FRONTAL ALPHA ASYMMETRY AND MUSIC INDUCED PLEASURE

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Abstract

Frontal alpha asymmetry (FAA) is a neural phenomenon studied for several decades. It has been connected to approach/avoidance motivation and emotional valence. Current study investigates FAA in the familiar and unfamiliar music conditions with low-cost wireless EEG device (Muse S). FAA as well as familiarity of music is linked to dopamine response in fMRI studies. Therefore, the current study suggests that the FAA measured with low-cost wireless EEG devices could be an affordable method to measure one's emotional state and felt pleasure. Based on previous studies this can be tested by playing subjects familiar and unfamiliar music while measuring EEG. Results of the current study suggest that familiarity of music has a significant effect on FAA and the results are more evident when the subject is listening to high valence music.

Keywords: EEG, Frontal alpha asymmetry, Familiarity, Pleasure, Dopamine, Emotions, BCI.

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1 INTRODUCTION

We are beings that are in constant interaction with the environment by shaping it and adapting to it. Our ancestors who lived in Manhattan thousands of years ago would not recognize their home if they could travel in time to the year of 2022 since the later generations have shaped the environment so drastically. At the same time, we feel the urge to close our eyes and fall asleep after we have been long enough without a source of light, just like our ancestors who lived in the forests of Manhattan.

The first chapter lays an image of our deep connection with the environment as a being that is shaping it and adapting to it. Thanks to technological development, we can add more layers and dimensions to this relationship by creating interfaces that can be used for emotional interaction with the environment. We have several products available for measuring our body to get metrics about our emotional state. By connecting this data innovatively to the environment, we can support our emotional well-being more effectively since we are constantly adapting our behavior based on the environment.

The current study is a pre-study for developing such a system by looking into available neurofeedback metrics. The interest of the current study is to use low-cost EEG devices to investigate the connection of music induced pleasure and emotional valence and frontal alpha asymmetry (FAA). FAA is a neural phenomenon that is linked to emotional valence (Zotev et al., 2016; Harmon-Jones, 2003) and therefore it is a promising biofeedback signal to use in adaptive environments with a brain-computer interface (BCI) technology. The current study paves a way for the future brain-computer interface development by looking into a data stream available with low-cost wireless EEG devices that is easy to adapt into real-life situations. The current study investigates the possibility to recognize changes in one's emotional state from a rather simple signal when compared to medical EEG devices with multiple electrodes. Research questions of the current study are:

1) How familiarity of music affects frontal alpha asymmetry?
2) How familiarity of music affects frontal alpha asymmetry in high valence music and low valence music conditions?
3) How pleasant and unpleasant audio-visual stimuli affect frontal alpha asymmetry?

Besides being a pre-study for emotion adaptive environment technology, the current study has other real-life applications as well. In the music business the gained knowledge of music induced pleasure could improve the way music recommendation and commercial radio station playlisting works. Based on previous research, the best-performing songs are optimally different from their peers (Askin & Mauskapf, 2017). Songs with an atypical low or high number of instruments outperform their contemporaries (Nunes & Ordanini, 2014). Songs that have more atypical lyrical topics within a particular genre perform better commercially (Berger & Packard 2018). The harmony of the most successful songs contains more surprises (Miles, Rosen & Grzywacz, 2017). Given these findings, making a great radio playlist, or giving best recommendations is quite difficult by just looking at the current trends. Studies have also shown that asking from a person is not an accurate method when it comes to predicting music listening behavior (Ward, Goodman & Irwin, 2013; Berns & Moore, 2012). Activation of reward related brain regions are linked to the commercial success of the songs and the consumption decisions of music listeners (Berns & Moore, 2012; Salimpoor, Bosch, Kovacevic, McIntosh, Dagher, & Zatorre, 2013). In that sense, EEG could be an affordable tool for streaming services, commercial radio stations, A&Rs and music supervisors to make more data-based decisions to better serve an everyday music listener.

2 THEORETICAL BACKGROUND

Theoretical background of the current study is based upon previous neuroscientific studies made with fMRI and EEG brain scanning methods. First chapter introduces the subcortical reward related brain regions studied with fMRI and the later chapters moves towards cortical areas studied with EEG. In the end, low-cost wireless EEG technology and its benefits and limitations are visited.

2.1 Music induced pleasure and reward related brain regions

When studying music induced pleasure with EEG, covering the literature concerning reward related brain regions is a natural way to start, even though most of the reward related brain regions are sub-cortical and cannot be measured directly with EEG. Still, it is important to cover these brain structures because the activity of reward related brain regions is closely linked with emotions.

Music evokes strong emotions that have been associated with dopamine release in the reward related brain regions. (Salimpoor, Benovoy, Larcher, Dagher, & Zatorre 2011). The activity of these brain regions is particularly affected by the familiarity with music (Pereira, Teixeira, Figueiredo, Xavier, Castro & Brattico, 2011). Dopamine release is a response to rewarding activities such as eating food or having sex. These activities play a crucial role in the survival of our species (Oei, Rombouts, Soeter, van Gerven,

& Both 2012; Kringelbach, Stein, & van Hartevelt 2012; Arias-Carrion, Stamelou, Murillo-Rodriguez, Menéndez-González & Pöppel 2010.) Dopamine is a neurotransmitter whose role is not fully agreed upon by researchers, but it has been associated with body movements, rewarding experiences, learning and motivation (Arias-Carrion et al. 2010; Phillips, Vacca & Ahn 2008). The dopamine system includes a mesolimbic and a mesocortical pathway which both start from the ventral tegmental area (VTA). The mesolimbic pathway runs to the nucleus accumbens (NAc) and the mesocortical pathway to the prefrontal cortex. (Arias-Carrion et al. 2010.) In addition to these, the orbitofrontal cortex (OFC) is strongly associated with rewarding experiences, emotions, and decision-making (Rolls, Cheng & Feng, 2020).

Over the past twenty years, researchers have begun to better understand the relationship between reward related brain regions and music. In a 2001 study, Anne Blood and Robert Zatorre found that chills induced by music are connected to increased brain activity in brain areas associated with emotions and reward (Blood & Zatorre 2001). Ten years later, a research team led by Valerie Salimpoor made the first direct observation that the rewarding experiences evoked by music are related to dopamine activity in the mesolimbic reward system that has evolved to reinforce the fundamental biological patterns of behavior (Salimpoor et al. 2011). Various prehistoric roles have been presented to explain the evolutionary significance of music and why music activates reward-related brain regions (Trainor & Schmidt 2003). However, music is not biologically rewarding the same as food, which is a necessity for an individual to survive. One explanation why music still activates the reward system is that strong emotions can be rewarding by themselves (Salimpoor et al. 2009). This point of view suggests that music itself is not rewarding the same way as eating food, but the ability to evoke strong emotions makes it capable to induce pleasure. After all, the biological purpose of emotions is guiding people into actions that are beneficial for an individual's survival (Dissanayke 2006, 2).

2.2 Music induced pleasure and EEG oscillations

The brain imaging method used in the studies presented above is fMRI. In recent years, the use of EEG in the studies of music induced pleasure has increased. The first reports of EEG were made in 1929 by researcher Hans Berger. Since that day, researchers have been able to connect event-related EEG oscillations with almost every cognitive process. (Herrmann, Strüber, Helfrich, & Engel, 2016.) There are five well established frequency bands in EEG data (delta, theta, alpha, beta, and gamma) and therefore it seems that EEG oscillations are part of different cognitive processes depending on a section of the brain the activity occurs and the other parameters in the signal (Herrmann et. al, 2016). The next chapters cover recent findings between activity in different frequency bands and processing of pleasurable musical experiences.

2.2.1 Alpha (8 – 12 Hz) and frontal alpha asymmetry

Since the early decades of the 20th century, many studies have shown a task-related decrease in alpha power. Alpha oscillations have often been seen as an inverse measure of the brain activation. (Knyazev, 2007.) This inverse relationship has also been demonstrated in subsequent studies. When studying the neural effects of music-induced pleasure, a team of researchers found that the decrease in alpha intensity in the PFC region has a strong association with music induced pleasure. The same study also found that the relationship between beta and alpha observed in the PFC area was related to the intensity of the pleasure provided by the music. (Chabin, Gabriel, Haffen, Moulin, & Pazart, 2020.) Alpha activity is also associated with emotions. In a study published in 2019, Hou and Chen studied what features in EEG signals were associated with different emotions evoked by music. Comparing the different frequency bands, they found that the emotions evoked by music were most clearly linked to activity in the alpha frequency range meaning that the alpha frequency range is more active when a person listens to emotionally evocative music. (Hou & Chen, 2019.)

