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ŞEVKİ ÖZER AKÇAY
Atatürk University, Türkiye
akcay_ozer@yahoo.com
orcid.org/0000-0002-0493-9897

FATİH AĞDUMAN
Atatürk University, Türkiye
f.agduman@atauni.edu.tr
orcid.org/0000-0002-5744-7191

An Investigation into Hemodynamic Activity in the Brain During Guitar Performance Using the fNIRS Method

ABSTRACT

The goal of this study is to reveal the relationships between brain activation and the quality of guitarists' solo performances by using Functional Near-Infrared Spectroscopy (fNIRS). Students' brain hemodynamics were measured with fNIRS while playing the guitar, and there was an attempt to determine hemodynamic activity occurring in four different regions of the brain during the best and worst performances. Video recordings were taken during the students' performances, and their performance levels were evaluated using the Guitar Performance Rating Scale [GPRS]. The fNIRS data obtained during guitar performances was analyzed by comparing the hemodynamic (OxyHb) activity in different regions of the cerebral cortex. Also, following this, the t-values of the data were calculated through the MATLAB software, and were visualized in the form of a cerebral cortex heat map.As a result of the fNIRS measurements, it was observed that significant activations occurred in all regions of the participants' brains, and activity was recorded in the regions expected to be activated in tasks associated with music. Especially in the parietal region, it was determined that there was more OxyHb activity during the worst performances than during the best performances. The same situation was observed in the occipital region during the best performances. While intense OxyHb activity was seen in the right hemisphere in the prefrontal cortex region during the best performance, it was determined that the intensity of activity changed towards the left hemisphere during the worst performances. In the temporal cortex region, high OxyHb activity was detected in both hemispheres, although it was more intense and spread over a wider area in the right hemisphere during the best performances. During the worst performances, it was determined that while the activity area in both hemispheres remained the same, the intensity of OxyHb activity decreased.

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Brain Activity in Music

Traditionally, it is assumed that certain regions of the brain are allocated for certain tasks, with different areas being labeled and classified according to their functions. However, this model is increasingly viewed as too simplistic. A more nuanced perspective considers the brain a dynamic system that continuously adapts its circuits to accommodate environmental conditions and bodily needs (Eagleman, 2021). According to modern neuroscience and neuromusicological research, many different regions of the brain engage in simultaneous interactions during processes related to music. These areas include the motor, sensory, visual, auditory, and prefrontal cortices, cerebellum, corpus callosum, hippocampus, nucleus accumbens, and amygdala (Levitin, 2015). All musical sounds are generated from an instrument-like mechanism through actions such as striking, pulling and rubbing, or from a person using their own voice for musical purposes. Therefore, it can be said that music making and movement are inseparable phenomena. According to Levitin (2013), mirror neurons located in the brain's motor cortex become active when listening to music, prompting the individual to engage in a movement associated with music. This movement can involve making music or dancing. The body's movement with music leads to activities in the premotor cortex, motor cortex, cerebellum, and basal ganglia in the brain. For example, fMRI results during a performance involving the right-hand part of a piano piece have shown that the contralateral primary motor cortex and posterior parietal cortex areas of the participants are bilaterally (in both hemispheres) activated (Meister et al., 2004).

Brain Regions Activated During Guitar Performance

The guitar's suitability for both solo performance and accompaniment, its amenability to harmonic functions, its affordability, and its ease of transport are important factors in its widespread use. For many years, numerous practices and studies have been conducted at national and international levels focusing on guitar performance, developing methods, and attempting to elevate guitar performance to higher levels with new methods and techniques. “The study of the neuronal substrate of human social behavior is currently gaining momentum in the young field of social neuroscience. In this context, some researchers argue that music performance is a suitable experimental paradigm to study human interaction and co-operation” (Acquadro et al., 2016). From this perspective, studies focusing on the cognitive/mental processes of guitar performance are increasingly considered to be of growing importance (Akçay, 2016; Butler et al, 2021). The ability of a person playing the guitar to execute numerous complex tasks simultaneously and harmoniously is directly related to the accurate, timely, and flawless inter-regional coordination of processes in the brain. While each region of the brain is responsible for different operations, some regions can also undertake multiple tasks during performance. "Functional brain imaging studies prove that all actions related to music, such as listening to music and playing an instrument, take place in close interaction with many non-musical functions such as movement, perception, attention, memory, and mood in the brain" (Torun, 2016: 68).

Music is a complex activity that encourages different regions of the brain to work together in harmony. This versatility complicates our understanding of the effects of music education and performance on the brain. This study aims to fill this gap, given the guitar's widespread use and its capacity to encompass various styles. Due to the potential of activities like singing to stimulate the speech center and the likelihood of blurring the distinction between speech and musical activity in the results obtained, the focus has been solely on instrumental performance. The guitar was chosen because its performance requires the use of the fingers of both hands. It is thought that more detailed results can be obtained from guitar perfromances than from those of other instruments such as the violin, where one hand's finger movement is more prevalent.

The Method of Functional Near-Infrared Spectroscopy (fNIRS) and Its Use in Music Research

Recent advances in neuroimaging techniques have allowed researchers to track the changes that occur in the brain when learning a new skill based on performance or behavior (Heinze et al., 2019). Functional near-infrared spectroscopy (fNIRS) is a safe and non-invasive technique that measures hemodynamic responses to brain activation in a particular region by detecting the absorption or scattering of light. Compared to other neuroimaging techniques (fMRI, PET, EEG, and MEG), the fNIRS method offers biochemical specificity by measuring the concentrations of various biochemical substances (such as oxy-Hb, deoxy-Hb, and CO redox) (Villringer and Chance, 1997). OxyHb indicates an increase in blood flow in the relevant area, while deoxyHb signals a decrease. This hemodynamic activity is associated with the task/function assigned to the relevant brain region. In addition, the fNIRS method is relatively resistant to variables such as head movement, muscle artifacts, blinking, speech, and environmental electrical noise (Balardin et al., 2017). In cognitive neuroscience, optical methods can be useful in localizing brain activity, especially when other methods cannot be applied. Optical measurements can be made under natural conditions (such as making music, playing a musical instrument, etc.) that are not easily accessible using other functional methods (Villringer and Chance, 1997). One of the main reasons for using the fNIRS method in social neuroscience is that it is cheaper compared to traditional neuroimaging systems with high initial costs such as multi-million-dollar fMRI. A second reason is the low cost of managing the participants in the research. And finally, fNIRS systems are relatively insensitive to participant movement and have a portable, compact, and ever smaller design. This means that fNIRS can be used flexibly in natural environments for improved ecological validity (Di Domenico et al., 2019).

