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THREATENING MUSIC MODULATES THE FRONTAL ALPHA ASYMMETRY EVOKED BY A THREATENING VISUAL DISTRACTOR

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ABSTRACT

Otso Lensu: Threatening music modulates the frontal alpha asymmetry evoked by a threatening visual distractor
Master's thesis
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Frontal alpha asymmetry has been used to study processing of emotion in the brain. More relative activation in the left than in the right frontal hemisphere has been associated with approach motivation, while more relative activation in the right than in the left frontal hemisphere has been related to withdrawal. This effect has also been observed when participants have listened to music associated with either negative or positive emotional valence. The current study aimed to investigate how listening to threatening music affects frontal alpha asymmetry in comparison to non-threatening music. Specifically, the present study focused on investigating if threatening music modulated the frontal alpha asymmetry evoked by a threatening visual stimulus. This was studied in two conditions: examining the effect of music heard simultaneously to seeing the visual stimulus, and examining the effect of previously heard music after the music had stopped. In addition, the effect of threatening music on resting state frontal alpha asymmetry was studied when participants listened to music with their eyes closed.

Twenty healthy participants performed an Executive RT test consisting of 24 blocks of trials and involving a threatening or a neutral visual distractor stimulus for each trial. During the first half of each block they heard either threatening or non-threatening music from their headphones during the presentation of the visual stimuli. During the second half, the music was stopped before the presentation of the visual stimuli. EEG was used to record the frontal alpha power brain activity of each participant. The relative activation between the left and right frontal hemispheres was analysed in all combinations of visual distractor stimuli and simultaneous or preceding music. In the music condition, for the electrode pair F3-F4, the relative right frontal cortical activation was greatest when both the music and visual distractor stimuli were threatening. For the electrode pair F7-F8, music had no effect on the frontal alpha asymmetry, but threatening visual stimuli evoked more relative right cortical activation than neutral visual stimuli. In the preceding music condition, on average, the neutral visual stimuli evoked more relative right frontal cortical activation than the threatening visual stimuli for the F3-F4 and F7-F8 electrode pairs. However, in the case of F3-F4, this was only apparent when the preceding music had been non-threatening. There was no difference in resting state frontal alpha asymmetry between threatening and non-threatening music.

The results suggest that listening to threatening music influences the frontal alpha asymmetry evoked by a visual distractor stimulus, although not in such a way as was expected. Thus, the affective priming paradigm could be used in future frontal alpha asymmetry research. However, more research into the effects of music and threatening visual stimuli on frontal alpha asymmetry is needed, as the results of this study were not unambiguous.

Keywords: alpha asymmetry, EEG, threat, music, visual distractor, affective priming

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Frontaalista alfa-asymmetriaa on käytetty tutkittaessa, miten aivot prosessoivat emootioita. Suhteellisesti suurempi aktivaatio vasemman kuin oikean aivopuoliskon frontaalialueilla on yhdistetty lähestymismotivaatioon, kun taas suhteellisesti suurempi aktivaatio oikeassa kuin vasemmassa frontaalisessa aivopuoliskossa välttämismotivaatioon. Tämä on havaittu myös silloin, kun osallistujat ovat kuunnelleet affektipiirteiltään joko positiiviseksi tai negatiiviseksi luokiteltua musiikkia. Tämä tutkimus pyrki selvittämään, kuinka uhkaavan musiikin kuuntelu vaikuttaa frontaaliseen alfa-asymmetriaan verrattuna ei-uhkaavaan musiikkiin. Erityisesti tässä tutkimuksessa keskityttiin tutkimaan, muuttaako uhkaavan musiikin kuuleminen uhkaavan visuaalisen ärsykkeen herättämää frontaalista alfa-asymmetriaa. Tätä tutkittiin kahdessa asetelmassa: samanaikaisesti kuullun musiikin vaikutuksena havaittuun visuaaliseen ärsykkeeseen ja edeltävän musiikin vaikutuksena havaittuun visuaaliseen ärsykkeeseen silloin, kuin osallistujan kuulema musiikki oli keskeytetty. Lisäksi tutkittiin, vaikuttiko uhkaava musiikki itsessään lepotilassa havaittavaan frontaaliseen alfa-asymmetriaan silloin, kun osallistujat kuuntelivat musiikkia silmät kiinni.

Kaksikymmentä tervettä osallistujaa suorittivat reaktioaikatestin, joka koostui 24:stä useita koekierroksia sisältävästä osiosta. Jokainen koekierros sisälsi joko uhkaavan tai neutraalin visuaalisen häiriöärsykkeen. Osioiden ensimmäisellä puoliskolla osallistujat kuulivat joko uhkaavaa musiikkia tai ei-uhkaavaa musiikkia visuaalisten ärsykkeiden näkemisen aikana, kun taas jälkimmäisen puoliskon ajaksi musiikki keskeytettiin ennen visuaalisten ärsykkeiden näkemistä. Osallistujien frontaalisen alfa-aktivaation määrää mitattiin EEG:llä. Suhteellisen aktivaation määrä vasemman ja oikean frontaalisen aivopuoliskon välillä analysoitiin kaikkien visuaalisten ärsykkeiden ja joko samanaikaisen tai edeltäneen musiikin yhdistelmien kohdalla. Samanaikaisesti kuullun musiikin tilanteessa F3-F4 elektrodiparin kohdalla huomattiin eniten suhteellista oikeanpuoleista frontaalista aivokuoren aktivaatiota silloin, kun sekä musiikki että visuaalinen häiriöärsyke olivat uhkaavia. Elektrodiparin F7-F8 kohdalla musiikki ei vaikuttanut frontaaliseen alfa-asymmetriaan, mutta suhteellisesti suurempaa oikean- kuin vasemmanpuoleista frontaalista aivokuoren aktivaatioita esiintyi enemmän, kun visuaalinen häiriöärsyke oli uhkaava kuin sen ollessa neutraali. Edeltävän musiikin tilanteessa neutraali visuaalinen häiriöärsyke herätti suhteellisesti enemmän oikean- kuin vasemmanpuoleista frontaalista aivokuoren aktivaatiota kuin uhkaavaa visuaalinen häiriöärsyke sekä elektrodiparilla F3-F4 että F7-F8. Elektrodiparilla F3-F4 tämä oli kuitenkin nähtävissä vain, kun edeltänyt musiikki oli ollut ei-uhkaavaa. Lepotilassa mitattu frontaalinen alfa-asymmetria ei eronnut uhkaavan ja ei-uhkaavan musiikin välillä.