Nicole Hurless et al. found that when people listened to music from the genre they liked, the amplitude of alpha oscillations were higher (Hurless, Mekic, Peña, Humphries, Gentry, Nichols, 2013). Comparing these observations with each other, one can observe the complex relationship between alpha oscillations and musical pleasure. The difference in the finding can be due to the length of the epochs interested in the analyses of three studies.

Even more promising indicator of music induced pleasure in the alpha range is frontal asymmetry between two frontal hemispheres. Frontal alpha asymmetry (FAA) is a widely used measure for approach and avoidance motivation and emotions (Zotev et al., 2016; Harmon-Jones, 2003, Kelley, et al., 2017). Its close relationship with motivation makes it interesting phenomenon to investigate in the context of familiarity since we know dopamine activation in the subcortical reward regions is driving factor of approach motivation (Hoebel, Avena, & Rada, 2013, 89-102) and reward system of the brain is more active while listening to familiar music (Pereira et al., 2011). There is also already some evidence that frontal asymmetry is dopaminergic based (Wacker, 2017). Frontal asymmetry is linked to positive emotions in the case of listening to music. (Altenmuller, 2002; Schmidt & Trainor, 2001). Therefore, the valence of the song is an important feature to take into consideration in the analysis. Based on findings presented above, frontal asymmetry is a promising EEG based indicator of music induced pleasure that can be measured with a low-cost wireless EEG device by using two electrodes on each hemisphere.

Mathematical description of frontal asymmetry is subtraction of logarithmic power of alpha on the left hemisphere from logarithmic power of alpha on the right hemisphere (Zotev et al., 2016). Since alpha oscillations have been seen as an inverse measure of brain activation (Knyazev, 2007) higher the ratio between two hemispheres calculated with formula present above, more active the left hemisphere is.

Investigation of frontal alpha asymmetry in the current study opens also interesting applications for music therapy since increased rightward frontal alpha asymmetry has related to various mental health diagnoses such as ADHD, depression, and anxiety (Hale et al., 2009; Thibodeau et al., 2006). Maybe environments that adapt to frontal alpha asymmetry could change behavior and help in the recovery process from such conditions.

The leading paradigm of frontal alpha asymmetry is that the left hemisphere is more active when perception of stimuli is positive. There are also studies that suggest a shift in the paradigm. They do not contradict the old paradigm totally but suggest that there is a difference in direction of lateralization between subjects (Schiffer et al., 2007). With some people the right hemisphere is more active while feeling positive emotions and the direction is consistent with different stimuli (Sourina, Liu & Nguyen, 2011). Therefore, it is reasonable to use multiple stimuli in the study when investigating frontal alpha asymmetry to be able to conclude variations in the direction of lateralization. Therefore, there is an audio-visual stimulus used in the current study alongside familiar and unfamiliar music that participants listen to. The audio-visual stimulus in use in the current study is a video containing unpleasant and pleasant pictures with musically enforced emotional impact. Participants were also asked to empathize with the emotions in the video by using memories. The audio-visual medium was decided as an alternative stimulus for familiar and unfamiliar music since variation in the direction of lateralization was studied with multiple sets of stimuli in previous studies (Sourina, Liu & Nguyen, 2011). The link to the video can be found from the attachment section at the end of the thesis paper.

2.2.2 Theta, beta and gamma oscillations and music induced pleasure

A team of researchers led by Thibault Chabin studied features in EEG signals associated with music induced chills (Chabin et al., 2020). They found that the theta activity in the prefrontal cortex (PFC) increased as participants' emotional experience intensified. They used chills as an indicator of the music induced pleasure that have been used as a sign of strong emotional arousal in previous studies and have been shown to be associated with the activation of the brain reward system (Salimpoor, Benovoy, Larcher, Dagher & Zatorre, 2011). The measurements were made with high density EEG to get a better spatial resolution. The research team was able to locate the origin of the theta oscillations to an orbitofrontal cortex (OFC). (Chabin et al., 2020.) The association between activation of OFC and the theta activity has also been observed in the previous studies (van Wingerden, Vinck, Lankelma, & Pennartz, 2010). In the previous studies frontal theta activity has been associated with the rewarding and positive emotional experiences, attention, and the memory-related cognitive processes (Gruber, Watrous, Ekstrom, Ranganath, & Otten, 2013; Aftanas & Golocheikine, 2001)

Beta and gamma oscillations have been associated with the liking of music (Hadjidimitriou & Hadjileontiadis, 2012). However, beta oscillations are also associated with musical features. For example, an increase in tempo also leads to an increase in beta oscillations (Hurless et al., 2013). The relationship between beta activity and tempo would also appear to depend on individual preference (Bauer, Kreutz & Herrmann, 2014). This effect might be due to connection between beta oscillations and motor processes and the ability of music to make us move (look Herrmann et al., 2016). The effect of the musical features presented above makes it challenging to study the relationship between beta activation and musical induced pleasure if the musical features are not properly controlled in the study. On the other hand, the groove to which the tempo of the song is also strongly connected to, activates the brain reward system (Matthews, Witek, Lund, Vuust & Penhune, 2020). In this way, musical features that are connected to movement evoked by music can also play a crucial role in musical music induced pleasure and positive emotions. Beta oscillations are also affected by the boredom of music. Tabatabaie's research team found a link between listening to boring music and decrease in beta oscillations. (Tabatabaie, Azadehfar, Mirian, Noroozian, Yoonessi, Saebipour, Yoonessi 2014).

Previous studies introduced in this chapter demonstrates that there is a great amount of brain oscillation related neural phenomena that are linked to music induced pleasure. In the current study the experimental part will focus on frontal alpha asymmetry since the analysis would expand too much if all the previous results would be under investigation. These results are still introduced to demonstrate that there are plenty of neuro markers that could be implemented when developing EEG based emotion detection algorithms that could be adjustable on a personal level.

2.3 Reliability of low-cost wireless EEG devices

Low-cost wireless EEG devices are becoming more common in neuroscientific research. Their advantages are low cost, the possibility to perform brain imaging outside the laboratory. They are also rather easy to use. Usually there are only a few electrodes in low-cost wireless EEG devices that reduces the possibility of spatial analysis compared to traditional EEG devices. Perhaps the rather small number of electrodes have also led researchers to question the reliability of the devices. With a smaller number of electrodes compared to clinical EEG devices, the spatial accuracy suffers, and it gets harder to pinpoint in which area of the brain activation occurs. The dry electrodes that are used in the low-cost wireless EEG device also have a lower signal-to-noise ratio when compared with gel assisted electrodes used with clinical devices. Scepticism is always relevant but at the same time it should not inhibit a new research design outside the laboratory that these devices enable. Unnaturalistic laboratory setting is one of the major issues of traditional EEG research and low-cost wireless EEG devices can give an alternative that can be used beside traditional laboratory studies.

Many low-cost wireless EEG devices have also shown a reliable result. One of these is Emotiv Epoc, which was compared by Chabin's research team to results obtained with an HD-EEG device (Chabin et al., 2020). In the present study, the EEG device in use is Muse S by the company called InteraXon. It is a third generation of Muse devices that have four electrodes (TP9, AF7, AF8, TP 10). Muse S is an improved version of Muse 1 and Muse 2. The data obtained with Muse devices have been shown to have sufficient quality of data even for ERP research (Krigolson, Williams, Norton, Hassaall & Colino, 2017).

In the preliminary state of the current study Emotiv Insight device was tested beside Muse S. The most distinctive benefit of Muse S is the fact that the device is headband made from fabric and more suitable for different head sizes. It can be fixed tightly around the subject's head, and it is not as sensitive for small movements compared to the Emotiv device. In the preliminary states subjects felt Emotiv device uncomfortable after fifteen minutes of use. With Muse S there were not similar issues and subjects felt fabric design more comfortable compared to plastic design used in Emotiv devices. Therefore, all the final measurements of the current study were made with Muse S.