The fNIRS method is used in many studies where music is examined from a neuroscientific perspective. In the literature, along with studies focusing on the detection of brain regions activated in active/passive music listening (Iwasaka et al., 2007; Wakatsuki et al., 2009), activation of various emotions with music (Moghimi et al., 2012), or creating musical images (Power et al., 2010) using the fNIRS method, there are also studies focusing on violinists and pianists using motor and music images to assess neural differences in music perception (Prychitko, 2017); brain function analysis of pianists' sonic environment perception and performance control (Matsuo et al., 2016); measurement of functional neural activity in violin duet performance (Vanzela et al., 2019); focus on prefrontal hemodynamic signals in response to piano chord sequences training (Heinze et al., 2019); examining frontal lobe activity in piano performance (Hashimoto et al., 2006), and measuring the effect of singing in music therapy (Tanaka and Nogawa, 2015). Furthermore, it can be said that the results of studies evaluating hemodynamic concentration changes in primary and premotor cortices as a result of hand gripping and sequential finger movement tasks (Kashou et al., 2016), although not directly in the field of music, represent a significant accumulation of research clarifying the subject as they study hand and finger movements that could explain an important part of the motor movement dimension of music.

The Objective

This study aims to contribute to this evolving perspective by examining hemodynamic activity during guitar performance. The goal of the study is to reveal the relationships between brain activation and the quality of guitarists' solo performances using Functional Near-Infrared Spectroscopy (fNIRS). In line with this goal, the study sought to address the following question, "What is the hemodynamic activity in the prefrontal, temporal, parietal, and occipital regions of the brain during the guitar performances of 8 participants?"

The Methodology

Participants

The participants in the study were 8 guitar students (4 female, 4 male) who are receiving undergraduate education in the Music Sciences Department of Ataturk University's Faculty of Fine Arts, are not left-handed, and do not have a history of any neurological health problems. The study group was selected according to the criterion sampling method, which is one of the non-random sampling methods.

Data Collection Procedure

The neurobiological data of the research (fNIRS measurements) were collected using the NIRX NIRSport II device located at Atatürk University Sports Sciences Application and Research Center. Participants gave their performances in a specially prepared room in the fNIRS laboratory at the research center, under normal light, sitting on a standard instrument stool. During rest periods, the sound level in the room was determined to be a maximum of 48.9 dB and an average of 38 dB. Written commands related to task periods (rest or perform) were given from a screen approximately 2 m away from the participants, and a sound warning was given simultaneously (Figure 1).

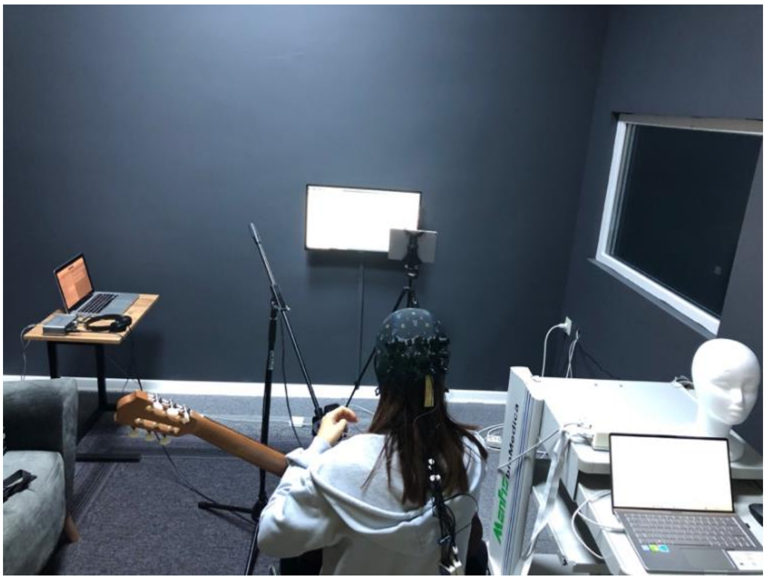

Figure 1. The room where fNIRS measurements were made, the equipment used, and the participant placement

In addition to neurobiological data related to guitar performance, participants' performances were recorded using video recording and these recordings were evaluated using the Guitar Performance Rating Scale developed by Akçay (2011). The video images of the participants' guitar performances were recorded using an iPad Pro 9.7 inch (model no. MLMV2TU/A) tablet at a resolution of 1080p HD, 60 frames/sec. Audio recordings of the performances were also made separately in Logic Pro X using a condenser microphone (Lewitt LCT 441-Flex multipattern condenser) in sync with the video recordings. Audio and video recordings were combined in Logic Pro X. No effects, filters, etc., and signal processors were applied to the audio files.

In the data collection process of the research, each participant repeatedly performed the piece they had chosen (the one which they think they perform best) for 4 separate regional measurements, with 2 blocks per regional measurement. Allowing participants to play a piece they chose themselves and think they play best was favoured to increase diversity and create a natural performance environment. Since the device used for fNIRS measurements is not suitable for measuring all regions at once, it was decided that to obtain more detailed information in each region, separate measurements would be made for four different brain regions on different days for participants. For each performance phase, a specially designed cap was used to detect hemodynamic activity in the relevant brain region (1. Frontal, 2. Temporal, 3. Parietal, and 4. Occipital) with fNIRS. Each stage consists of 2 repetitions of a measurement block consisting of 60-seconds rest (R) and 60-seconds guitar performance task (T) parts (1 block = R + T + R + T + R + T + R = 7 min.).