Tutkimuksen tulokset viittaavat siihen, että uhkaavan musiikin kuuntelu vaikuttaa uhkaavan häiriöärsykkeen herättämään frontaalisen alfa-asymmetriaan, mutta ei tosin odotetulla tavalla. Siten affektiivisen virittämisen paradigmaa voidaan tulevaisuudessa käyttää tutkittaessa frontaalista alfa-asymmetriaa. Koska tulokset eivät kuitenkaan olleet täysin yhdenmukaiset, lisää tutkimusta musiikin ja uhkaavien visuaalisten ärsykkeiden vaikutuksista frontaaliseen alfa-asymmetriaan tarvitaan.

Avainsanat: alfa-asymmetria, EEG, uhka, musiikki, visuaalinen häiriöärsyke, affektiivinen virittäminen

Contents

INTRODUCTION

Understanding how the human brain processes emotions is an interesting topic, not just in itself, but in how it bears relevance for understanding the possible neural mechanisms of several mental illnesses. A vast amount of research has investigated how experiencing emotions of different valence affects brain activity, and how this effect may differ between healthy individuals and those who are struggling with mental illness (Barrett, Mesquita, Ochsner & Gross, 2007). Thus, understanding how the brain reacts to and regulates emotional stimuli, and finding possible biomarkers for mental illnesses such as anxiety disorders, go hand in hand (Berking & Wupperman, 2012; Cisler, Olatunji, Feldner & Forsyth, 2010).

A measure of brain activity that has been associated with the experience and regulation of evoked emotions is the difference in alpha power between the left and right frontal hemispheres, also known as frontal alpha asymmetry (Heller, 1993; Palmiero & Piccardi, 2017; Reznik & Allen, 2018). Some electroencephalography (EEG) studies have shown that less relative alpha activity in the left frontal hemisphere, as compared to the right, is related to approach motivation; whereas less relative alpha activity in the right frontal hemisphere is associated with withdrawal (Gable & Poole, 2014; Harmon-Jones & Allen, 1998). Other studies have associated frontal alpha asymmetry with the valence of emotional experiences (Berntson, Norman & Cacioppo, 2011; Heller, 1993). Furthermore, less relative right than left frontal alpha activity has been associated with heightened vigilance towards threatening stimuli (Grimshaw, Foster & Corballis, 2014).

Alpha asymmetry has often been studied from data that have been recorded when participants are sitting still with their eyes closed and thus in a resting state. However, Coan, Allen and McKnight (2006) have suggested that frontal alpha asymmetry reflects individual emotional regulation capacities and should be measured when participants are attending to a task. Previously this has been done by engaging the brain in a challenging task while activating the brain's emotional circuitries with emotional visual stimuli (Grimshaw et al., 2014; Sun, Peräkylä & Hartikainen, 2017). However, it has not been studied if this reaction to emotional stimuli, indicated by a change in frontal alpha asymmetry, could be enhanced by the presentation of other emotionally congruent stimuli. Previous studies have shown that emotional music can affect the processing of other emotional stimuli. For example, when participants have been instructed to judge words as pleasant or unpleasant as fast as possible, preceding emotionally congruent music has resulted in reduced reaction times (e.g. Goerlich et al., 2012; Steinbeis & Koelsch, 2011).

In this study I will investigate if listening to threatening music modulates the effects of threatening visual stimuli on task-related frontal alpha asymmetry when healthy participants are performing a computer-based reaction time task that challenges multiple executive functions simultaneously (Erkkilä, Peräkylä & Hartikainen, 2018). Additionally, I will investigate if there is a difference in resting state frontal alpha asymmetry when participants are listening to threatening music compared to when they are listening to non-threatening music.

Threat-related emotional and attentional processes

The neural processes involved in processing and experiencing emotions have been studied considerably during the last few decades. These processes do not happen in isolation, but rather they interact with our cognition. Studies have shown that emotions impact such cognitive processes as attention, perception, memory, response inhibition, and decision making; while cognition impacts emotion mainly in the ways of emotion regulation (Dolcos, Iordan & Dolcos, 2011; Hartikainen, Siiskonen & Ogawa, 2012). The interaction between attention and emotion has been investigated both from the experimental and clinical point of view (Hartikainen, Ogawa & Knight, 2000; Hartikainen, Ogawa & Knight, 2012; Mäki-Marttunen et al., 2015; Yiend, 2010). Emotional stimuli have been shown to capture our exogenous (automatic) attention to a greater extent in comparison to neutral stimuli (Carretié, 2014; Hartikainen et al., 2000). Similarly, emotionally relevant stimuli are most often prioritized in attentional selection (Pourtois, Schettino & Vuilleumier, 2013; Vuilleumier & Schwartz, 2001). These effects can be seen in some well-known classic experimental tasks that have been replicated a number of times, such as the Stroop test, where having an affective meaning for each word whose colour needs to be named, slows down the action even if it is completely irrelevant for the task (e.g. Richards & Blanchette, 2004; Williams, Mathews & MacLeod, 1996). In visual search tasks, participants have found the searched for targets among the distractors faster if the target has been emotionally relevant, such as a happy/angry face or a snake (e.g. Fox, 2002; Öhman, Flykt & Esteves, 2001). Moreover, in an attentional blink task the number of failures to identify a visual target after a continuous stream of stimuli is decreased if the target stimulus is emotionally relevant (Anderson, 2005). These results suggest that when our attentional resources are limited, emotional information is prioritized in our awareness and attentional processes (Hartikainen et al., 2007; Vuilleumier, 2005).

