also revealed that emotions elicited by music are similar to emotions elicited by visual stimuli. One study found that priming an emotion by either listening to happy or sad music enhanced the perceived emotion of happy, sad, or neutral faces (Logeswaran & Bhattachary, 2009). Familiarity and memory of a piece of music also impact emotional responses (Hunter & Schellenberg, 2010; Huron, 2006). Music that was more familiar to an individual was self-reported to be more enjoyable (Hunter & Schellenberg, 2010).

Music has also been shown to have a strong connection with memory. One study revealed that music facilitates semantic memory in individuals with dementia, and healthy older adults (Schulkind, 2009). Through self-report studies, music has also been shown to have strong links to memories of associated events, and that music aids in the recall of these past life events (Jäncke, 2008). Perfect pitch is a phenomenon that has been studied concerning musical memory as well, with the hypothesis that perfect pitch is a type of musical memory (Jäncke, 2008; Zatorre, 2003). Perfect pitch is the ability for some people to identify or sing a note without relating it to a previously played note. This is a rare ability, however, it has been found that 50% of individuals, whether musicians or not, sang a popular song on the correct pitches with no prompting. This suggests that both non-musicians and musicians have a strong memory for musical pitch (Jäncke, 2008).

Vocalists and instrumentalists

The subcategories within musicians of vocalists and instrumentalists have been a topic of research due to their differences in musical training and musical expertise. A study of differences in discrimination and production of musical pitches in instrumentalists and vocalists found that vocalists were more consistent in their production than instrumentalists, but both groups were more accurate than non-musicians (Nikjeh, 2006). It is hypothesized that vocalists were more consistent than instrumentalists due to their experience and expertise in this skill (Nikjeh, 2006). The present study is interested in exploring if previous findings that individuals with more experience with a specific skill perform better, translates into individuals with more experience with types of classical music having greater electrical activity within the brain, and if so, where that activity is located.

Previous studies have investigated vocalists, instrumentalists, and non-musicians' control of language. In tests of memory skills, speech perception, and lexical tone perception, instrumentalists and vocalists do not differ significantly from one another but perform significantly better than non-musicians (Kirkham et al., 2011; Kumar & Krishna, 2019). While the present study is interested in exploring music perception in instrumentalists and vocalists rather than non-musical auditory skills, the similarities in performance in those tasks suggests that there are many similarities between the brain development and cognition of all musicians.

EEG

Electroencephalography (EEG) is a method of recording and measuring electrical activity within the cerebral cortex via electrodes placed externally on the head. The electrical activity that is recorded is created by neurochemical signaling within the brain, specifically NMDA receptors becoming permeable to calcium ions (Rana et al., 2016). This creates an output with the electrical activity of each electrode over time. The waves seen in EEG output are classified by frequency. Delta rhythm is the slowest wave with a frequency of between 1 and 4 Hz, theta waves have frequencies of between 4 and 8 Hz, alpha waves have a frequency between 8 and 13 Hz, beta waves have a frequency of between 14 and 30 Hz, and gamma waves have a frequency above 30 Hz.

Sonification

Sonification is a way to present data in an auditory context. Sonification is thought to be an effective method for uncovering structures and patterns within data because of the capacity for our auditory system to process and understand multiple auditory streams at once, whereas, the human visual system must process multiple objects through serial processing (Hinterberger & Baier, 2005). Sonification can be done using a variety of methods, however, it is critical that the method used is able to be both aesthetically pleasing, without transforming the data to be unrecognizable (Schmele & Gomez, 2012). Therefore, different methods of sonification are used for different purposes. In the present study, two different methods will be used, spectral mapping sonification and the modified parametric orchestral sonification of EEG in real-time (POSER). Spectral mapping sonification involves each channel, and in this case, each electrodes activity, being sonified on its own, with increased frequency leading to increased pitch. Electrodes can then be compared by superimposing them (Hermann et al., 2002). This method allows for easy comparison between specific electrodes. The POSER method assigns each frequency band to a different musical instrument digital interface (MIDI) channel and different timbre. The pitches are then controlled by the percentage of that frequency band in the area of interest. The POSER method was originally created to be used in real-time while the EEG was being conducted, however, it is easily modified to sonify data post collection and analysis (Hinterberger & Baier, 2005). This method allows for many channels to be heard at once.