During fNIRS measurements, a calibration process was applied before each stage to ensure that all optodes worked correctly for each participant. The measurement of 1 phase for a participant, including solving signal transmission problems originating from the structure of the hair (dark color, density, length, etc.) in optodes with disturbed signal transmission, took about 15-30 minutes during the calibration process. For each participant, only a single brain region measurement was made in one day. The measurements lasted for 2 weeks, 1 week in June 2021 for male participants and 1 week in November 2021 for females. Measurements were made on Monday (frontal) and Tuesday (temporal), a break on Wednesday, and other measurements on Thursday (parietal) and Friday (occipital). The device used for fNIRS measurements during participants' guitar performances has 16 optodes, 8 light sources, and 8 detectors. A separate cap and optode placement model with different numbers/arrangements were used for each stage in the experimental procedure. This study was approved by the Committee on Fine Arts Ethic of Ataturk University with judgement 4 numbered and dated 15th February 2021.

Data Analysis

In the analysis of the data, the Guitar Performance Rating Scale (GPRS) was used to determine the performance levels of the participants, and all measurements for all brain regions were evaluated according to the order of measurement. The scores obtained from the measurements performed sequentially for each region were listed, and the best and worst performances of each participant were determined. The fNIRS data of these performances were selected and relevant relational statistical analyses were performed.

In the study, oxyhemoglobin values from cerebral cortex hemodynamic data measured at a light wavelength of 760 nm with the fNIRS device during the guitar performance of participants were analyzed. Before starting the analysis, the data quality of the channels (gain = 1, variation coefficient = %7.5) was checked using the nirsLAB software. After determining no major physiological artifacts were present, it was decided to include all channels in the analysis. Functions from the Homer II interface with MATLAB were used in the data pre-processing steps. A Butterworth filter was used to eliminate potential respiration and heart rate signals and unwanted high-frequency noise (Huppert et al., 2009). As a first step, the Butterworth band-pass (0.005 – 0.08 Hz) filter was applied with the hmrBandpassFilt function. Afterwards, to reduce the movement artifacts in the signal, the CBSI (Correlation Based Signal Improvement) method was applied using the hmrMotionCorrectCbsi function.

In fNIRS analyses, the block average technique was used. The block average method is used to minimize the chance that cerebral activity during the task may be random. The OxyHb activation in different regions of the cerebral cortex during the guitar performance was analyzed by comparing it to the resting state through the fNIRS recording. Moreover, after calculating the t-values of the data through MATLAB software, they were visualized as a cerebral cortex heat map.

Findings

Findings Related to Guitar Performance Levels

According to the results obtained, the average Guitar Performance Rating Scale (GPRS) scores during the prefrontal brain region measurements of the participants ranged from 48.33 to 80.33. The lowest score received was 41 (Participant 3), and the highest score was 86 (Participant 4). The averages of the temporal brain region scores ranged from 49.33 to 78.66, with the lowest score 38 (Participant 3), and the highest score 83 (Participant 4). The average scores for the parietal region ranged from 51.16 to 78.16. The lowest score was 47 (Participant 3), and the highest score was 81 (Participant 4 and Participant 8). The averages of the occipital region scores ranged from 54.00 to 78.66. The lowest score was 51 (Participant 3), and the highest score was 88 (Participant 4). The data obtained with GPRS (Table 1) indicates that the average scores related to poor performance of the participants gradually increased from the first day when the prefrontal region measurements were made to the last day when the occipital region measurements were made (respectively prefrontal-48.33, temporal-49.33, parietal-51.16 and occipital-54.00), but the best performance scores did not change significantly (even though there was a very small decrease, this decrease was considered insignificant).

Table 1. GPRS scores of participants

Participant	Cortex	Lowest score / Measurement	Highest score / Measurement	Average score
P1	Prefrontal	62p/3rd measurement	68p/1st measurement	65.16
P2		43p/4th measurement	60p/6th measurement	53.66
P3		**41p/3rd measurement**	58p/1st measurement	**48.33**
P4		72p/6th measurement	**86p/3rd measurement**	**80.33**
P5		52p/3rd measurement	63p/4th measurement	57.50
P6		52p/1st measurement	69p/6th measurement	59.33
P7		59p/2nd measurement	65p/6th measurement	63.33
P8		70p/6th measurement	79p/2nd measurement	73.16
P1	Temporal	60p/4th measurement	68p/6th measurement	65.16
P2		46p/5th measurement	57p/3rd measurement	51.66
P3		**38p/3rd measurement**	63p/4th measurement	**49.33**
P4		71p/2nd measurement	**83p/5th measurement**	**78.66**
P5		59p/6th measurement	72p/3rd measurement	65.00
P6		58p/6th measurement	66p/2nd measurement	63.00
P7		62p/4th measurement	68p/6th measurement	64.00
P8		68p/2ndmeasurement	76p/4th measurement	69.83
P1	Parietal	65p/3rd measurement	71p/1st measurement	67.66
P2		55p/3rd measurement	72p/4th measurement	61.33
P3		**47p/3rd measurement**	56p/1st measurement	**51.16**
P4		74p/3rd measurement	**81p/2nd measurement**	77.83
P5		56p/4th measurement	65p/6th measurement	60.16
P6		55p/1st measurement	65p/6th measurement	60.83
P7		63p/3rd measurement	65p/6th measurement	64.00
P8		74p/1st measurement	**81p/3rd measurement**	**78.16**
P1	Occipital	68p/5th measurement	75p/2nd measurement	70.16
P2		57p/3rd measurement	66p/5th measurement	61.16
P3		**51p/3rd measurement**	56p/4th measurement	**54.00**
P4		71p/3rd measurement	**88p/1st measurement**	**78.66**
P5		63p/6th measurement	70p/2nd measurement	66.33
P6		60p/2nd measurement	70p/4th measurement	66.00
P7		67p/6th measurement	71p/2nd measurement	69.33
P8		75p/2nd measurement	81p/3rd measurement	77.83

Accordingly, it can be said that the participants showed slight improvements in their poor performances due to the influence of their practice and to repeated measurements taken during the process, but their best performance levels remained unchanged. In other words, it can be said that they corrected their mistakes and improved their poor performances as they repeatedly played the same piece during repeated measurements. Whether the musical activity is listening to music or making music, it is clear that a series of intense activations in many regions of the brain are triggered. The time spent in these musical activities and the level of immersion in the activity (concentration, interest-desire, motivation, flow, etc. intrinsic factors) may be decisive in the formation of new neural networks in the brain, strengthening existing neural networks, and turning into anatomical changes as practice increases. As the duration and the quality of the duration increase, the change and transformation occurring in the brain can also increase (Akçay, 2021).