3 THE CURRENT STUDY

The current study investigates the relationship between frontal alpha asymmetry (FAA) and familiarity of audio stimuli. The research questions of the current study are:

1) How familiarity of music affects frontal alpha asymmetry?
2) How familiarity of music affects frontal alpha asymmetry in high valence music and low valence music conditions?
3) How pleasant and unpleasant audio-visual stimuli affect frontal alpha asymmetry?

Familiarity of music is closely connected to the pleasure and the activation of subcortical reward regions of the brain. It has been shown that most of the brain activity associated with emotions and pleasure is related to the familiarity of music and not so much to the musical preference of the listener (Pereira, Teixeira, Figueiredo, Xavier, Castro & Brattico, 2011). Therefore, an increase in FAA is expected when participants are listening to familiar music since FAA is also connected with activation reward related brain regions (Wacker, 2017). The results are also expected to be more evident when a participant is listening to high valence music since increased FAA is also connected to the positive emotions. Another hypothesis is that the left hemisphere is more active on the group level when listening to familiar music, but at the same time the personal variance in the direction of lateralization can happen, but the results should be constant between different sets of stimuli. This hypothesis is supported by the previous studies (Schiffer et al., 2007; Sourina, Liu & Nguyen, 2011). Therefore, the research question 3 is incorporated to bring data from different kinds of stimuli condition beside familiar and unfamiliar music that is the focus point of the current study.

4 RESEARCH METHODS

In the current research the participants listened to music that they are familiar with and music they have never heard before. They also watched a video containing pleasant and unpleasant audio-visual stimuli. The current study is an empirical experiment where an independent variable, familiarity of music, is controlled while other variables such as differences in audio features are minimized. The effect of preference is also minimized by using unfamiliar songs that are similar as possible to familiar songs subjects pick themselves. The study investigates the effect of the independent variable to the dependent variable which is the frontal alpha asymmetry. In the analysis the relationship between the independent and the dependent variable is tested by comparing mean FAA in different musical conditions and statistical significance is analyzed using paired sample t-test.

4.1 Research design

4.1.1 Participants

20 subjects participated in the study. All the participants were young adults from early twenties to early thirties (females = 9, males = 11) Most of the participants were music students. A few participants that did not study music had played some instrument as

a hobby for several years or were other way musically experienced. With the first 12 participants one familiar and one unfamiliar song was used as stimuli. For the latter 8 the number of stimuli were increased to two of each enabling more comprehensive analysis of one's direction of lateralization since results gathered with audio-visual stimuli were not as evident as expected.

4.1.2 Sound source and the listening environment

The measurements were conducted in the subject's familiar space and with a familiar sound source. With most of the participants, measurements were made in their home. Participants also used headphones they were used to listening to music. By using low-cost EEG devices, it was possible to make measurements in a naturalistic environment. The perception of familiar music can be different if the environment and the sound source is unfamiliar which ultimately affects the experience of familiarity.

4.1.3 Stimuli

The first 12 participants reported one and later 8 two (one high valence and one low valence) familiar song that they enjoyed listening to. Then the unfamiliar counterpart was searched by using Spotify Song Radio and Spotify API audio features. Having as similar song pairs as possible aimed to ensure that the audio features of the songs and preference towards certain types of music have minimal effect on the results. Audio features of all the songs were analyzed using Spotify API audio features.

Spotify API includes MIR algorithms developed by a company called Echo Nest to give audio feature information of any song on Spotify. Before Spotify bought the algorithms from Echo Nest, they were used in many studies such as in study by Askin and Mauskapf (2017) presented in introduction. One gets audio features out of Spotify

API with a song id which is highlighted section between slash and question mark in the https link of the song:

https://open.spotify.com/track/5ygDXis42ncn6kYG14lEVG?si=01fe84e760a846d6

With song id and token, Spotify gives audio features as a following text:

{
  "audio_features": [
    {
      "danceability": 0.829,
      "energy": 0.886,
      "key": 8,
      "loudness": -1.746,
      "mode": 1,
      "speechiness": 0.112,
      "acousticness": 0.259,
      "instrumentalness": 0,
      "liveness": 0.0559,
      "valence": 0.777,
      "tempo": 115.056,
      "type": "audio_features",
      "id": "5ygDXis42ncn6kYG14lEVG",
      "uri": "spotify:track:5ygDXis42ncn6kYG14lEVG",
      "track_href": "https://api.spotify.com/v1/tracks/5yg-DXis42ncn6kYG14lEVG",
      "analysis_url": "https://api.spotify.com/v1/audio-analysis/5yg-DXis42ncn6kYG14lEVG",
      "duration_ms": 80927,
      "time_signature": 4
    }

]
}

In the current study, values on the linear scale where match between familiar and unfamiliar songs. More specifically: danceability, energy, valence, and tempo. Other features such as acousticness were based on the researcher's evaluation. In the case of instrumentalness and acousticness algorithm place a prediction how likely the song is instrumental or is recorded with organic instruments. For human being this binary evaluation is rather easy, but objective valuation of danceability or valence is a much harder. In these cases, it would require a great number of people to evaluate the song to even out the subjectivity in evaluations. Therefore, the current study resorted to the use of an algorithm.

Other stimuli used in the study was a video containing an unpleasant and pleasant picture. In the video emotions were enhanced with musical stimuli that matched to the emotion of the picture. The music was created with the same digital instruments and effect plug-ins, but emotional content was altered by changing a few intervals between pleasant and unpleasant conditions. You can find a link to the video in the attachments. Audio-visual stimuli beside familiar and unfamiliar music made it possible to compare results from two types of stimuli and it was also used to evaluate possible alterations in direction of lateralization of FAA.

4.1.4 Measurement procedure

In the measurement participants first read the announcement of the study and then wrote the consent form. The EEG device (Muse S) was then placed on the forehead of the participant. Each participant got a brief introduction to the EEG data in the Mind

Monitor app that was used for recordings in the study. For instance, participants were asked to plink their eyes so they could see the spikes in raw EEG data caused by muscular activation. This step was added to lower the stress or excitement participants might have felt about the brain measurements. Usually, people do not know much about EEG, and they might have some presumptions about the device's abilities to ''read a mind''. The knowledge about the nature of data (series of numbers) might lower the expectations and help to focus on the stimuli. This few minutes' time was also to ensure the better quality of the signal because dry electrodes of the device connect better after the small amount of sweat form between the skin and the sensors.

After the good connection was ensured, recordings were started by watching the audio-visual stimuli from YouTube containing unpleasant and pleasant pictures. After watching the video participants were asked if they recognize the unfamiliar counterpart song from the name of the song. They also heard a few seconds of the song to ensure that they had not heard the song. Then participants listened to familiar and unfamiliar songs from Spotify in random order. Many of the participants told right after the measurements that they really liked the unfamiliar song and only few told that they did not like the unfamiliar song. With later 8 participants there was a short break between two sets of songs, but the procedure was not changed in any other way.

4.1.5 Signal processing

The current study uses a data stream pre-processed by device in real time. This is because many of the real-life applications, some of which are presented in this study, are too expensive and complex if they need heavy human supervised pre-processing protocols. Therefore, the data used in the analysis was PSD data that was already preprocessed by the device. The PSD stands fro power spectrum density. The PSD data is obtained by converting time-domain EEG data into frequency-domain data by using fast Fourier transform (FFT). The sample rate of the data was set to 1 Hz. The units of the PSD data in the device are Bels normalized from -1 to 1. In the attachments, there are links to technical manual and FAQ sections of the Mind Monitor app that is gathering the data. From the Mind monitor app data was uploaded into Dropbox as a csv file where it was downloaded onto the computer where the signal processing was made. The next step of the signal processing was carried out in the Matlab. First, data samples where the device detected blink or jaw movement were deleted. Then Matlab smooth function was used to smoother the signal. This procedure was used to smooth the spikes occurring only for a few seconds to make the normalization of data between stimuli possible. After this the data was ready to be analyzed.

4.1.6 Analysis

FAA is a ratio of alpha activity between right and left frontal hemispheres: **FAA = αAF8 / αAF7**. The unit of PSD data in use is Bels, which means that data is logarithmic. In the case of logarithmic values division is calculated by subtracting the numbers. After calculation of FAA, signal was split based on the timestamps of the stimuli and starting point of signal collected during each stimulus was normalized to zero. This way alterations in FAA caused by different stimuli were independent from each other.