Present study

The study intended to recruit and test a large number of subjects in each group, however, due to unforeseen circumstances including a broken electrode cap and the COVID-19 pandemic, only three subjects, one in each category, were tested. Therefore, this study was an exploratory study on the impact of a variety of genres of classical music on the electrical activity within the brains of instrumentalists, vocalists, and non-musicians. This study functioned as an exploratory study, with the following goals in mind,

1. Identify if instrumentalists, vocalists, or non-musicians have greater electrical activity in different areas of the brain when listening to classical music, and if so, which areas.
2. Identify whether musicians listening to music within their area of expertise have a greater electrical response than when listening to less familiar music, and if so, which areas of the brain are most active.
3. Compare and contrast spectral mapping and the POSER methods of sonification in regard to their ability to present data while still being aesthetically pleasing.

Materials

Questionnaire

Participants were given the following questionnaire prior to testing.

1. What is your age?
2. What is your gender?
3. Are you right or left-handed?
4. Have you ever had any formal instrumental training?

    If yes…

    In what instrument(s)?

    How many years?

    Do you currently play your instrument?

    On average, how many days per week do you play?

    On average, how many hours per week do you play?

5. Have you ever had any formal vocal training?

    If yes…

    In what setting (choral, musical theater, opera, etc.)

    How many years?

    Do you currently sing in a serious capacity?

    On average, how many days per week do you sing?

    On average, how many hours per week do you sing?

6. Have you ever studied the history of classical music?

If yes, for how many years?

7. Have you ever studied western music theory?

If yes, for how many years?

8. Do you listen to classical music?

If yes, on average, how many days per week?

9. Is there anything else about your musical background you would like to add?

Electrophysiological Recording

The electrophysiological recordings took approximately 45 minutes total, with approximately 20 minutes of set up, 10 minutes of testing, and 15 minutes for cleanup.

An electroencephalogram (EEG) machine with a Compumedics® Neuroscan™ Quik-Cap with 64 sewn in electrodes and six external electrodes was used to record electrophysiological data. Prior to placing the cap on the participant, they were asked to wipe their forehead and around their eyes with an alcohol wipe to prepare their faces for the external electrodes. The cap was then placed on the participants head and secured under the chin to fit snugly, with the front of the cap on the forehead and centered in relation to the bridge of their nose. The six external electrodes were then placed and secured using medical tape. They were positioned on the side of the left eye (HEOL) and the right eye (HEOR) as well as below (VEOL) and above the left eye (VEOU). The remaining two electrodes were placed on the left (M1) and right (M2) mastoid bones in order to record the base connectivity of the scalp, which was subtracted from all recordings upon data analysis.

The EEG cap was then connected to the Neuroscan™ headbox, which was connected to the SynAmpRt amplifier, which had a 24-bit resolution, DC-3500-Hz bandwidth, filtered between 0.1 Hz and 100 Hz, with a low-pass 30 Hz filter, and a maximum sampling rate of 20 kHz. Curry 7 was then used to monitor electrode impedance. Before putting any gel in the electrodes, the impedance reading for all electrodes were at 50.0 kΩ. A BD™ 10-mL syringe with a Luer-Lok™ tip and a BD™ 16-gage ¾ blunt square grind PrecisionGlide® needle was then used to fill electrodes with filled with Compumedics® NeuroMedical Supplies Quik-Gel™. This was prepared by mixing approximately 95 mL of Quik-Gel™ with 30 mL of water, and then warmed in the microwave for 45 seconds. Each electrode was filled with the gel so that the impedance was below 20 kΩ and often as low as 5 kΩ. This was monitored using the electrode montage on Curry 7, where each represented electrode turned from red to light blue to represent this change.

Musical Stimuli

The excerpts of musical pieces were chosen to be a variety of unfamiliar classical pieces. The pieces chosen were a variety of major/minor and fast/slow tempo, with 3 primarily vocal and 3 instrumental pieces. All pieces chosen were written between 1670 and 1890 all composed within the rules of the common practice, the tonal system, and rules used in Western music which correspond with our perception of consonance and overall pleasant music (Richard, 2019). Pieces were also chosen to have little or no rhythmic deviance or tempo changes.

The six excerpts that were chosen each represent a category of classical music in order to assure that participants in the instrumentalist and vocalist categories were played at least one piece that aligns with their typical practice and performance. All pieces chosen were also lesser known but composed by a well-known composer in order to use music with similarities to what the instrumentalists/vocalists often play/sing, without it being immediately recognizable. Pieces were chosen to not be recognizable by participants because the recognition of melodies leads to a significant change in alpha waves in the left and right occipital lobes (Walker, 1980). These categories are mixed vocal ensemble, male solo voice, female solo voice, symphonic, solo piano, and small chamber ensemble.