Findings on Hemodynamic Activity in the Prefrontal Region

According to fNIRS measurements, it has been determined that there is OxyHb activity in 11 channels during the best performances and in 8 channels during the worst performances in the prefrontal region (Figure 2). It has been identified that there is an increase in activation in the *agranular frontal, opercular (Broca), frontopolar (DLPFC[1]), orbital, intermediate frontal*, and *middle frontal gyri* in the participants' brains during guitar performance

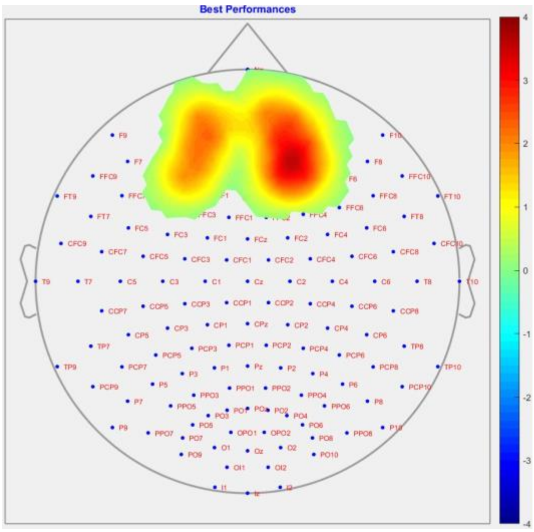

Figure 2. OxyHb activity observed in the prefrontal region during the best performances

[1] Dorsolateral prefroantal cortex

In Figure 2, more OxyHb activity is seen in the prefrontal region of the right hemisphere during the best performance. In the study by Iwasaka et al. (2007), it was stated that playing the strings with both hands on stringed instruments creates a fundamental effect that increases blood or OxyHb volume in the frontal lobe, near the positions F3, F7 or F4, F8[2] in the 10-20 system. The same study presents data that there is an increase in frontal lobe OxyHb activity during tone production in vocal and instrumental performance. While activations occurring in the prefrontal region in both hemispheres during musical tasks cannot be fully explained, there is some evidence that regions that play an active role in language-related processes are also activated in musical processes. Since the prefrontal cortex also plays a mediating role in accessing the hippocampus, it mediates access to long-term and working memory for music (Akçay, 2021). The left prefrontal cortical region is usually an area active in functions such as encoding new aspects of information retrieval from semantic (meaningful) memory (Matsuo et al., 2016). In an fNIRS study investigating the prefrontal hemodynamic response during a single left-hand arpeggio learning session in piano performance, a statistically significant hemodynamic response difference was detected in the right medial orbitofrontal cortex during the execution of the arpeggio task compared to being at rest. It has been suggested that right hemisphere lateralization could be explained by the use of the left hand to play the chords. Additionally, a theory regarding the involvement of the orbitofrontal cortex, possibly related to the control of motor responses and error monitoring, is supported by literature that identifies this area as a top-down motor controller (Heinze et al., 2019).

[2] F3-F4: Intermadiate frontal gyrus (includes frontal eye fields), F7-F8: Orbital gyrus

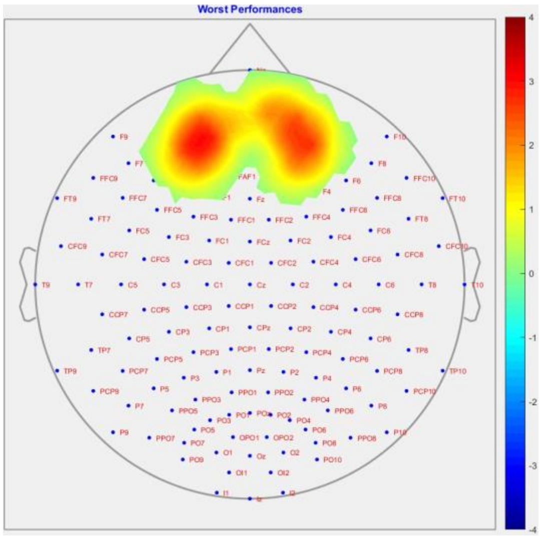

Figure 3. OxyHb activity observed in the prefrontal region during the worst performances

As seen in Figure 3, the regions where OxyHb activity is observed and the intensity of the activation during a poor performance are different when compared to a good performance. It is observed that the OxyHb activity, which is intense in the right hemisphere during a good performance, is at a lower level during a poor performance, and the area where the activity spreads has relatively shrunk. However, an increase in OxyHb activity is seen in the left hemisphere. This shift in the hemodynamic response during the worst performances can suggest underlying neural mechanisms responding to the less accurate execution of the musical piece. The differentiation in prefrontal activation between the best and worst performances may be a new contribution to our understanding of musical cognition, especially since it is related to motor control, error monitoring, and possibly emotional regulation during the performance. Hemodynamic activity in the prefrontal region during guitar performance provides unique insights into the cognitive and emotional processes involved in music performance. This study, utilizing fNIRS, provides valuable information that is consistent with current research about complex brain dynamics during music performance and sheds new light on the interactions between motor control, error detection, memory access, and emotional response. Findings not only emphasize the importance of the prefrontal region in musical tasks, but also present a new perspective on the complex relationship between music, memory, and emotion. Future research can expand these findings by exploring other musical instruments or integrating additional brain imaging techniques for a more comprehensive understanding of the neural basis of musical expression.

Hemodynamic Activity Findings in the Temporal Region

During the best performances, it was found that there was OxyHb activity in 12 channels in the temporal region measurements, while during the worst performances, it was in 11 channels (Figure 4). During the best guitar performance, it was observed that there was OxyHb activity in *the Broca area, orbital gyrus, anterior & posterior transverse temporal, middle temporal gyrus, supramarginal gyrus, angular gyrus, and Heschl's gyrus (primary auditory cortex)* regions of the brain.