If participants consistently had more active right hemisphere during pleasant or familiar stimuli the frontal alpha ratio is multiplied by -1 to convert the direction of the signal. If the participant gives inconclusive evidence about direction of lateralization, the data is analyzed based on the traditional paradigm that participants have a relatively more active left hemisphere when engaging with familiar or pleasant stimuli. Conclusive evidence of rightward FAA is that all the familiar or pleasant stimuli presented to participants induce a more active right hemisphere. This paradigm of having variance in direction of lateralization has been supported by previous studies (Schiffer et al., 2007; Sourina, Liu & Nguyen, 2011).

Two participants had consistently rightward direction of lateralization when engaging with familiar and pleasant stimuli. In those cases, the FAA signal was converted. In the case of three participants some of the data was excluded. In two cases the exclusion decision was made because after the measurement participants reported that they had recognized the unfamiliar song from a different section than the one they were playing before the test. One participant was excluded completely because of the connection issues of the device that caused substantial losses in the data. This was discovered after the measurements.

After these procedures were made, the mean of the normalized FAA signal was then calculated in each familiar and unfamiliar music conditions as well as pleasant and unpleasant audio-visual stimuli conditions. After the whole data set was analyzed in the described manner, statistical significance on the group level was tested with paired samples t-test in SPSS. All the results were analyzed within-subject by comparing the result obtained from the unfamiliar condition to the familiar condition. With participants that had listened to multiple song pairs, each song pair formed its own data point representing the difference between familiar and unfamiliar conditions.

After the analysis of the whole data set, familiar and unfamiliar music conditions were divided into the high valence and the low valence groups. With the first 12 participants who only listen to one song, all the Spotify API valence values were analyzed as a group. The mean valence was calculated and the songs with a higher valence than the mean were added into the high valence group and songs with lower valence were added to the low valence group. With later 8 participants songs were divided as they were reported, but the Spotify API valence value was still carefully monitored in each case to match the level of high and low valence set by the first 12 participants.

After these procedures were made statistical significance on the group level was tested in high valence familiar and high valence unfamiliar music conditions as well as low valence familiar and low valence unfamiliar music conditions with paired samples t-test in SPSS.

To visualize the effect that familiarity has on FAA, the first 60 seconds of signal was extracted from each familiar and unfamiliar music sample. In the case of familiar music, the FAA usually increased in the beginning of the song. In the case of unfamiliar music, the effect was frequently inverted, and the signal decreased in the beginning of the song. These visualizations can be found in Figures 5, 6 and 7 (Figure 5; Figure 6; Figure 7).

5 RESULTS

5.1 Frontal alpha asymmetry in familiar and unfamiliar music conditions

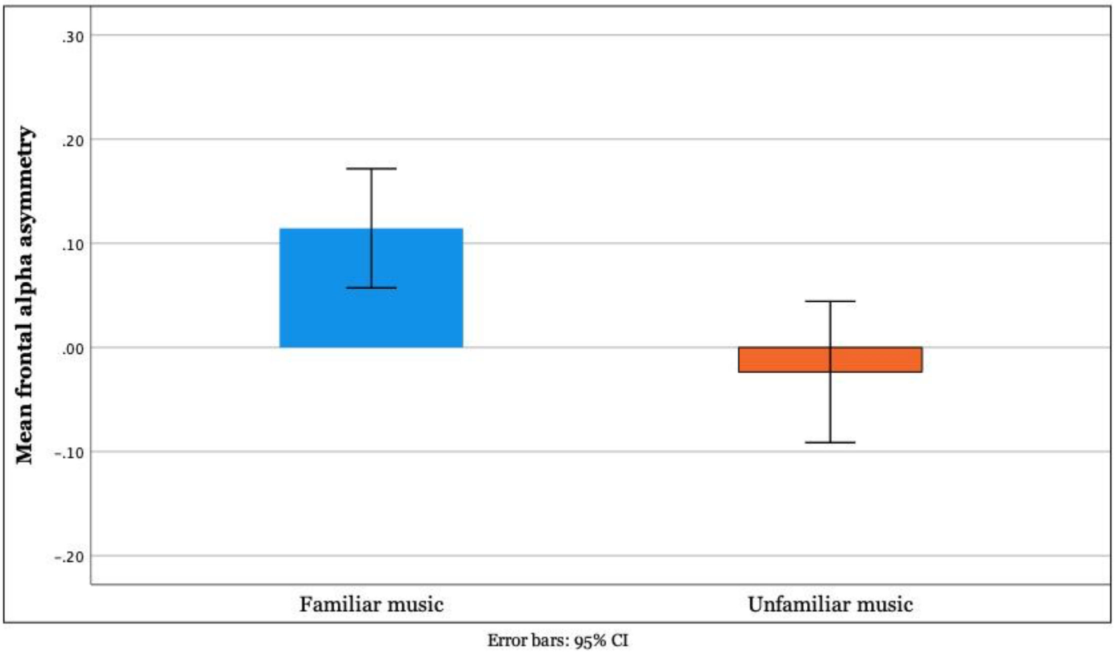

FIGURE 1 Mean frontal alpha asymmetry in familiar and unfamiliar music conditions. (N=23, t = 3.717, p = .001, Cohen's d = .775)

Figure 1 demonstrates mean FAA of all participants in familiar and unfamiliar conditions with both high valence and low valence music samples (Figure 1). Mean FAA for familiar music was 0.114 and mean FAA for unfamiliar music was -0.023 (N=23, t = 3.717, p = .001, *Cohen's d* = .775). There were 23 included song pairs fulfilling the inclusion criteria described earlier, giving statistically significant results ($p \leq .005$) with medium effect size (*Cohen's d* ≥ 0.5).

5.2 Frontal alpha asymmetry in high valence familiar and high valence unfamiliar music conditions

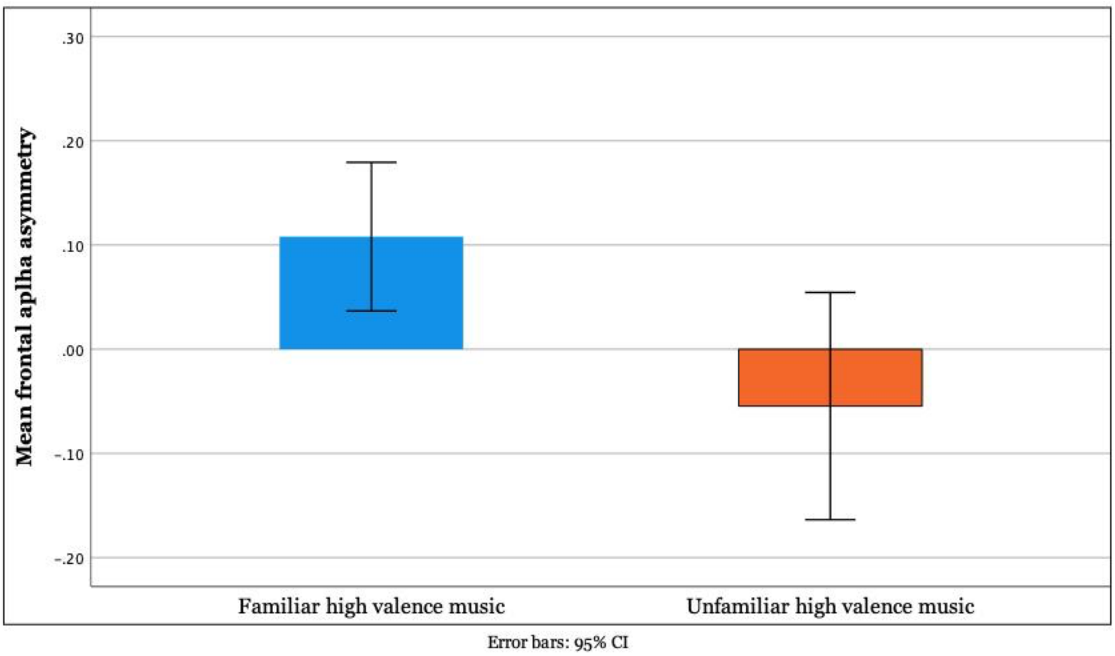

FIGURE 2 Mean frontal alpha asymmetry in high valence familiar and high valence unfamiliar music conditions. (N=12, t = 3.956, p = .002, Cohen's d = 1.142)

Figure 2 demonstrates mean FAA of all participants in familiar and unfamiliar conditions with high valence music samples (Figure 2). Mean FAA for familiar high valence music was 0.108 and mean FAA for unfamiliar high valence music was -0.054 (N=12, t = 3.956, p = .002, *Cohen's d* = 1.142). There were 12 included song pairs fulfilling the inclusion criteria described earlier, giving statistically significant results ($p \leq .005$) with medium effect size (*Cohen's d* ≥ 0.5).