Name of Piece	**Composer**	**Year written**	**Type of piece**	**Time signature and Tempo**	**Major/Minor**
O God, Thou Art My God	Henry Purcell	1662	Mixed vocal ensemble	2/2 60 bpm	Major
8th Symphony in G Major: Op. 88 - mvt.III	Antonín Dvořák	1889	Symphonic	6/8 60 bpm	Minor
So muss allein ich bleiben from Die Fledermaus	Richard Strauss	1874	Female Solo: Opera Aria	2/2 85 bpm	Minor
Piano Sonata No. 8 in C Minor, Op.13: mvt. III	Ludwig Van Beethoven	1798	Piano	4/4 100 bpm	Minor
Liederkreis: Wehmut Op.39	Robert Schumann	1840	Male Solo: Lieder	4/4 50 bpm	Major
String Quartet No. 11 in E-flat: mvt. II	Wolfgang Amadeus Mozart	1773	String Quartet	6/8 50 bpm	Major

The mixed vocal ensemble piece that was used was ‘O God, Thou Art My God’ composed by Henry Purcell (1659-1695). This piece is an a cappella piece for four voices, in a major key and an adagio tempo. The excerpt of this piece used was from approximately 1:20-2:20, or measures 25-68. This section was chosen because all four voices are singing throughout this section, and it fulfills the requirements stated above (Purcell, 1659-1695).

The symphonic piece that was used was the ‘8th Symphony in G Major, Op.88: mvt III – allegro’ by Antonín Dvořák (1841-1904). This orchestral piece is one of Dvořák’s lesser-known symphonies, and this movement begins with a simple, yet memorable memory in the string instruments. Following this introduction, the woodwinds introduce a countermelody in conversation with the strings. This piece is allegro and in a minor key. The beginning of this piece from 0:00-1:00 or measures 1-50 were used as the excerpt due to the prominence of all instruments in the orchestra within this section (Dvorak, 1889).

The female solo vocal piece used was ‘So muss allein ich bleiben’ from Die Fledermaus by Richard Strauss (1864-1949). This piece is from the opera Die Fledermaus, a lesser-known opera by Strauss. The section used was approximately 0:08-1:08, or measures 5-28. This section of the piece is for a female voice with minimal orchestral accompaniment. It is a moderate tempo and in a minor key (Strauss, 1874).

The piano piece used was ‘Piano Sonata No. 8 in C Minor, Op.13: mvt. III’ by Ludwig van Beethoven (1770-1827). This piece was chosen because it is a lesser-known piano piece written by a composer with many popular piano pieces. This piece is fast and in a minor key. There is a sudden change to a slower tempo at approximately 1:00, or measure 47, therefore 0:00-1:00 or measures 1-47 will be used (Beethoven, 1798).

The male solo vocal piece used was ‘Liederkreis: Wehmut Op.39’ composed by Robert Schumann (1810-1856). This piece is Lieder, a musical setting of an often romantic poem, a very common genre of music of classical vocal pieces. Along with fulfilling the requirements stated above, this piece was also chosen because many vocalists sing lieder or a similar style of piece. This piece is for a male voice with minimal piano accompaniment and is slow and lyrical in a major key. The excerpt used was from 0:00-1:00 or measures 1-13 (Schumann, 1840).

The small chamber ensemble piece used was ‘String Quartet No. 11 in E-flat: mvt. II’ by Wolfgang Amadeus Mozart (1756-1791). This piece was chosen because of the prominence of string quartets as chamber ensembles, and due to this also being a lesser-known piece by a prominent composer. This piece is allegro in a major key. The beginning of the piece is primarily the first violin, so the trio (middle section) which displayed the instruments of more equal importance, was used. The excerpt used was 1:00-2:00 or measures 27-50 (Mozart, 1773).

The 6, 1-minute excerpts were played in the order outlined above in order to alternate between vocal and instrumental pieces. There were 15 seconds of silence at the beginning, and in between each musical excerpt.

Following the testing, participants were asked whether they recognized any of the pieces and if so, to describe the piece and their level of familiarity. This was recorded by the individual administering the test.