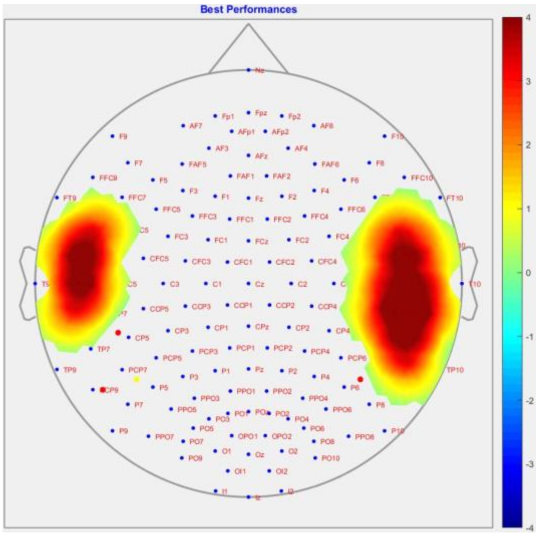

Figure 4. OxyHb activity seen in the temporal region during the best performances

In Figure 4, it can be seen that there is more OxyHb activity in the temporal region of the right hemisphere during the best performance. Auditory pathways do not just go up and down to the cortex; there are many important connections between the auditory cortices in the left and right hemispheres through the corpus callosum. These connections between hemispheres are organized tonotopically. There are also cortico-cortical pathways that allow the integration of auditory processes with other sensory systems, working and long-term memory processes, stored memories, and information. Along with ascending and descending pathways, cortical pathways represent complex connection patterns that are critical not only for processing sound but also for integrating information into other regions of the brain (Baars and Gage, 2010). When musicians perform music, they need to focus on the music they are performing without allowing distracting stimuli from their environment to hinder them. For this, executive inhibition is a very important cognitive function (İnal, 2019: 17).

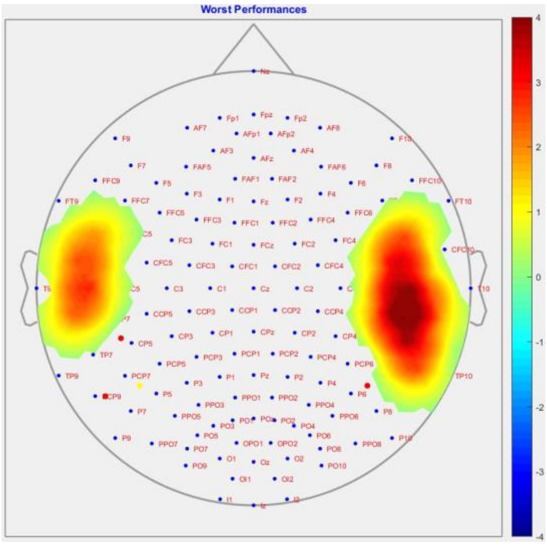

Figure 5. OxyHb activity seen in the temporal region during the worst performances

As can be seen in Figure 5, it has been determined that the level of OxyHb in the temporal cortex regions in both hemispheres is lower when compared to the best performances. In the temporal cortex, the most functionally important regions in terms of musical tasks can be said to be the auditory cortex, the Broca and Wernicke areas, which are language processing areas, the planum temporale, and the middle temporal gyrus. The auditory cortex is not a single brain area, it consists of several structural (anatomical) areas that differ in their roles in decoding the sound. The auditory cortex is a region specialized for sound processing within the cortex. It is located within the Sylvian fissure on the surface of the Supratemporal plane and upper parts of the superior temporal gyrus in each hemisphere. Although the role of each area in the human auditory cortex is not fully understood, work is ongoing to map the areas within the auditory cortex and their corresponding roles in perception. Researchers have noted that the language function tends to be lateralized to the left hemisphere and have proposed that the larger left hemisphere planum temporale (PT) reflects its role in decoding auditory language (Baars and Gage, 2010). Early anatomical studies provide significant evidence that the PT in the human auditory cortex is much larger in the left hemisphere in individuals using their right hand. The prevalence of this asymmetry and its proximity to Wernicke's speech comprehension area in the auditory fields suggests the hypothesis that the PT is an auditory speech and language processing area. This idea is supported by neuroimaging studies investigating the functional role of the PT in speech perception. However, neuroimaging studies of the PT's response to different speech classes and non-speech sounds also support the idea that the functional role of the PT is not limited to speech sounds. Recognized sounds among environmental sounds activate the regions in the superior temporal sulcus and the middle temporal gyrus (MTG) in both hemispheres (Baars and Gage, 2010).

There are many similarities in speech and music perception: music has complex expression structures, and its perception involves matching sound to meaning (and emotion). Music perception allows for the recognition of melodies despite differences in instruments, tonalities, and tempos; therefore, it cannot be a system based on absolutes but must be represented through relativities. The fundamental difference between speech and music perception is that all typically developing humans master speech perception. People are not only good at perceiving speech, they are masters at it! The situation is not the same in music perception. There is much more variability in music perception ability and it involves significant explicit learning processes along with a degree of musical acumen. The variability in music perception ability combined with many levels of music education and skill has made the study of music perception challenging due to these intrinsic differences. Music perception is quite different from speech perception, as many musical signals do not contain any lyrics. Therefore, music perception processes likely have a more abstract (non-linguistic) representational basis. The structure in music is resolved in a broader network of brain areas in both hemispheres. Some aspects of music perception, especially musical structure (syntax) and musical meaning (semantics), share the same neural area with brain areas specialized for language processing (Baars and Gage, 2010). In the literature, there are studies associating the activity of listening to music with the right hemisphere, and the activity of hearing music with the left hemisphere. In a study where music perception in professional musicians was investigated with the fMRI method, the activation determined in the left superior temporal gyrus region while listening to music of the type in which they specialize, was defined as "hearing music" and associated with familiarity with music. The activation observed in the right superior temporal gyrus region while listening to music of types in which they do not specialize was defined as "listening to music" and, it is argued, is the result of analytical listening (Bozkır, 2009).