5.3 Frontal alpha asymmetry in low valence familiar and low valence unfamiliar music conditions

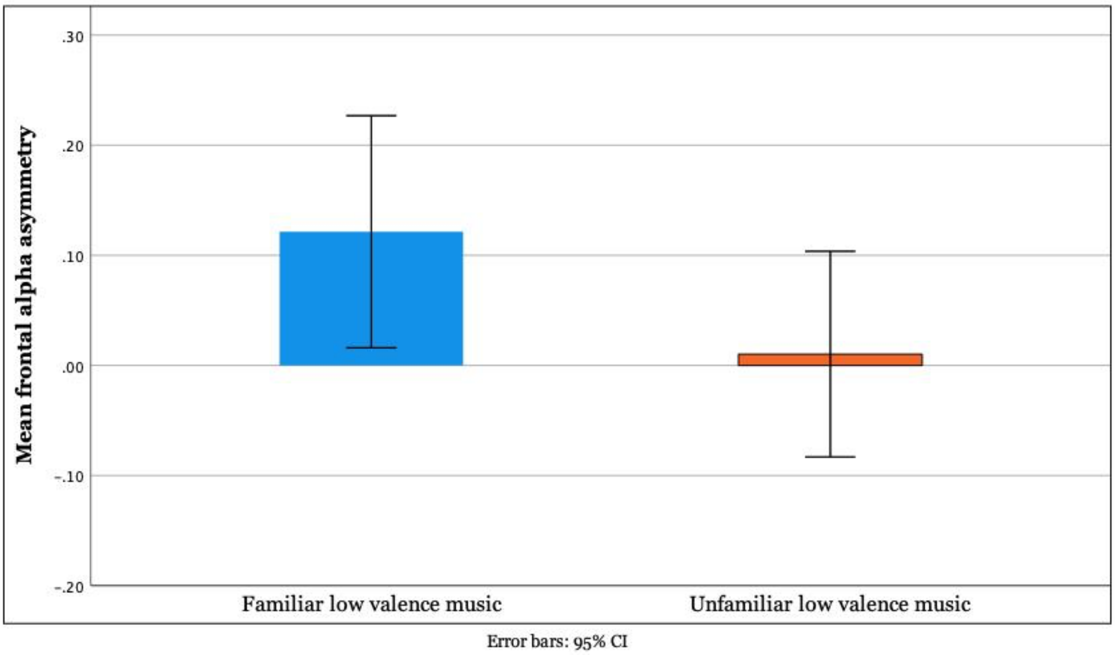

FIGURE 3 Mean frontal alpha asymmetry in low valence familiar and low valence unfamiliar music conditions. (N=11, t = 1.720, p = .116, Cohen's d = .519)

Figure 3 demonstrates mean FAA of all participants in familiar and unfamiliar conditions with low valence music samples (Figure 3). Mean FAA for familiar low valence music was 0.121 and mean FAA for unfamiliar low valence music was 0.01 (N=11, t = 1.720, p = .116, *Cohen's d* = .519). There were 11 song pares fulfilling the inclusion criteria described earlier, giving statistically insignificant result ($p \geq .005$) but with medium effect size (*Cohen's d* ≥ 0.5).

5.4 Frontal alpha asymmetry in pleasant and unpleasant audio-visual conditions

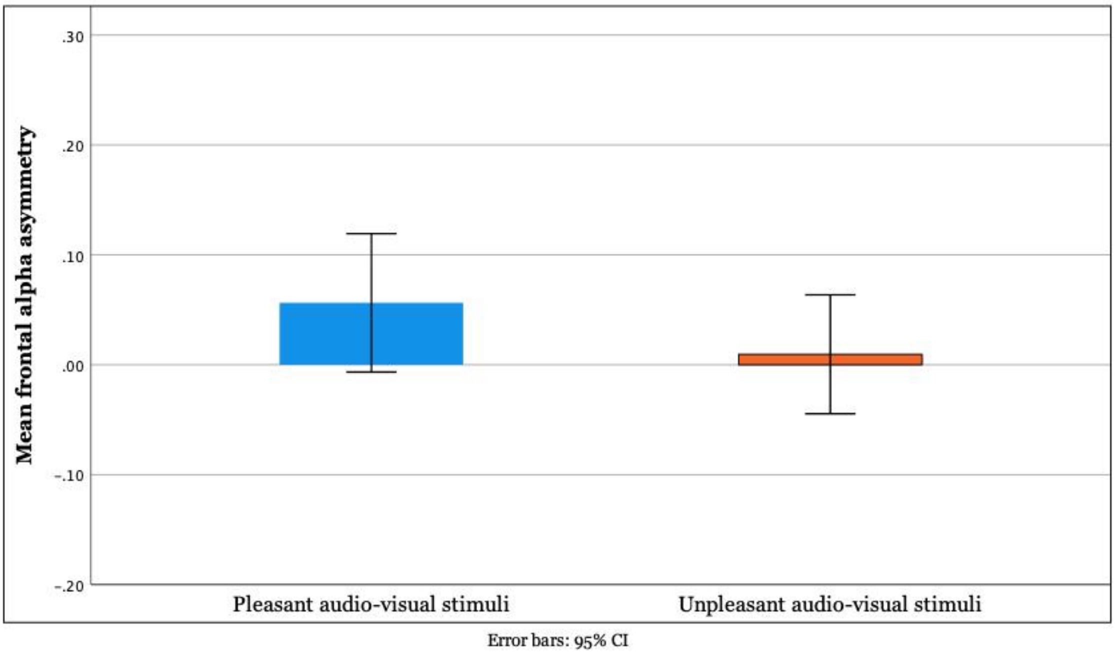

FIGURE 4 Mean frontal alpha asymmetry in pleasant audio-visual stimuli and unpleasant audio-visual stimuli conditions. (N=19, t = 1.222, p = .237, Cohen's d = .280)

Figure 4 demonstrates mean FAA of all participants in pleasant audio-visual stimuli and unpleasant audio-visual stimuli conditions (Figure 4). Mean FAA for pleasant audio-visual stimuli was 0.056 and mean FAA for unpleasant audio-visual stimuli was

0.009 (N=19, t = 1.222, p = .237, *Cohen's d* = .280). There were 19 included samples since one participant was excluded completely due to data lost caused by bad connection. This gives statistically insignificant results ($p \geq .005$) with a small effect size (*Cohen's d* ≤ 0.5).