Methods

Participants

Participants were students from Trinity College, two of which were recruited via an email to individuals involved with music on campus, including the Chapel Singers, A Capella, and music majors. The non-musician participant was an individual I had contact with, who was aware that a study was being conducted and was interested in participating. All three participants were right-handed. In order to be classified as a vocalist or an instrumentalist, the participants were required to have 5+ years of formal training in their respective mediums. In order to be classified as a non-musician, individuals could not have more than a year of training, and could not currently be playing or singing, or taking any music theory or history classes. The mean age of participants was M=21.66, SD=0.58, and included 1 non-musician, 1 individual with primarily instrumental training who also some vocal experience, and 1 vocalist.

The non-musician is a 22 year old, right-handed female, with no instrumental or vocal experience. On average, she currently listens to classical music one day a week for 2 hours while studying or engaging in other activities such as painting or drawing.

The instrumentalist with vocal experience is 22 year old, right-handed female, with 12 years of formal instrumental training in piano, clarinet and saxophone, with a specialty in jazz saxophone. She has not played her instruments in a serious capacity for approximately a year. She has 2 years of choral experience in the Chapel Singers, singing 4 days a week for approximately 6 hours per week. She has studied music history for 1 year, and music theory for 4 years. She currently listens to classical music 4 times a week for an average of 3 hours per week.

The vocalist is a 21 year old, right-handed female with no history of formal instrumental training. She has been in choirs and musical theatre for 14 years and has taken voice lessons and studied opera for 10 years. She also took a year off of school to study voice intensely. Currently, she sings 7 days a week, approximately 12-14 hours per week. This includes singing in Chapel Singers, musical theatre, and individually. She has studied music history for 3 years, with a focus on opera and also studied music theory on and off for a total of 2 years. She currently listens to classical music on average 2 days a week for 6-8 hours per week.

Procedure

Prior to recruiting or testing subjects, the experiment was reviewed and approved by the Institutional Review Board at Trinity College.

The 64 Compumedics® Neuroscan™ Quik-Cap was placed on the participant and set up as described above. Following set up, participants were instructed that they would be played a variety of one-minute excerpts of classical music. They were told that this testing phase would last less than 10 minutes, and that their only job was to listen to the music. Participants were also encouraged to close their eyes while they listened in order to decrease their interaction with non-auditory stimuli. The participants were then left alone in the room as the stimuli were played through a speaker. Following the testing phase, the cap was removed, and the data was saved.

The data was uploaded to EEGLAB, a MATLAB plugin, for analysis. The data was re-referenced to the mastoid electrodes (M1 and M2), and the epoch baseline was removed. The data was filtered with the lower edge of the frequency pass band set at 0.5 Hz. A plugin, Cleanline (Mullen, 2012) was then used to remove sinusoidal noise above 60 Hz. Channels were then inspected, and noisy channels were removed by eye and EEGLAB's built-in automatic channel rejection. A channel spectral density and map analysis was created using the built-in program and settings. An ICA was then run. Components were then examined, rejected and components of interest were identified using the plugin 'SemiAutomatic Selection of Independent Components for Artifact correction in the EEG' (SASICA) (Chaumon, 2015). A time/frequency plot and analysis were then created for components of interest with the ‘bootstrap significance level’ set to 0.05 (5%).

Results

Subject 1: Non-musician

Background: The non-musician has no instrumental or vocal training. They have also never studied music history or theory. They currently listen to classical music for approximately 2 hours a week while studying or engaging in other activities such as painting or drawing.

Results: Analysis of the data revealed overall increased electrophysiological response to all stimuli around the frontal-central electrodes (F3, F1, FZ, FC3, FC1), with the most significant response in F1. This pattern of spectral density was seen at all frequencies, however the levels of spectral density decreased significantly at 10 Hz (figure 1). After running an ICA, ICA1 was found to be a component of interest and a time/frequency analysis was conducted. There was found to be an increase in the prevalence of gamma waves between 160-180 seconds, 190-210 seconds and 290-310 seconds, where the stimuli were the female solo vocal piece, piano piece, and string quartet piece respectively (figure 2).