Hemodynamic Activity Findings in the Parietal Region

The best performances during parietal region measurements revealed OxyHb activity in

2 channels (Figure 6), while the worst performances displayed OxyHb activity in 7 channels (Figure 7). By looking at the difference in OxyHb levels between the best and worst performances, activation was detected in 2 areas (Figure 8). *The angular gyrus* and *peristriate (tertiary or associative visual cortex, V3)* regions were found to be activated during the best guitar performances.

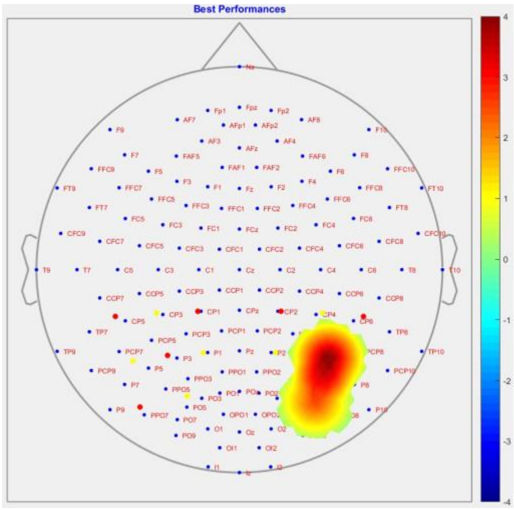

Figure 6. OxyHb activity in the parietal region during the best performances

Figure 6 shows intense OxyHb activity in the right parietal region. This may be related to the fact that playing the guitar requires more intricate motor movements in the left hand.

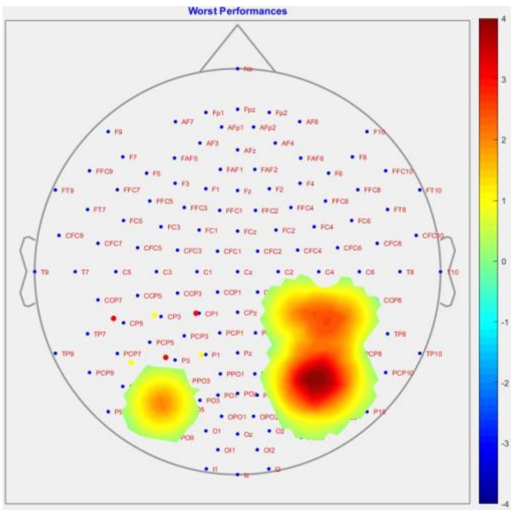

Figure 7. OxyHb activity in the parietal region during the worst performances

In the worst performances, in addition to the areas active during the best performances, the preparietal (somatosensory assoc. cortex) and supramarginal gyrus regions were found to be activated. Figure 7 shows that the OxyHb activity in the right parietal region was spread over a wider area compared to the best performances, and OxyHb activation occurred in the peristriate (tertiary or associative visual cortex, V3) region in the left hemisphere, which is active in processing visual information. This suggests that the increase in these areas may be due to the compensation made for errors during poor performances, and the processing of visual information regarding whether the positions of hands and fingers are correct.

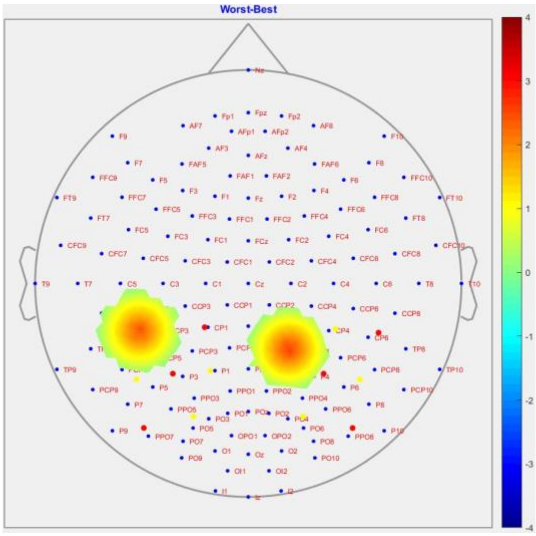

Figure 8. The difference in OxyHb activity of the best and worst performances in the parietal region

When looking at the difference between performances, it was found that in the gigantopyramidal (primary motor cortex) and intermediate, caudal, and rostral postcentral (primary somatosensory cortex) regions, there was more OxyHb activity in the worst performances than in the best.

The parietal lobe is closely associated with processes related to the sense of touch. It has a map-like structure where the body is represented, and in the parietal lobe, the representation of the fingers occupies a larger area than do other limbs (e.g., arms, feet, toes) (Baştuğ-Şen, 2002: 113; Yağışan, 2008: 70). The areas of difference seen in Figure 8 are the gigantopyramidal (primary motor cortex) in the left hemisphere and the preparietal (somatosensory assoc. cortex) and superior parietal (somatosensory assoc. cortex) regions in the right hemisphere. These areas are brain regions that are activated in motor movements, touch, saccadic movements, primary motor movements, motor imagery in the left hemisphere; moving fingers, hands, and arms, processing pain information, visuomotor attention, motor imagery, and working memory functions in the right hemisphere. The level of OxyHb in these areas was found to be higher in the worst performances than in the best performances. This is thought to be due to the planning and execution of motor movements during poor performance, and to visual attention given to the hands and fingers related to these movements.

In particular, the activation in the inferior temporal gyrus region is thought to be due to the participants' movement dependent on visual stimuli, such as focusing on the instrument and hands-fingers while playing the guitar, not making mistakes or compensating for the mistakes made (Gaser and Schlaug, 2003). The parietal lobe in the right hemisphere plays a crucial role in the perception of spatial relationships. Perception of spatial relationships between objects, drawing, playing an instrument, etc. are important for these movements.