When perceiving biologically relevant targets, such as something threatening, the bias towards emotion-related information seems to be especially strong (Lang, Davis & Öhman, 2000). Fear is known to enhance selective attention by inhibiting the processing of other non-threatening stimuli, thus aiding survival in a situation that threatens one's wellbeing (Finucane, 2011). As normally functioning phenomena, attentional and perceptual biases towards threatening stimuli are important and useful, but overly heightened attention to threat has often been associated with trait anxiety and anxiety disorders (Kindt & van den Hout, 2001; Lawrence, Brett, Bishop & Duncan, 2004).

Neuroimaging studies have supported the theories of attention-emotion interaction by showing robust connections and interaction between those brain areas relevant to emotion and those relevant to attention (Pourtois et al., 2013; Mäki-Marttunen et al., 2014; Vuilleumier, 2005). One of the critical nodes in emotion-attention networks is the amygdala, whose role is especially crucial in threat processing (Alheid & Heimer, 1988; Pourtois et al., 2013). It is known to have extensive connections to regions of the brain associated with attention, feelings, and emotion regulation, such as the frontal and parietal cortical areas (for a review see: Vuilleumier, 2005). Furthermore, studies have shown that the right hemisphere plays an important role in attention (Mesulam, 1981; Okada, Sato & Toichi, 2006; Shulman et al., 2010), as well as processing emotions of negative valence (Adolphs, Jansari & Tranel, 2001) and perhaps even processing emotions altogether (Borod et al., 1998). In a study by Hartikainen et al. (2000), emotional stimuli were found to delay reaction times for targets in the left visual field more than for targets in the right visual field. This effect was stronger with threatening stimuli than with pleasant stimuli, and was later shown to be associated with reduced event-related potential responses to left visual field targets, especially over the right hemisphere (Hartikainen et al., 2007). Similar results have been found by Oren, Soroker and Deouell (2013), who compared healthy people and patients with left-sided neglect. For both groups, a preceding threatening stimulus impaired reaction times for targets in the left visual field more than a neutral stimulus. Additionally, this effect was stronger for the neglect patients than for the healthy participants. Furthermore, in one study participants had to discriminate between global and local features of Navon-type hierarchical letters, which were preceded by emotional distractors (Hartikainen, Ogawa & Knight, 2010). Their results showed that unpleasant distracters reduced right parietal activity, which is known to be related to detecting global features of targets. Moreover, Mäki-Marttunen and colleagues (2012) observed in their magnetic resonance imaging (MRI) study that unpleasant stimuli hindered the activation of the frontoparietal attention network, especially in the right hemisphere. Altogether these studies suggest that automatic processing of threatening stimuli captures right hemispheric processing resources, and thus interferes with right hemispheric functions such as attention.

Frontal alpha asymmetry

Lately an increasing amount of research concerning brain processes associated with emotion and attention has focused on the alpha rhythm, which is defined as oscillations in electric potentials within the 8 to 13 Hz range (Laufs et al., 2003). Alpha activity is most robust when the brain is in a resting state and is suppressed when the brain becomes more active (Allen, Coan & Nazarian, 2004). Thus, the alpha power in different regions of the brain varies depending on how active the region in question is at any given moment. For example, when the right side of the brain is activated, alpha power diminishes compared to the inactivated left side of the brain. This phenomenon can be observed by studying either evoked or induced alpha oscillations, the former of which is phased-locked to stimulus onset while the latter is not (David, Kilner & Friston, 2006; Herrmann, Rach, Vosskuhl & Strüber, 2013). The difference in frontal alpha power between the left and right frontal hemispheres is known as frontal alpha asymmetry, and it has increasingly been used to study the processing of affective stimuli (Palmiero & Piccardi, 2017; Reznik & Allen, 2018; Smith, Reznik, Stewart & Allen, 2017). Furthermore, frontal alpha asymmetry has been observed to be related to the activity in the sub-cortical networks responsible for emotion processing (Daly et al., 2019).

In some theories, greater relative right than left frontal cortical activity, meaning less relative alpha power in the right frontal lobe, has been associated with experiencing emotions of negative valence; while experiencing positive emotions has been related to greater relative left than right frontal cortical activity, meaning less relative alpha power in the left frontal lobe (Berntson, Norman & Cacioppo, 2011; Coan & Allen, 2004a, 2004b; Heller, 1993). This theory based on the negative/positive valence dimension of emotions has been challenged by studies showing that in addition to positive emotions, anger also activates the left frontal lobe and thus decreases left-sided alpha activity (Harmon-Jones, 2004a, 2004b; Hewig, Hagemann, Seifert, Jaumann & Bartussek, 2004). Because of this, a more fitting theory has been proposed in which frontal alpha asymmetry is more related to the withdrawal and approach motivation elicited by emotions rather than the valence itself (Gable & Poole, 2014; Harmon-Jones, 2007; Harmon-Jones & Allen, 1998; Harmon-Jones, Gable & Peterson, 2010; Harmon-Jones, Lueck, Fearn & Harmon-Jones, 2006). This idea is supported by a functional MRI study by Berkman and Lieberman (2010), as well as an EEG study by Adolph, von Glischinski, Wannemüller and Margraf (2017). The approach/withdrawal theory is extended by Coan and colleagues (2006) in their capability model. They propose that frontal alpha asymmetry is a better indicator of approach and withdrawal motivation when individuals are performing an emotion-related task than when at rest. They argue that frontal alpha asymmetry may reflect individual emotion regulation capacities in a demanding situation. This model has gained support from further studies (Allen & Reznik, 2015; Goodman, Rietschel, Lo, Costanzo & Hatfield, 2013). Moreover, frontal alpha asymmetry has been associated with arousal by some studies (Mikutta, Altorfer, Strik & Koenig, 2012; Zhang, Zhou & Oei, 2011), but how these results relate to the approach/withdrawal theory is still unclear.