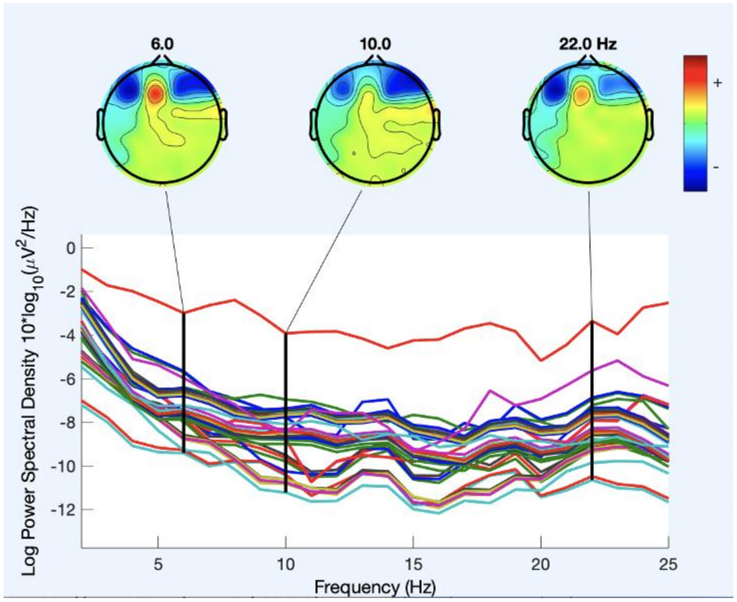


Figure 1: Channel spectral density and map from subject 1 (non-musician). The frequency bands are represented on the X axis and spectral density is represented on the Y axis. Each line represents a channel (electrode), and the topographic maps represent the spectral density at the specific frequency represented by the black band. At all three represented frequencies, the spectral density is localized around frontal electrodes.

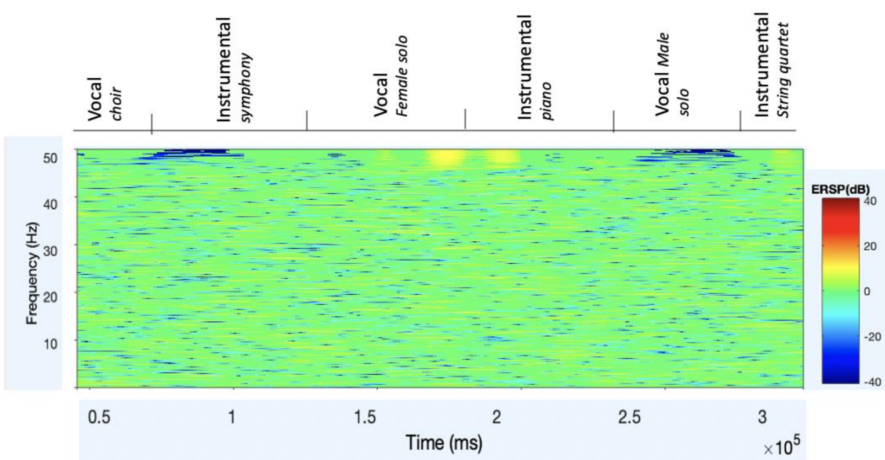


Figure 2: Time/frequency analysis of ICA 1 from subject 1 (non-musician). Time is represented on the X axis and frequency (Hz) is represented on the Y axis. Stimuli that were playing at the time are indicated above the plot. Increased ERSP (dB) as represented by colors indicate

increased prevalence of that frequency. There was an increased prevalence of gamma waves during the female vocal and piano pieces.

Subject 2: Instrumentalist:

Background: The instrumentalist has 12 years of formal instrumental training in piano, clarinet and saxophone, with a specialty in jazz saxophone. She recently began singing in a singing and now has 2 years of choral experience. Over the past year, she has sung significantly more than she has played her instruments. She has studied music history for 1 year, and music theory for 4 years. She currently listens to classical music 4 times a week for an average of 3 hours per week.

Results: Analysis of the data revealed overall increased electrophysiological response to all stimuli around the frontal-central electrodes (F5, F3, F1, FZ, FC5, FC3 FC1) with the electrode with most significant changes in response being F1. There was also an increase in spectral density in C1, CZ, CP1, and CPZ at a frequency of 10 Hz (figure 3). After running an ICA, ICA1 was found to be a component of interest and a time/frequency analysis was conducted. There was found to be an increase in the prevalence of gamma waves between 50-70 seconds, 110-130 seconds, 160-200 seconds, and 290-310, where the stimuli were the mixed vocal piece, the symphonic piece, the female solo vocal piece, and the instrumental string quartet piece respectively. The highest percentage of the gamma wave frequency band was produced during the female solo vocal piece, an operatic aria, with the second highest during the mixed choir piece (figure 4).