The behavior of a musician in performance requires numerous complex skills such as translating the visual data of the note into motor movements where both hands are used in a coordinated manner; processing multiple sensory data; developing good movements for the metrical precision of the non-dominant hand, and evaluating the auditory feedback of the performance (melodic, harmonic and rhythmic accuracy, intonation, etc.) (Schlaug, 2015). Therefore, it can be said that a person playing the guitar needs to perform complex behaviors such as reading the notes, understanding the notes, making the movements demanded by the notes, remembering the musical situations and movements not written in the notes, listening other musician/musicians if playing with them, and listening to their own playing. Making music and enacting movements are inseparable phenomena. The body's movement with music leads to activities in the regions of the brain related to movement. Therefore, one of the dimensions related to playing the guitar can be defined as a broad organization of movement involving the muscular and skeletal systems. The degree of harmony and automation in the coordination of these movements is considered to be directly proportional to the excellence of the guitar performance (Akçay, 2016). Therefore, it can be thought that as the guitarist's performance is perfected, the hemodynamic activity in the parietal region will decrease. More controlled studies are needed for this.

Findings of Hemodynamic Activity in the Occipital Region

During the best performances, OxyHb activity was detected in 10 channels in the occipital region measurements (Figure 9), and during the worst performances, in 4 channels (Figure 10). Looking at the difference in OxyHb levels between the best and worst performances, it was determined that there was more OxyHb activity in 1 channel (Figure 11) in the best performances than in the worst. During the best guitar performance, OxyHb activity was observed in *the angular gyrus; peristriate (tertiary or associative visual cortex., V3), on the left fusiform gyrus and on the right precuneus; parastriate gyrus (secondary visual cortex., V1); on the left middle occipital gyrus and on the right inferior occipital gyrus; striate gyrus (primary visual cortex., V1)* regions of the brain.

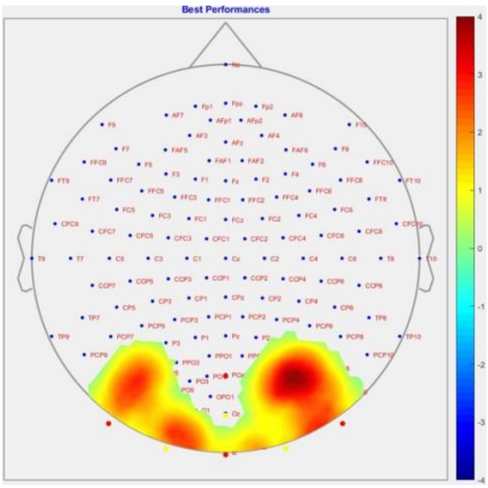

Figure 9. OxyHb activity observed in the occipital region during the best performances

In Figure 9, intense OxyHb activity is observed in the right occipital region. This could be associated with the more delicate and complex motor movements related to playing the guitar in the left hand, and thus the performance of hand movements in a wider area (the guitar keyboard is approximately 45 cm).

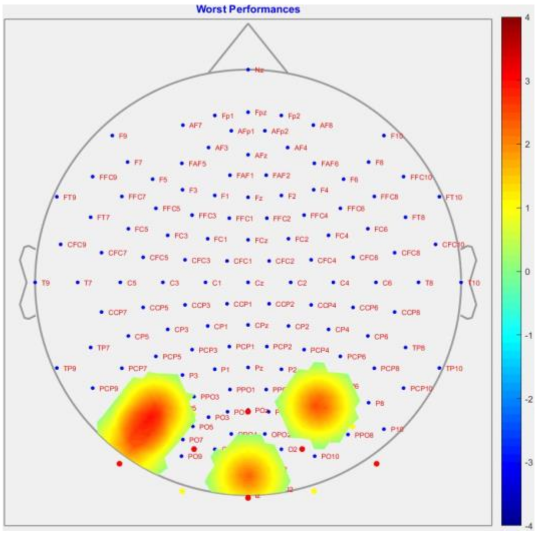

Figure 10. OxyHb activity observed in the occipital region during the worst performances

In Figure 10, more intense OxyHb activity is seen in the left occipital region. This could be related to the right-hand movements in guitar playing being in a narrower area (just moving from string to string) and being mostly finger movement.

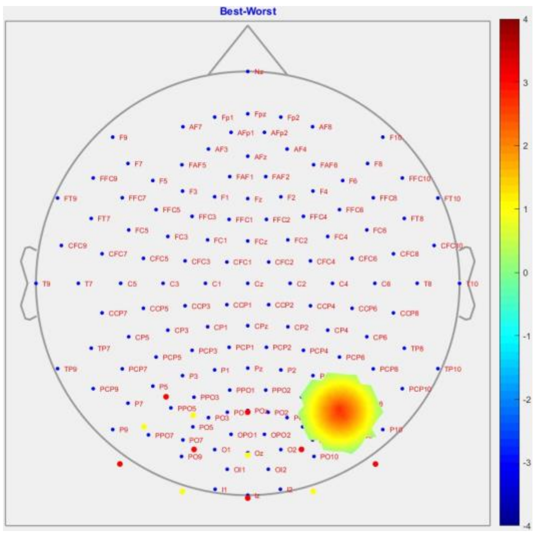

Figure 11. The difference in OxyHb activity of the best and worst performances observed in the occipital region

The occipital lobe is usually closely related to processes related to the processing of visual and visual-spatial information. In particular, the right occipital lobe is more active in the processing of visual-spatial information (İnal, 2019: 6). The understanding of the position of an object in space together with its features takes place via two neural pathways that are related but independent. Both neural pathways are associated with the primary visual cortex. The neural pathway that enables the evaluation of object features is defined as the occipitotemporal pathway, and the pathway that allows the evaluation of the object's position in space and its relation to its surroundings is defined as the occipitoparietal pathway. The ‘what’ and ‘where’ information coming from these two pathways merges in the prefrontal cortex. It is associated with the assumption that musicians have better-than-average eye-hand coordination and respond more quickly to visual stimuli (İnal, 2019: 7-16). During a musician's performance, activations resulting from activities such as reading music, decoding information to play/sing, and monitoring the instrument’s performance (Ata, 2015: 16) occur in the visual cortex. In this study, as there were no tasks such as reading music, decoding, etc., it was accepted that the determined hemodynamic activity originated from the guitarist's monitoring of his/her own performance.