Theories concerning the proposed role of frontal alpha asymmetry in emotional processing and approach/withdrawal motivation has led to studies investigating alpha asymmetry as a possible biomarker of depression (for a review see: Allen & Reznik, 2015; for meta-analysis see: Thibodeau, Jorgensen & Kim, 2006; van der Vinne, Vollebregt, van Putten & Arns, 2017) and anxiety disorders (Mathersul, Williams, Hopkinson & Kemp, 2008; Mennella, Patron & Palomba, 2017; Thibodeau et al., 2006). While some studies have observed evidence that greater relative right than left frontal cortical activity is connected with depressive symptoms, the most recent meta-analysis by van der Vinne and colleagues (2017) claimed resting state alpha asymmetry to be a more unreliable explanatory variable than some previous studies have suggested. The inconsistent associations may be explained by the conditions in which the frontal alpha asymmetry has been recorded. Some studies have suggested that the relative alpha asymmetry would be more predictive of anxiety and depression during an emotion-related task than when measured in a resting state (Perez-Edgar, Kujawa, Nelson, Cole & Zapp, 2013; Stewart, Coan, Towers & Allen, 2014). This might be compatible with the idea of frontal alpha asymmetry reflecting individual emotion regulation capacities during an emotional task (Coan et al., 2006). Some studies have also suggested that greater relative right than left frontal cortical activity is a biomarker of vulnerability for major depressive disorder or anxiety disorder, instead of being a biomarker for the disorders itself (Adolph & Margraf, 2017; Allen & Reznik, 2015; Bruder, Stewart & McGrath, 2017; Pössel, Lo, Fritz & Seemann, 2008; Wen et al., 2017). Thus, it could be seen as a trait-like vulnerability for anxiety and depression. This is supported by the results showing that a decrease of depressive symptoms in patients does not always indicate a corresponding change in their frontal alpha activity (Allen, Urry, Hitt & Coan, 2004; Gollan, 2014; Pössel et al., 2008).

Frontal alpha asymmetry and threat processing

There have been some studies concerning the association between frontal alpha asymmetry and threat processing. Grimshaw et al. (2014) found that greater relative right than left frontal and parietal cortical activity were related to increased vigilance towards angry faces. They argue that frontal alpha asymmetry reflects effects in the fronto-parietal network that control attention to threat. The association between greater relative right than left frontal cortical activity and attentional biases to threat has also been observed by another study showing that right frontal EEG activation in response to stress was associated with greater vigilance to angry faces in a dot-probe task (Perez-Edgar et al., 2013). Furthermore, a study by Adolph and colleagues (2017) showed that greater relative right than left frontal cortical activity, evoked by seeing threatening pictures, predicted enhanced early spatial attention and diminished late positive potentials, phenomena which are often associated with bias to threat. Additionally, participants with greater relative right frontal activation evaluated the pictures as more threatening than those with greater relative left frontal activation. The researchers argued that frontal alpha asymmetry could enhance allocation of attention resources to threatening and other subjectively important stimuli (Adolph et al., 2017).

One way of studying this association is to see if frontal alpha asymmetry is modulated by seeing task-irrelevant threatening stimuli while performing a Go/No-go task. One such task is the Executive RT test, which is a computer-based reaction time task that requires the use of multiple cognitive functions simultaneously, and involves seeing a threatening or neutral visual distractor during each trial (Hartikainen et al., 2010). Threatening stimuli used in the task have been shown to interfere with the performance of participants (Hartikainen et al., 2014; Sun, Peräkylä, Holm, et al., 2015, 2017; Sun, Peräkylä & Hartikainen, 2017). The Executive RT test has proven reliable (Erkkilä et al., 2018) and it has previously been used to investigate evoked frontal alpha asymmetry (Sun, Peräkylä, Holm, et al., 2017; Sun, Peräkylä & Hartikainen, 2017). Its advantage is that it constantly challenges various cognitive functions, especially those that are related to the right hemisphere, such as attention, response inhibition, and emotion regulation, which are needed for ignoring threatening distractors (Erkkilä et al., 2018). A challenging task also leaves less room for mind-wandering and hence may lessen the variability of the results.

Previously the Executive RT test has been used for studying if the frontal alpha asymmetry evoked by threatening visual stimuli can be affected by neuromodulation techniques targeting the limbic circuits of the brain. In their research, Sun, Peräkylä and Hartikainen (2017) found that high frequency electric stimulation of the anterior thalamic nuclei, an integral node of the limbic system, increased both the greater relative right than left frontal cortical activity as well as reaction times within the same participants in the context of threatening distractors. Similar effects of strengthened greater relative right than left frontal cortical activity have been found by stimulating the vagus nerve (Sun, Peräkylä, Holm, et al., 2017). These results indicate that frontal alpha asymmetry evoked by threatening stimuli is directly affected by modulation of the limbic circuits, and could possibly be used as a biomarker for impact of neuromodulation on affective circuits.

Threatening music and its association with frontal alpha asymmetry

Music is known to impact human emotions (e.g. Gerrads-Hesse et al., 1994; Koelsch, 2011; Lundqvist et al., 2009) and arousal (Chabris, 1999; Dillman Carpentier & Potter, 2007). This has been recognized as a universal phenomenon, for these effects are similar between different cultures (Egermann, Fernando, Chuen & McAdams, 2015; Fritz et al., 2009). Music is a useful stimulus for studying the brain's emotional activity as it is known to evoke both negative and positive emotions, depending on the structure of the music piece in question (Koelsch, 2005).