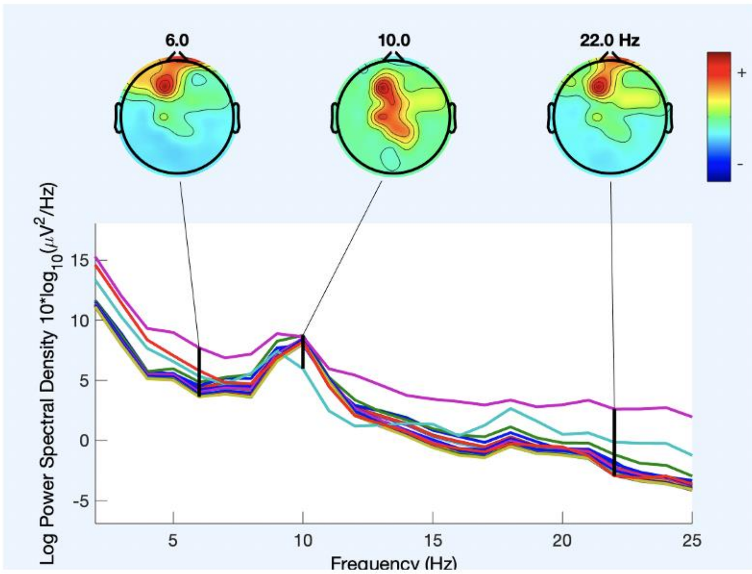


Figure 3: Channel spectral density and map from subject 2 (instrumentalist). At all three represented frequencies, the spectral density is localized around frontal electrodes (F5, F3, F1, FZ, FC5, FC3 FC1), and an increased spectral density in the central electrodes at 10 Hz (C1, CZ, CP1, CPZ).

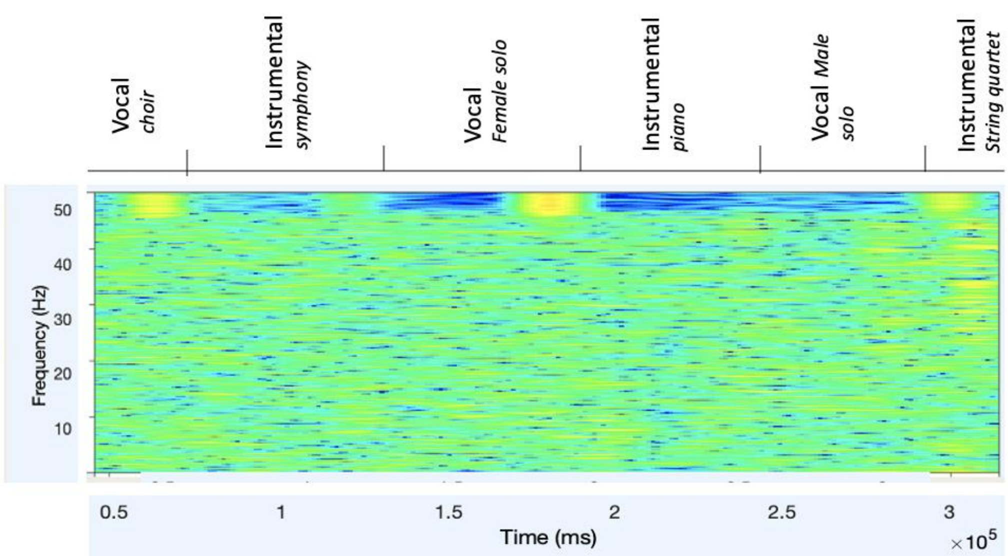
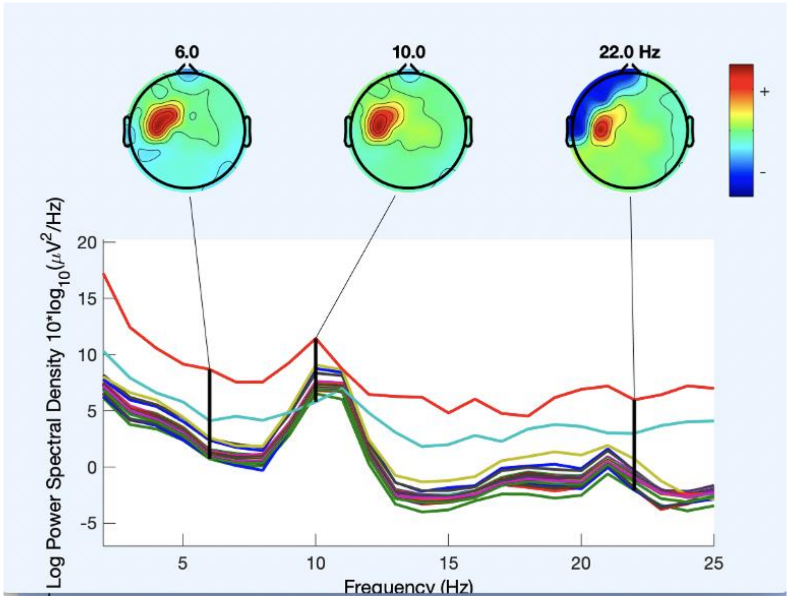


Figure 4: Time/frequency analysis of ICA 1 from subject 2 (instrumentalist). There was an increased prevalence of gamma waves during the mixed choir, symphonic, female solo and string quartet stimuli.