Results and Discussion

The fNIRS measurements of the study revealed that significant activations occurred in all regions of the participants' brains, and that activity was recorded in areas expected to be activated in tasks associated with music. According to the measurements related to the prefrontal cortex region, it was shown that the activity during the best performance was intense in the right hemisphere, while in the worst performances, the density in the right hemisphere decreased and the density in the left hemisphere increased. This situation may have arisen from the fact that the left prefrontal region is generally associated with semantic (meaningful) memory and the right prefrontal region with functions such as controlling motor responses. In the context of musical skills, while rhythms, intervals, pitches, and melodic structures are processed analytically in the left hemisphere, meaning-making processes that determine behaviors such as emotional excitement, appreciation, etc. occur in the right hemisphere (Akçay, 2016; Sachs et al, 2016). Sachs and colleagues (2016), using a combination of survey data, behavioral and psychophysiological measurements and diffusion tensor imaging, found that the white matter connectivity between the sensory processing regions in the superior temporal gyrus and the emotional and social processing regions in the insula and medial prefrontal cortex explains individual differences in reward sensitivity to music. The researchers suggest that individual differences in sensory access to the reward system have a neural basis and that social-emotional communication through the auditory channel may provide an evolutionary foundation for music-making as an aesthetically rewarding function in humans. In a study of a decoding approach aimed at predicting an individual listener's musicianship class from the dynamic neural processing of musical features, the brain regions chosen by the decoder that best individually differentiated between musicians and non-musicians were identified as the bilateral anterior cingulate and paracingulate gyrus (ACG), which form the opercular part of the right inferior frontal gyrus, and the right superior temporal gyrus (rSTG). This group of areas can be considered as core areas that are most affected by musical education and as a result, exhibit the highest discrimination power in processing musical features among all brain areas (Saari et al., 2018).

According to the measurement results related to the temporal cortex region, it was determined that there was intense OxyHb activity in the brain regions activated in functions such as understanding pitches in the brain, listening or remembering song lyrics, rhythm, tempo, timbre, pitch tracking, musical syntax, tonal expectations and semantic recall, episodic memory, interval and melody processing, musical memory (planum temporale), decoding the code of auditory language, decoding the code of spatial position, auditory object identification, musical performance, calculation/planning, behavioral control (inhibition), somatosensory integration, consciousness, and attention, regardless of whether the performance is good or bad. There are also cortico-cortical pathways that enable the integration of auditory processes with other sensory systems, working memory and long-term memory processes, stored memories, and information. Together with ascending and descending paths, cortical pathways represent complex connection patterns that are critical not only for processing sound but also for integrating information into other areas of the brain (Baars and Gage, 2010). When musicians perform music, they need to focus on the music they perform without allowing distracting stimuli from their surroundings to inhibit them. Executive inhibition is a very important cognitive function for this (İnal, 2019: 17).

Playing a musical instrument typically requires the simultaneous integration of multimodal sensory and motor information with multimodal sensory feedback mechanisms to monitor performance. It is known that motor-related regions such as the premotor and cerebellar cortex play a critical role in planning, preparing, executing, and controlling bimanual sequential finger movements. In particular, it is known that the superior parietal region plays an important role in integrating multimodal sensory information (e.g., visual, auditory, and somatosensory) and guiding motor operations through intense reciprocal connections with the premotor cortex (Gaser and Schlaug, 2003). The parietal lobe is often closely associated with processes related to the sense of touch. According to the measurement results related to the parietal cortex region, during the best performances of the participants, intense OxyHb activation was observed in the brain regions activated in connecting different subsystems to each other, semantic memory, consciousness attention, control of behaviors, planning, and processing of visual information. During the worst performances, in addition to these regions, intense OxyHb activation was observed in brain regions activated in functions such as moving fingers, hands and arms, visuomotor attention, motor movement images, working memory, musical memory, and calculation/planning. In a comparative MRI study on a sample consisting of professional musicians, amateur musicians, and non-musicians, it was determined that the gray matter density in the primary motor and somatosensory area, premotor area, anterior superior parietal area, and inferior temporal gyrus (bilaterally) was high in professional musicians, medium in amateur musicians, and low in non-musicians (Gaser and Schlaug, 2003).

According to the measurement results related to the occipital cortex region, it was observed that during the best and worst performances, one of the main connection centers connecting different subsystems to each other in the brain was activated: the region activated during semantic memory, familiarity/similarity, consciousness, visual attention, and biological visual movement in the right hemisphere; visual perception, visual scanning in the left hemisphere, saccadic eye movement; visual centers associated with wide line/pattern models in the right hemisphere. This can be said to be due to the guitarist focusing on finger and fret positions in his/her left hand and string transitions in his/her right hand while playing, and the change of these focuses (saccadic eye movements). Furthermore, regarding the processing of visual information, the intense OxyHb activity recorded in the right occipital region during the best performance may be associated with the fact that the motor movements related to playing the guitar are more delicate and complex in the left hand, and as a result, hand movements are made in a wider area (the guitar keyboard is about 45 cm). The intense OxyHb activity recorded in the left occipital region during the worst performance may be related to the fact that the right-hand movements related to playing the guitar are in a narrower area (only from string to string) and are predominantly finger movements.

In textbooks, advertisements, and popular culture, the brain is often depicted as an organ with different regions dedicated to specific tasks. All brain regions can be labeled and classified according to certain tasks and functions. However, this model is inadequate and overlooks the most important characteristic of the brain. This is because the brain is a dynamic system that continuously changes its circuits to adapt to the requirements of environmental conditions and the capabilities of the body (Eagleman, 2021). "The very recent application of network science algorithms to brain research allows an insight into the functional connectivity between brain regions. These studies in network neuroscience have identified distinct circuits that function during goal-directed tasks and resting states" (Reybrouck et al, 2018). Especially starting music education at an early age or engaging in music-related activities for a long time is counted among the activities (such as reading books, doing sports, learning a new language, or being interested in other branches of art, etc.) that affect the most in this dynamic process where the brain reorganizes itself and constantly changes its circuits. The main reason why music is one of the most influential activities is that it activates many regions in almost the entirety of the brain sequentially and simultaneously. More controlled research is needed to understand the details of the effects of music education and engaging with music on the brain. Especially in the context of connectomics, understanding what is happening in the brain during musical tasks and investigating how much performance in non-musical tasks and functions is affected by music education/engaging in musical activities can provide evidence that will open new ways for music education programs and music education strategies to be designed and updated in the future.

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