5.5 Initial reaction of frontal alpha asymmetry in familiar and unfamiliar music conditions

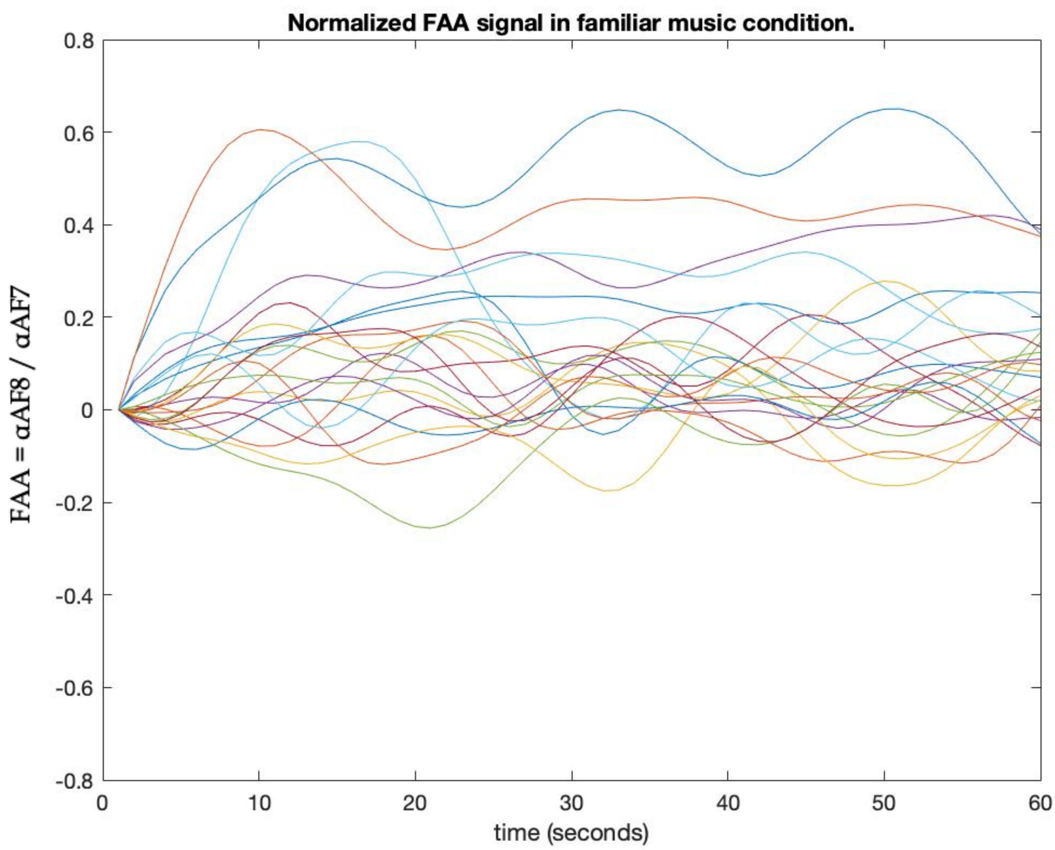

FIGURE 5 This plot visualizes all 60 second epochs extracted from familiar music conditions from 23 included high valence and low valence song pairs.

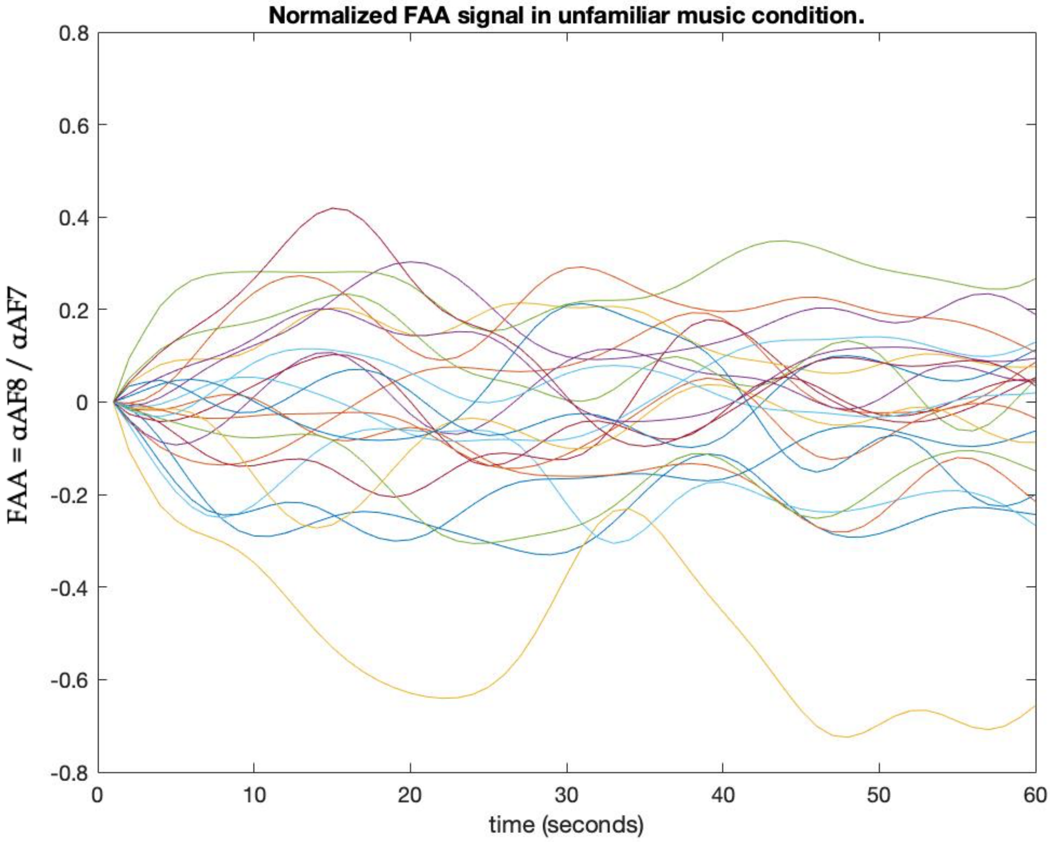

FIGURE 6 This plot visualizes all 60 second epochs extracted from unfamiliar music conditions from 23 included high valence and low valence song pairs.

The most evident difference between familiar and unfamiliar music conditions was the initial reaction in the FAA signal induced by familiar and unfamiliar music. To highlight this visually, the first 60 seconds of normalized FAA signal was extracted and averaged between subjects. In Figures 5 and 6 there is visualization of all the extracted epochs (Figure 5; Figure 6). In Figure 7 there is the average signal of all the extracted epochs (Figure 7). Figures highlight how familiarity of music increases the FAA signal significantly more than unfamiliar music during the beginning of the song.

Since the stimuli differ between subjects and songs have different structures the averaging is not a perfect solution to show the effect on group level. Still during the first 10 seconds there is a distinctive difference between familiar and unfamiliar conditions (Figure 7) that may explain the overall results presented in Figures 1, 2 and 3.

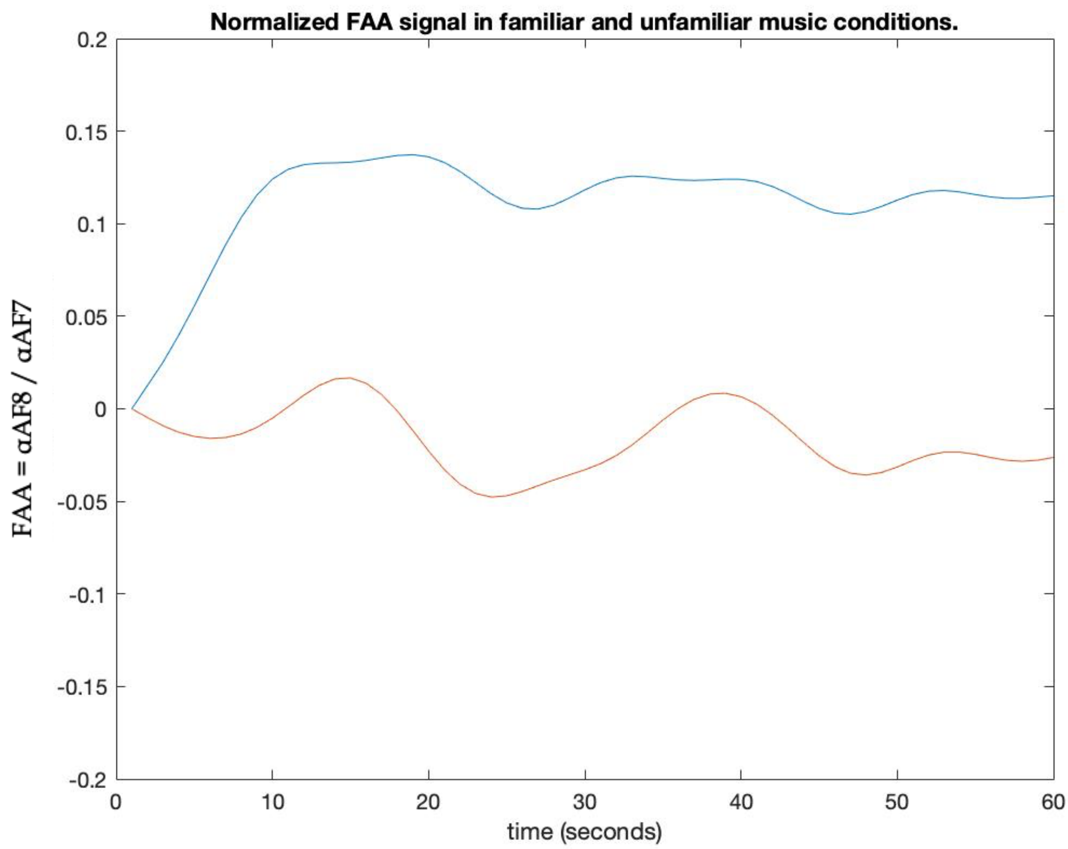

FIGURE 7 This plot visualizes the distinctive increase in FAA during the first 60 seconds of the song when the subject is listening to familiar music (blue line) compared to unfamiliar music (orange line). Both signals are averaged FAA signals from all the included subjects.