Subject 3: Vocalist:

Background: The vocalist has no formal instrumental training, has been in choirs and musical theatre for 14 years, and has been taking voice lessons with a focus in opera for 10 years, including a gap year where she studied voice full time. She currently sings approximately 12-14 hours a week, including singing with The Trinity College Chapel Singers, musical theatre productions on campus, and individually.

Results: Analysis of the data revealed overall increased electrophysiological response to all stimuli around the frontal-central electrodes of the left hemisphere (F5, F3, F1, FZ, FC5, FC3 FC1) with the electrode with most significant changes in response being FC3. This pattern of spectral density was seen at all frequencies (figure 5). After running an ICA, ICA1 was found to be a component of interest and a time/frequency analysis was conducted. There was found to be an increase in the prevalence of gamma waves between 50-70 seconds, 100-130 seconds, 160-200 seconds, and 290-310, where the stimuli were the mixed vocal piece, the symphonic piece, the female solo vocal piece, and the instrumental string quartet piece respectively. The highest percentage of the gamma wave frequency band was produced during the female solo vocal piece, an operatic aria (figure 2).



Subject 5: Channel spectral density and map from subject 3 (vocalist). At all three represented frequencies, the spectral density is localized around the left frontal-central electrodes (F5, F3, F1, FZ, FC5, FC3 FC1).

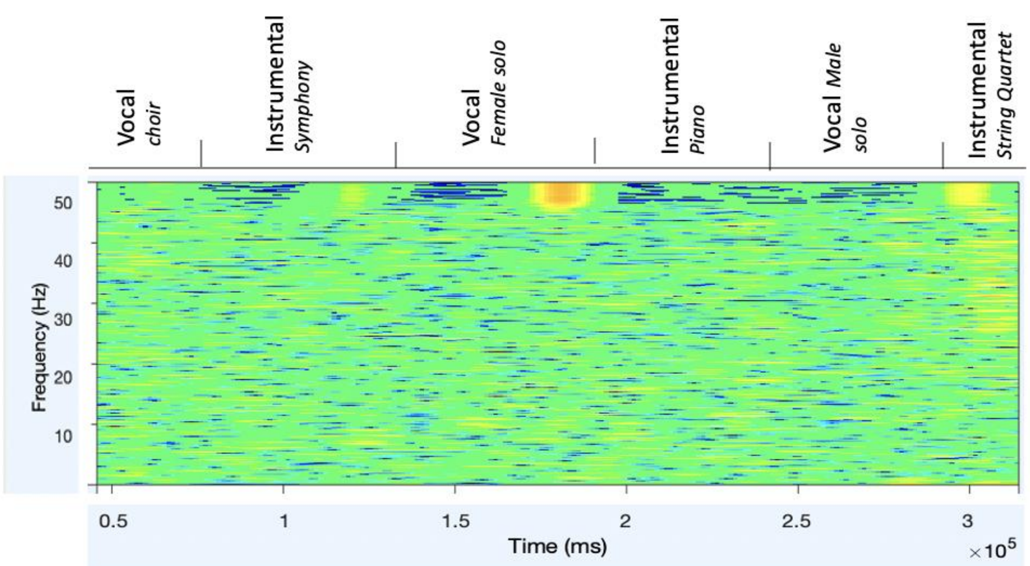


Figure 6: Time/frequency analysis of ICA 1 from subject 3 (vocalist). There was an increased prevalence of gamma waves during the mixed choir, symphonic, female solo and string quartet stimuli. The greatest increase of gamma waves was during the female solo piece.