The effects of threatening music on our emotions is a particularly interesting topic. Fear has been recognized as one of the basic emotions (Ekman, 1972) and it has been shown to be universal (Elfenbein & Ambady, 2002). Furthermore, a meta-analysis from Juslin and Laukka (2003) displayed evidence that the effect of threatening music seems to be universal as well: people from different cultures perceive certain kinds of music as intimidating. In general, studies have shown that lower-pitched melodies and voices are perceived as more threatening than higher-pitched ones (Huron, Kinney & Precoda, 2006), although using sudden changes to high pitches may also make music fearsome (Blumstein, Davitian & Kaye, 2010). Other aspects that give music a threatening tone include falling pitch contour (Juslin & Laukka, 2003), loudness (Huron et al., 2006), varying tempo (Park et al., 2014), nonlinear acoustic attributes such as harmonic dissonance (Blumstein et al., 2010), minor chords on the third and sixth degree (Vieillard et al., 2008), and approaching sounds (Bach, Neuhoff, Perrig & Seifritz, 2009). These features differentiate threatening music from music associated with other emotions of negative valence, such as sad music, which is strongly associated with slower tempo (Vieillard et al., 2008) and less intensity (Vuoskoski, Thompson, McIlwain & Eerola, 2012). When investigating emotions evoked by certain music, it is important to keep in mind that in addition to sadness and distress, sad music may also elicit positive emotions such as aesthetical satisfaction (Eerola, Peltola & Vuoskoski, 2015; Vuokoski et al., 2012). In turn, threatening music may be seen as more specific to exclusively negative emotions and thus could be a better stimulus for studying the negative affect evoked by music.

The effects of threatening musical stimuli on brain activity have been researched widely with functional neuroimaging. Listening to threatening music has been shown to primarily affect the amygdala, especially in its left superficial parts (Koelsch et al., 2013). This has also been demonstrated by lesion studies where patients with damage to either the whole medial temporal lobe, or just to the amygdala, have had impaired recognition of scary music (Gosselin et al., 2005; Gosselin, Peretz, Johnsen & Adolphs, 2007; Gosselin, Peretz, Hasboun, Baulac & Samson, 2011). In these studies, the damage did not affect the ability to recognize other types of music, such as happy or sad music.

Past research has demonstrated that emotional music induces similar EEG effects on frontal alpha asymmetry as other emotional stimuli studied. These results show that listening to joyful/happy-sounding music evokes greater relative left than right frontal cortical activity (Arjmand, Hohagen, Paton & Rickard, 2017; Daly et al., 2019; Schmidt & Trainor, 2001; Tsang, Trainor, Santesso, Tasker & Schmidt, 2001), whilst greater relative right than left frontal cortical activity is associated with sad, fearful, fearsome, or unpleasant music (Daly et al., 2019; Flores-Gutiérrez et al., 2007; Schmidt & Trainor, 2001; Tsang et al., 2001). Similar results have been observed when investigating the subjective enjoyment of music, with greater enjoyment of music being associated with greater relative left than right frontal cortical activity (Altenmüller, Schürmann, Lim & Parlitz, 2002; Schmidt & Hanslmayr, 2009). Furthermore, in a clinical context, pleasurable music has been shown to have an immediate effect on listeners by decreasing greater relative right than left frontal cortical activity in depressed adolescents (Field et al., 1998) and depressed mothers (Tornek, Field, Hernandez-Reif, Diego & Jones, 2003). This music-evoked activity in the frontal regions of the brain is connected to activity in subcortical areas of the brain associated with the limbic system (Daly et al., 2019). In addition, right frontal alpha suppression evoked by music appears to have associations with a listener's state of arousal (Mikutta et al., 2012).

There is some discussion in the field concerning the exact features and procedures that are responsible for the effect of emotional music on frontal alpha asymmetry. In their study, Altenmüller et al. (2002) suggested that the effect on alpha asymmetry is not caused by the features of acoustic structure, such as the genre of the music, but it is rather related to the emotions elicited by the music. Their research group also established that the subjective experience of emotion may differ from the emotional valence of the music piece, especially in the case of sad music. This idea was somewhat challenged by a study from Hausmann, Hodgetts and Eerola (2016), which showed that listening to happy, sad, or neutral music had differing influences on how participants performed on three well-established lateralization tasks, by either increasing or decreasing lateral biases. They argued that this effect reflects differences in relative frontal cortical activation. As the ratings of pleasantness did not differ between the types of music, they interpreted the frontal activation to be a result of the affective qualities of the music, not the subjective enjoyment.

Affective priming by music

For this study, I was interested in examining if listening to emotional music would modulate the frontal alpha asymmetry evoked by threatening visual stimuli. This phenomenon where the perception of a specific stimulus has an effect on how one processes the following stimulus is known as priming (Bargh & Chartrand, 2000). A well-known example of priming is affective priming, where the previous stimulus facilitates the processing of the following stimulus, if their emotional content is congruent (Klauer & Musch, 2003). This is traditionally observed when an emotional prime word (e.g. sunshine) hastens the processing of a following emotional word of congruent affective valence (e.g. love). In addition, affective priming has been observed extensively in studies using a wide array of negative and positive stimuli; such as photographs of self, significant others, animals, black-and white line drawings, positive and negative odours (Klauer & Musch, 2003), speech and music prosody (Goerlich et al., 2012), faces (Mograbi & Mograbi, 2012), eye gaze (Chen, Peltola, Ranta & Hietanen, 2016) and even simple geometric shapes (Wang & Zhang, 2016). Studies have shown that affective priming can be observed with highly specific emotions and not just simple negative/positive judgements. For instance, a preceding fear-related stimulus may only affect the processing of other fear-related stimuli, not all stimuli of negative emotional valence (Neumann & Lozo, 2012; Rohr, Degner & Wentura, 2012). Although most priming studies have concentrated on subliminal priming, where the preceding stimulus is masked in a way that the individual does not consciously perceive it (Klauer & Musch, 2003), there is also clear evidence that the priming effect exists when the stimulus is explicit (Mograbi & Mograbi, 2012). Indeed, some studies have even suggested that there is always at least some level of conscious experience needed for affective priming to take place (Lohse & Overgaard, 2019; Lähteenmäki, Hyönä, Koivisto & Nummenmaa, 2015). There have been a number of EEG studies which have shown that affective priming can be observed in brain responses (e.g. Baumgartner, Lutz, Schmidt & Jäncke, 2006; Hietanen & Astikainen, 2013; Yang, Xu, Du, Shi & Fang, 2011; Zhang, Li, Gold & Jiang, 2010).