TABLE 1 Results of the current study in four stimuli conditions. Condition 1 = Mean frontal alpha asymmetry in familiar and unfamiliar music conditions. Condition 2 = Mean frontal alpha asymmetry in high valence familiar and high valence unfamiliar music conditions. Condition 3 = Mean frontal alpha asymmetry in low valence familiar and low valence unfamiliar music conditions. Condition 4 = Mean frontal alpha asymmetry in pleasant audio-visual stimuli and unpleasant audio-visual stimuli conditions.

Condition	**N**	**t**	**p**	**Cohen's d**
1	23	3.717	0.001	0.775
2	12	3.956	0.002	1.142
3	11	1.720	0.116	0.519
4	19	1.222	0.237	0.280

6 DISCUSSION

Results of the current study suggest that familiarity of music has a significant effect on FAA and the results are more evident when the subject is listening to high valence music. When mean of the FAA in familiar music condition was compared to mean of the FAA in unfamiliar as well as mean of the FAA in familiar high valence music condition was compared to mean of the FAA in unfamiliar high valence music results were statistically significant with a medium effect size. When mean of the FAA in familiar low valence music condition was compared to mean of the FAA in unfamiliar low valence music results were statistically insignificant with a medium effect size. When mean of the FAA in pleasant audio-visual stimuli condition was compared to mean of the FAA in pleasant audio-visual stimuli condition results were statistically insignificant with small effect size.

The results support the two hypotheses that were based on previous studies made in laboratory settings with medically approved EEG devices with higher number of electrodes. This gives a positive indication that low-cost wireless EEG devices and non-human supervised pre-processing methods give sufficient data that could be applied in many real-life applications presented in this study. The current study is also paving a way to do neuroscience in more naturalistic settings. We still need controlled laboratory environments to make precise measurements when covering something entirely new. At the same time new technology enables the use of more naturalistic settings in studies where there is prior knowledge to base the hypothesis on.

6.1 Limitations

Since the research design and data processing was unconventional compared to standard neuroscience research, skepticism towards the results is reasonable. This research was designed to take a leap into unknown territory where many things could have gone wrong. In many ways, the result should be interpreted as a demonstration of the possibility to measure one’s emotional experiences in real life situations with low-cost wireless EEG devices. After all, results supported the hypothesis that was based on conventional neuroscience research and repetition of results reinforces the results of earlier studies. By itself the results of the current study should not be interpreted the same way as results gained from the studies made with more controlled setting.

Since the research was conducted as a master's thesis the scope of the research problem was narrowed down. For instance, to enhance the reliability of the results, data collected with low-cost wireless EEG devices should be compared to data collected with medical devices with higher number of electrodes. This plan was abandoned since it would have been almost a separate research problem too large to conduct with the resources of the master's thesis. Because of the narrow scope and more time efficient measurement and analysis procedure, there was a possibility to have more participants than in most neuroscience research made as a master’s thesis to increase the statistical significance of the results. Still the sample size used in the current study is quite small and the statistical significance should be considered with extra attention.

Changing the research procedure during the measurements is also a bit problematic even though it did not change the way each data point was obtained. Since the data obtained from audio-visual stimuli condition was not reliable enough to determine the direction of lateralization it might be that with the first 12 participant this process did not work as planned. This might have influenced the results which is important to note.

Because the current study was designed to be a naturalistic passive listening test, there was no self-reported data about level of pleasure or experienced emotional state during the listening sessions. After each measurement the FAA signal was compared to the different sections of the songs with the participant. In most cases the experience of the participants corresponded with the FAA signal. The correlation of experience and the FAA signal raised amazement among the participants and it is unfortunate that there is no self-reported data to support this other than the observation of the researcher. Then again collection of self-reported data would have contradicted the naturalistic approach since usually people do not consciously evaluate their emotional state when listening to music. Inclusion of the self-reported data into a research design is also an interesting direction for the future research.

Even though the research design was more naturalistic than laboratory setting, music listening was still forced, and presence of the researcher and the EEG device might affect the experience. In the future this research design could be revisited with a measurement of voluntary and spontaneous music listening where participants would have the device in their home and could use it when they want to listen to music. During the current study this design was already piloted on one occasion where participants had their own low-cost wireless EEG device. It should be noted that the data obtained from this pilot is not included in this study, although the results were very similar to those of this study.

6.2 Future research

In the future, results of the current study can be used in development of emotion adaptive auditive environments created with BCI technology. Nowadays biofeedback is used in many wellbeing products but usually they only give the index of emotional state when data is downloaded from the device. This method does not support efficient change of harmful behavior and does not give actual tools in real-time. Therefore, we should use biofeedback indexes such as FAA to create software that supports emotional wellbeing in everyday life by integrating biofeedback information into the environment. On a practical level this could mean emotion adaptive background music during a workday that would help one to understand emotional reactions better and recover during the workday. In the case of the FAA, this type of interaction could be beneficial for emotional wellbeing since disturbances in the FAA are connected to depression and anxiety as stated earlier. Described application is a simple and cheap way to support mental wellbeing that is an ever-growing problem in modern society. Future research is necessary, but the current study brings this possibility closer to reality.

To add reliability of the results the current study should also be repeated with clinical EEG devices in the controlled setting. This could be conducted with addition of self-reported data about the experience of the participant. Also, the spontaneous music listening setting would be interesting, since there are always problems with controlled environments since we are not used to listening to music in such setting. Compared to the current study this would also eliminate the effect of researchers.

6.3 Conclusion

The results of the current study suggest that higher level of familiarity and higher level of valence increases FAA in musical conditions. These results are in line with hypothesis based on previous studies made with clinical EEG devices. This suggest that low-cost wireless EEG technology is suitable to measure FAA as an indicator of emotional valence and felt pleasure in real-life situations. The current study was designed to be a pre-study for the development of emotion adaptive environments power by BCI technology. It has many limitations that have been cover in earlier chapters, but the results are promising when it comes to applications that may arise from the results.

We are still in early states of understanding human brain. That is because of the complex nature of the brain signals. Another reason is the cost and difficulty of conducting brain research that leads to quite limited amounts of data. The hope is that the current study is also demonstration of the new possibilities in the field of neuroscience to generate more data with more cost-efficient research designs. This applied method is reasonable when there is already laboratory evidence available about the phenomenon under investigation. Neuroscience has a lot to offer for society if researchers are open to consider new possibilities before rejecting them. Rejection is sadly sometimes the initial and only reaction.

REFERENCES

Arias-Carrion, O., Stamelou, M., Murillo-Rodriguez, E., Menéndez-Gonzalez, M. & Pöppel, E. (2010). Dopaminergic reward system: a short integrative review. *International Archives of Medicine, 3*(24), 1–6.

Altenmüller, E. (2002). Hits to the left, flops to the right: different emotions during listening to music are reflected in cortical lateralisation patterns. *Neuropsychologia, 40*(13), 2242–2256.

Askin, N. & Mauskapf, M. (2017). What Makes Popular Culture Popular? Product Features and Optimal Differentiation in Music. *American Sociological Review, 82*(5), 910–944.

Bauer, A.-K. R., Kreutz, G., & Herrmann, C. S. (2014). Individual musical tempo preference correlates with EEG beta rhythm. *Psychophysiology, 52*(4), 600–604.

Berger, J. & Packard, G. (2018) Are Atypical Things More Popular?. *Psychological Science, 29*(7), 1178–1184.

Berns, G. S., & Moore, S. E. (2012). A neural predictor of cultural popularity. *Journal of Consumer Psychology 22*, 154–160.

Blood, A. J. & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *PNAS 98*(20), 11818–11823.