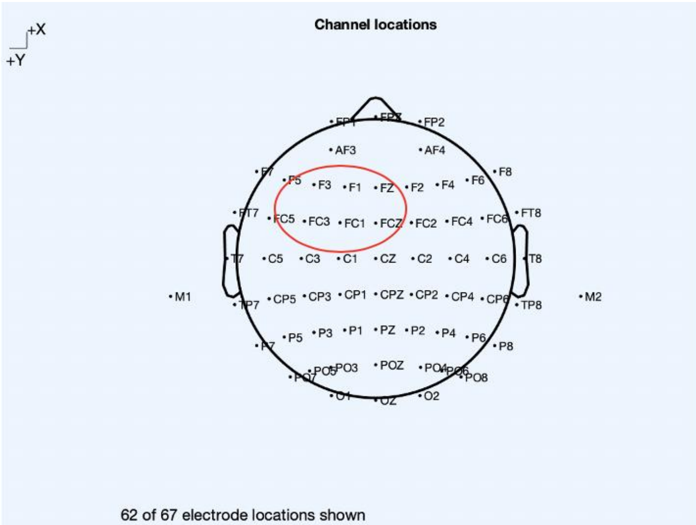


Figure 7: Greatest electrophysiological activity in all subjects.

Discussion

While the results cannot be tested for significance, conclusions about the individuals can still be drawn. The three participants had different electrophysiological responses, in both frequency band prevalence and the stimuli that led to these changes. This indicates that musical experience and background does impact the electrophysiological response to classical music. While the time and frequency band prevalence differed between subjects, all subjects had the greatest electrophysiological response in the same areas of the brain. Activity in all subjects was localized in the left frontal-central areas of the brain (F5, F3, F1, FZ, FC5, FC3 FC1, FCZ) (figure 1). Previous studies have also shown this to be an area of interest in processing music, specifically in responding to ERPs from musical stimuli. These ERPs led to a response in the left hemisphere of musicians but not non-musicians (Overman et al., 2003; Habibi et al., 2012). Similarly, the present study found that continuous musical stimuli also lead to a greater response in musicians than non-musicians, however, there was still a significant electrophysiological response in non-musicians which has not been seen in previous research.

In the case of the vocalist, they responded most strongly to the stimuli that best aligned with their musical expertise and experience, the female opera aria. Previous research found that vocalists were more consistent in perceiving and reproducing sung pitches than instrumentalists due to their previous experience with this skill (Nikjeh, 2006). The results from the vocalist in the present study suggest that this hypothesis could extend to the perception and cognition of continuous musical stimuli. However, these results were not paralleled in the instrumentalist. The instrumentalist had the greatest electrophysiological response to the female vocal piece and the second greatest to the mixed choral piece. They also had an increase in the gamma frequency band prevalence during the symphonic and string quartet pieces. This could be explained by the fact that the instrumentalist is currently singing more than they are playing. They have 12 years of instrumental experience but began singing 2 years ago, and over the past year have been singing more than they have been playing. This suggests that musical stimuli that align with more immediate experience may have a greater electrophysiological response than musical stimuli that align with overall training and background in music.

In all subjects, the increased prevalence of the gamma frequency bands only lasted 20-40 seconds, not the entire musical excerpt. This suggests that the response could be due to something that happened during the excerpt, and that some individuals responded to these events to a greater extent than others. Previous studies using musical ERPs found similar results. Musicians had a greater response to musical ERPs than non-musicians (Overman et al., 2003; Habibi et al., 2012). While any major musical changes were controlled for, smaller changes could have elicited ERPs and have caused a brief increase in activity rather than a prolonged increased response throughout the stimuli.

All subjects had a significant response at 160 secs, which fell during the female vocal excerpt. This suggests that there may be an event at this time that caused a response in all individuals. At this time, there was a change in the music. Preceding this moment, the singer is singing in a minor key, and as the phrase ends, there is a brief moment of silence before the orchestra and singer reenter in the relative major key. In regard to western music theory, this is very common and predictable. In previous experiments, this change was not categorized as an event that would elicit an ERP (Overman et al., 2003; Habibi et al., 2012). However, this change may have acted as an ERP, causing a significant response in all individuals, but a greater response in the vocalist and instrumentalist compared to the non-musician.

Future Research

Results from the instrumentalist raise questions of whether the difference in brain structure or difference in recent experience impact electrophysiological response. It is known that playing an instrument, especially starting at a young age, creates lasting changes in brain structure (Hyde et al., 2009). Therefore, future research could investigate electrophysiological responses in individuals with similar musical upbringings with differing current musical practice.

Throughout this study, unfamiliar musical stimuli were used. Future studies could compare well known classical pieces or pieces that musicians have studied themselves to similar, unfamiliar stimuli. This would further the hypothesis that familiarity and expertise lead to a greater response.

While no definite conclusions can be drawn from this study due to the small sample size, it is clear that there is a connection between musical experience and electrophysiological response to classical music, with promising potential for future research.

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