Although the scientific field concerning affective priming by music is not as vast as that concerning affective priming by words, there are some studies investigating this phenomenon. Most of these studies have found that emotionally loaded music increases the ability to recognize words when the emotional valence of the music and the word are congruent (Goerlich et al., 2012; Ignacio, Gerkens, Aguinaldo, Arch & Barajas, 2019; Steinbeis & Koelsch, 2011). The priming effect has also been observed when using faces as target stimuli. Logeswaran and Bhattacharya (2009) showed that emotional music influenced how sad or happy participants rated faces, while Ignacio et al. (2019)

observed that happy and sad faces were processed faster when preceded with affectively congruent music. However, not all research has observed similar effects; Lense, Gordon, Key and Dykens (2014) found no difference in reaction times when typically developed adults had to identify facial emotions that were preceded by either happy, sad, or neutral music excerpts lasting 500 ms. In addition, music has been demonstrated to enhance the emotional experience: viewing emotional pictures together with music associated with the matching emotional valence evokes stronger emotional experiences and neural activation in comparison to just observing an emotional picture on its own (Baumgartner, Lutz, et al., 2006; Baumgartner, Esslen & Jäncke, 2006). While not examining threatening music per se, Lowe, Loveland and Krishna (2019) demonstrated that low-pitch sounds (which are also associated with threatening music) work as an affective primer for a heightened threat response.

Research proposal and hypotheses

In this thesis I will study how threatening music modulates frontal alpha asymmetry. This will be studied in three different conditions: during a task with simultaneous music, during a task with preceding music, and during a resting state with simultaneous music.

Firstly, I will examine whether listening to threatening music will work as an affective prime and thus modulate the impact of threatening visual distractors on frontal alpha asymmetry. This effect is compared to listening to non-threatening music. Frontal alpha activity is recorded while participants are performing the Executive RT test. Secondly, I will examine if preceding threatening music will also affect the impact of threatening visual distractors on frontal alpha asymmetry when the participants are continuing to perform the reaction time task after the music has been stopped. This effect is compared to a situation where the music participants were hearing was non-threatening. Thirdly, I will examine if listening to threatening music solely will increase greater relative right than left frontal cortical activity in comparison to non-threatening music. This will be recorded while participants are in a resting state with their eyes closed.

For the first research question, it is expected that the threatening visual distractor will evoke more relative right frontal cortical activity than the neutral visual distractor. Similarly, listening to threatening music is expected to evoke more relative right frontal cortical activity than listening to non-threatening music. Because previous research has shown music to work as an affective prime (e.g. Goerlich et al., 2012), it is expected that the relative right frontal cortical activity evoked by a threatening visual distractor will be stronger when the participants are listening to threatening music than when listening to non-threatening music. When the visual stimulus is neutral, there is not expected to be a difference in the evoked alpha asymmetry regarding threatening and non-threatening music.

Similarly, in the preceding music condition, the threatening visual distractor stimulus is expected to evoke more relative right frontal cortical activity than the neutral visual distractor stimulus. Furthermore, it is expected that when preceded by threatening music, the threatening visual distractor stimulus will evoke more relative right frontal cortical activity than when it is preceded by non-threatening music. The preceding music is not expected to modulate the alpha asymmetry evoked by the visual stimulus when the visual stimulus is neutral.

For the third research question, it is expected that when the participants are in a resting state, listening to threatening music will evoke more relative right frontal cortical activity than listening to non-threatening music, thus the results would be consistent with previous studies (e.g. Schmidt and Trainor, 2001).

METHODS

Participants

The participants were 20 right-handed adults with no history of neurological disorders (mean [*M*] age = 24.89 years, standard deviation [*SD*] = 3.13). Thirteen of them were female and the rest were male. All participants provided their written consent and voluntarily participated in the study. They were selected by convenience sampling and mostly recruited from students of the University of Tampere. The data were recorded between September 2016 and November 2017. The study was approved by the Tampere University Hospital Ethics Committee using the reference number R14149.

The Executive RT test

The participants performed an Executive RT test (Erkkilä et al., 2018; Hartikainen et al., 2010). It is a visual attention Go/No-go task that includes emotion-related distractors. Each trial started with a picture of a white triangle in the centre of the participant’s screen, pointing either up or down, and presented for 150 ms, indicating whether the participant had to press the up or the down key on their keyboard. The triangle was followed by a fixation cross lasting for 150 ms in the middle of the screen. Thereafter, the Go/No-go signal, a red or green traffic light, appeared on the screen for 150 ms informing the participant if they should respond or not. The meaning of the traffic light colour was changed from block to block; in half of the cases the green light was a Go signal and the red light was a No-go signal, while in other half of the cases, the green light was a No-go signal and the red light was a Go signal. In a Go case, participants had to press either the up or the down key as quickly as they could, while in a No-go case, they had to withhold from pressing any key. In the middle of the traffic lights there was always a distractor which was randomly either threatening or neutral. The visual stimuli used as distractors were a black line drawing of a spider (threatening) or a black line drawing of a flower (neutral). These distractors were composed of the exact same line elements but in a different configuration (see Figure 1). The Go/No-go signal was followed by a fixation cross for 1550 ms, so altogether one trial lasted for two seconds. See Figure 1 for a visual illustration of a single trial.