Chabin, T., Gabriel, D., Chansophonkul, T., Michelant, L., Joucla, C., Haffen, E., Moulin, T., Comte, A., & Pazart, L. (2020). Cortical Patterns of Pleasurable Musical Chills Revealed by High-Density EEG. *Frontiers In Neuroscience, 14*, 1–11.

Chabin T, Gabriel D, Haffen E, Moulin T, Pazart L (2020) Are the new mobile wireless EEG headsets reliable for the evaluation of musical pleasure? *PLoS ONE 15*(12), 1–19.

Dissanayke, E. (2006). Ritual and Ritualization: Musical Means of Conveying and Shaping Emotion in Humans and Other Animals. In S.Brown & U.Volgsten (ed.),

Gruber, M., Watrous, A., Ekstrom, A., Ranganath, C., & Otten, L. (2013). Expected reward modulates encoding-related theta activity before an event. *Neuroimage, 64,* 68–74.

Hadjidimitriou, S. K., & Hadjileontiadis, L. J. (2012). Toward an EEG-Based Recognition of Music Liking Using Time-Frequency Analysis. *IEEE Transactions on Biomedical Engineering, 59*(12), 3498–3510.

Hale, T. S., Smalley, S. L., Hanada, G., Macion, J., McCracken, J. T., McGough, J. J., & Loo, S. K. (2009). Atypical alpha asymmetry in adults with ADHD. *Neuropsychologia, 47*(10), 2082–2088.

Harmon-Jones, E. (2003). Clarifying the emotive functions of asymmetrical frontal cortical activity. *Psychophysiology, 40*(6), 838–848.

Herrmann, C. S., Strüber, D., Helfrich, R. F., & Engel, A. K. (2016). EEG oscillations: From correlation to causality. *International Journal of Psychophysiology, 103*, 12–21.

Hoebel, B., Avena, N., & Rada, P. (2008). An Accumbens Dopamine-Acetylcholine System for Approach and Avoidance. In Elliot, A., & Elliot, A. J. (2013). Handbook of Approach and Avoidance Motivation (p. 89-102). Psychology Press.

Hou, Y., & Chen, S. (2019). Distinguishing Different Emotions Evoked by Music via Electroencephalographic Signals. *Computational Intelligence and Neuroscience 2019*, 1–18.

Hurless, N., Mekic, A., Peña, S., Humphries, E., Gentry, H. & Nichols, D, F. (2013). Music genre preference and tempo alter alpha and beta waves in human non-musicians. *The Premier Undergraduate Neuroscience Journal*, 1-11.

Kelley, N. J., Hortensius, R., Schutter, D. J., & Harmon-Jones, E. (2017). The relationship of approach/avoidance motivation and asymmetric frontal cortical activity: A review of studies manipulating frontal asymmetry. *International Journal of Psychophysiology, 119*, 19–30.

Krigolson, O. E., Williams, C. C., Norton, A., Hassall, C. D., & Colino, F. L. (2017). Choosing MUSE: Validation of a Low-Cost, Portable EEG System for ERP Research. *Frontiers in Neuroscience, 11*.

Kringlebach, M. L., Stein, A. & van Hartevelt, T. J. (2012). The functional human neuroanatomy of food pleasure cycles. *Physiology & Behavior 106*, 307–316.

Knyazev, G. G. (2007). Motivation, emotion, and their inhibitory control mirrored in brain oscillations. *Neuroscience & Biobehavioral Reviews, 31*(3), 377–395.

Matthews, T. E., Witek, M. A. G., Lund, T., Vuust, P., & Penhune, V. B. (2020). The sensation of groove engages motor and reward networks. *NeuroImage, 214*, 116768.

Miles, S. A., Rosen, D. S. & Grzywacz, N. M. (2017). A Statistical Analysis of the Relationship between Harmonic Surprise and Preference in Popular Music. *Frontiers in Human Neuroscience, 11*, 1-13.

Nunes, J. C. & Ordanini, A. (2014). I like the way it sounds: The influence of instrumentation on a pop song's place in the charts. *Musicae Scientiae, 18*(4), 392–409.

Oei, N.Y., Rombouts, S. A., Soeter, R. P., van Gerven, J. M. & Both, S. (2012). Dopamine modulates reward system activity during subconscious processing of sexual stimuli. *Neuropsychopharmacology 37*, 1729–1737.

Pereira, C. S., Teixeira, J., Figueiredo, P., Xavier, J., Castro, S. L., Brattico, E. (2011) Music and Emotions in the Brain: Familiarity Matters. *PLoS ONE, 6*(11), 1–9.

Phillips A. G., Vacca, G. & Ahn, S. (2008). A top-down perspective on dopamine, motivation and memory. *Pharmacology, biochemistry, and behavior 90*(2), 236–249.

Rolls, E., Cheng, W., & Feng, J. (2020). The orbitofrontal cortex: reward, emotion and depression. *Brain Communications, 2*(2), 1—25.

Salimpoor, V.N., Benovoy, M., Larcher, K. Dagher, A. & Zatorre, R. J. (2011) Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *nature neuroscience 14*(2), 257–262.

Salimpoor, V. N., Benovoy, M. Longo, G. Cooperstock, J. R. & Zatorre, R. J. (2009) The Rewarding Aspects of Music Listening Are Related to Degree of Emotional Arousal. *PLoS ONE 4*(10), 1–14.

Salimpoor, V. N., Bosch, I., Kovacevic, N., McIntosh, A. R., Dagher, A. & Zatorre, R. J. (2013) Interactions Between the Nucleus Accumbens and Auditory Cortices Predict Music Reward Value. *Science 340*, 216–219.

Schiffer, F., Teicher, M. H., Anderson, C., Tomoda, A., Polcari, A., Navalta, C. P., & Andersen, S. L. (2007). Determination of hemispheric emotional valence in individual subjects: A new approach with research and therapeutic implications. *Behavioral and Brain Functions, 3*(1), 13.

Schmidt, L. A., & Trainor, L. J. (2001). Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions. *Cognition and Emotion, 15*(4), 487–500.

Sourina, O., Liu, Y., & Nguyen, M. K. (2011). Real-time EEG-based emotion recognition for music therapy. *Journal on Multimodal User Interfaces, 5*(1–2), 27–35.

Tabatabaie, A. F., Azadehfar, M. R., Mirian, N., Noroozian, M., Yoonessi, A., Saebipour, M. R. & Yoonessi, A. 2014) Neural Correlates of Boredom in Music Perception. *Basic and Clinical Neuroscience, 5*(4), 259-266.

Thibodeau, R., Jorgensen, R. S., & Kim, S. (2006). Depression, anxiety, and resting frontal EEG asymmetry: A meta-analytic review. *Journal of Abnormal Psychology, 115*(4), 715–729.

Trainor L. J. & Schmidt L. A. (2003) Processing emotions induced by music. Teoksessa I. Peretz & R. J. Zatorre (toim.) The cognitive neuroscience of music (s. 310-324). Oxford: New York: Oxford Unversity Press.

Wacker, J. (2017). Effects of positive emotion, extraversion, and dopamine on cognitive stability-flexibility and frontal EEG asymmetry. *Psychophysiology, 55*(1), e12727.

Ward, M. K., Goodman, J. K., Irwin, J. R. (2013) The same old song: The power of familiarity in music choice. *Marketing Letters 25*(1).

Wingerden, M., van Vinck, M., Lankelma, J., and Pennartz, C. M. A. (2010). Theta-band phase locking of orbitofrontal neurons during reward expectancy. *The Journal of Neuroscience. 30*, 7078–7087.

Zotev, V., Yuan, H., Misaki, M., Phillips, R., Young, K. D., Feldner, M. T., & Bodurka, J. (2016). Correlation between amygdala BOLD activity and frontal EEG asymmetry during real-time fMRI neurofeedback training in patients with depression. *NeuroImage: Clinical, 11*, 224–238.

ATTACHMENT LINKS

Audio-visual stimuli used in the measurements:

https://www.youtube.com/watch?v=JE8k1OunXGA

Links to Mind Monitor manuals and FAQ pages:

https://mind-monitor.com/Technical_Manual.php#help_graph_absolute (2.12.2021)

https://mind-monitor.com/FAQ.php#csvspec (2.12.2021)