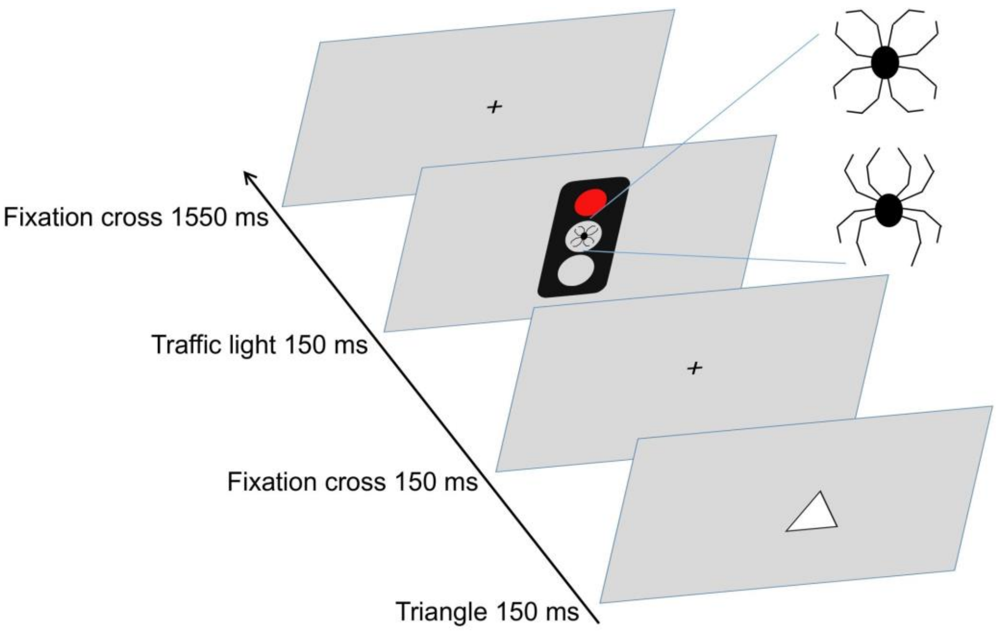

Figure 1. A single trial of the Executive RT test including an illustration of the visual distractor stimuli. The upper stimulus was a neutral distractor (flower) and the lower stimulus was a threatening distractor (spider).

Other materials and questionnaires

The musical stimuli contained 24 pieces of classical music. They were divided into two equally sized categories of threatening and non-threatening music. The music pieces were initially chosen by a research group with medical and music degrees and evaluated by a larger research group, who carefully picked those musical pieces that unambiguously fitted these categories (Raudasoja, 2018). Music they classified as threatening contained typical elements of threat-related music, such as lower-pitched melodies, varying tempo, loudness, and falling pitch contour. A full list of the music used can be found in Table 1.

The participants' subjective estimate of how threatening each of the musical stimuli sounded was measured using a nine-point visual Likert scale, where 1 meant very threatening and 9 meant very safe. Furthermore, participants rated every musical stimulus on a similar nine-point Likert scale for pleasantness (1 = very unpleasant, 9 = very pleasant) and how much they thought the music affected their performance (1 = decreased remarkably, 9 = improved remarkably). At the end of the study, another questionnaire was used to measure the participants' interest in music by asking how often they listen to music (daily, 3–5 times a week, 1–2 times a week, 1–3 times a month, or less often), if they play any instruments (yes or no), and if they listen to classical music in their spare time (yes or no). In addition, the participants were asked if they noticed the distractors (spider or flower) during the task. They were also asked to rate both of the distractor stimuli on visual nine-point Likert scales for pleasantness (1 = very unpleasant, 9 = very pleasant) and calmness (1 = very agitated, 9 = very calm). For all the Likert scales, a nine-point variation of the Self-Assessment Manikin (Bradley & Lang, 1994) was used (see Figure 2).

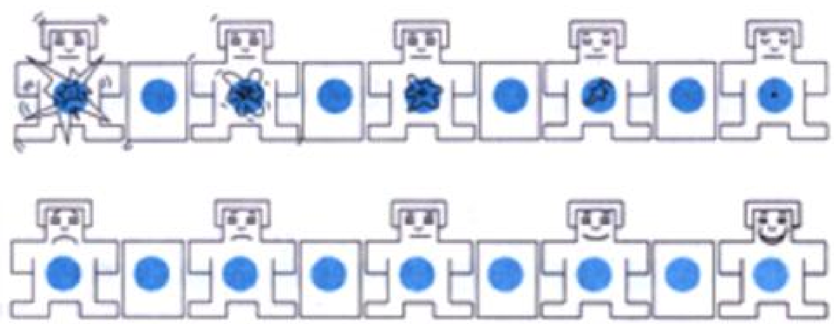

Figure 2. The Self-Assessment Manikins used for evaluating the musical and visual stimuli. The manikins in the top row were used for rating the music and visual stimuli's level of threat, while the manikins in the bottom row were used for all other ratings.

Table 1. Music used in the study.

Threatening	Non-threatening
S. Prokofiev: *Romeo and Juliet, Op. 64: Dance of the Knights*	J.S. Bach: *Brandenburg Concerto No. 5 in D Major, BWV 1050: III. Allegro*
L. Beethoven: *Coriolan Overture, Op. 62*	F.J. Haydn: *Concerto for Flute and Orchestra in D Major*
I. Stravinsky: *Firebird Suite: Infernal Dance*	W.A. Mozart: *Piano Concerto No. 21 in C Major, K. 467: III. Allegro vivace assai*
G. Ligeti: *Etude No. 13, Book II: The Devil's Staircase*	J.C.F. Bach: *Trio Sonatas in A Major, VII/6: I. Allegro moderato*
F. Mendelssohn: *Symphony No. 4 in A Major, Op. 90: IV. Saltarello: Presto*	G.P. Telemann: *Oboe Concerto in G Major, TWV 51:2: II: Vivace*
L. Beethoven: *Symphony No. 5 in C Minor, Op. 67: I. Allegro con brio*	J.S. Bach*: Gloria in Excelsis Deo, Cantata BWV 191: I. Choral*
D. Shostakovich: *Symphony No. 5 in D Minor, Op. 47: Allegro non troppo*	L. Beethoven: *Piano Concerto No. 5 in E-flat Major, Op. 73: III. Rondo: Allegro*
F. Liszt: *Totentanz, Paraphrase on Dies irae, S.126*	W.A. Mozart*: Piano Concerto No. 23 in A Major, K. 488: III. Allegro assai*
I. Stravinsky: *The Rite of Spring: Sacrificial Dance*	F.J. Haydn: *Symphony No. 33 in C Major: I. Vivace*
W.A. Mozart: *Requiem in D Minor, K. 626: Dies irae*	J.S. Bach: *Trio Sonata No. 5 for Organ in C Major, BWV 529: Allegro*
D. Shostakovich: *String Quartet No. 7 in F-sharp Minor, Op. 108: Allegro*	J.S. Bach: *Violin Concerto No. 2 in E Major, BWV 1042: I. Allegro*
D. Shostakovich: *Symphony No. 10 in E Minor, Op. 93: Allegro*	A. Vivaldi: *Recorder Concerto in C Major, RV 444: I. Allegro non molto*

Procedure

The data were collected in the Behavioral Neurology Research Unit at the Tampere University Hospital. Upon the participants' arrival at the laboratory, they were informed of the general aspects of the experiment. They were also informed that all of the information would be handled in confidence and that they may quit the experiment at any given moment if they wished. They signed a written consent form regarding their participation in the experiment. During the experimental task, participants sat one metre away from a 21-inch computer screen. For the music stimuli, participants wore Sony MDR-EX110LPB EX in-ear headphones. The experimental task was presented using Presentation software (Neurobehavioral Systems, Inc., Berkeley, CA, USA). For the electrophysiological recording, an EEG cap was put on their head and scalp EEG was recorded.

The test consisted of 25 blocks, including 24 actual blocks and one practice block. To collect the resting state data, at the beginning of each block the participants were instructed to close their eyes and listen to the music coming from their headphones. After 30 seconds, participants heard a beeping noise from their headphones which signalled that the reaction time test would start. Each block consisted of 72 two-second trials, meaning one block lasted for approximately 3.5 minutes. After each block, the participants filled in an answer sheet consisting of questions concerning the musical piece they had heard. A video camera was used to follow when the participants were ready for the next block. For the first 36 trials music was playing from the participants' headphones, whereas during the last 36 trials there was no music at all. During the practice block, there was always the same non-threatening music playing. Half of the participants started the first actual block with threatening music, while the other half started with non-threatening music. The music excerpt changed after every block, and there were always two threatening or non-threatening excerpts in a row. After all the blocks, participants filled in one more answer sheet consisting of questions concerning the visual stimuli and the participants' interest in music.

EEG

A continuous EEG signal was recorded with 64-channel Ag/AgCl electrodes and a QuickAmp EEG amplifier (Gilching, Germany). BrainVision Analyzer 2 software (Brain Products GmbH, Germany) was used for offline processing of the EEG signal. Two frontal electrode pairs (F3-F4 and F7-F8) were chosen for the analyses as they are the most commonly used in frontal alpha asymmetry studies (Reznik & Allen, 2018). Additionally, the parietal electrode pair P3-P4 was chosen as a control. As for the reference, central electrode Cz was chosen. For all the chosen electrode pairs, the data of one participant had to be discarded as the trial markers used in the EEG data failed to match the real trials. The data of two other participants also had to be discarded due to noise contamination in the EEG signal. Furthermore, for the electrode pair F7-F8, the data of one participant had to be discarded due to a noisy signal. Thus, the final EEG data consisted of 17 participants (*M* age = 24.76, *SD* = 3.17, 11 female and six male) for both electrode pairs F3-F4 and P3-P4, and 16 participants (*M* age = 24.50, *SD* = 3.08, 10 female and six male) for the electrode pair F7-F8.

Eye-movement artifacts were corrected from the data using the Independent Component Analysis (ICA) ocular correction function of the BrainVision Analyzer 2 software, where signals are decomposed into independent components with an extended infomax algorithm, and the corresponding eye movements of the components rejected. Thereafter, the signal was band-pass filtered at 1–30 Hz and the data were manually inspected for artifacts. Then the EEG signal recorded during the Executive RT test was segmented into epochs of 1400 ms, which consisted of 200 ms before the onset of the visual stimulus (flower or spider) and 1200 ms after the visual stimulus. Segments including bad intervals were rejected. An automatic artifact rejection system was used with all the segments and the segments were then averaged. Following this, the power spectrum ($\mu V^2/Hz$) of all segments was calculated using the Fast Fourier Transformation. The resting state EEG signal was segmented into 2.048 second epochs with 1.5 second overlap, with segments containing artifacts being rejected. Thereafter, the power spectrum ($\mu V^2/Hz$) of all segments was calculated using the Fast Fourier Transformation and the segments were then averaged. Finally, spectral power at the alpha range (8–13 Hz) was exported from both the resting state and the task-related data.

Data analysis

The statistical analyses were done using the IBM SPSS 25.0 program. The Student's t-test was used for analysing the differences in participants' estimates of how threatening and pleasant the music excerpts sounded. When analysing how threatening the music sounded, the answers of two participants were discarded for being unreliable: one for rating all of the musical pieces with the same score, and one for answering only 8 and 9 (very safe) for all of the threatening musical pieces. Thus, the sample was 18 participants (*M* age = 24.94, *SD* = 3.40, 13 female and five male) for these analyses. For analysing the pleasantness of music, no participants were discarded.

For the data recorded during the Executive RT test, distribution of alpha power within and between participants was first examined for outliers by using a box plot. Because the data were not normally distributed, the alpha power of electrode pairs F3-F4 and F7-F8 was natural log transformed. The frontal alpha asymmetry scores were calculated subtracting the ln-transformed values at F3 from the values at F4, as well as the values at F7 from F8. Furthermore, parietal alpha asymmetry was calculated for the electrode pair P3-P4 by subtracting the ln-transformed alpha power values at P3 from the ln-transformed alpha power values at P4. Finally, the analyses were conducted using a 2x2 repeated measures analysis of variance, using visual stimuli (threatening, neutral) and music or preceding music (threatening, neutral) as factors. The repeated analysis of variance was also used for the further pairwise analyses.

The resting state data were first examined for possible outliers by using a box plot graph. The alpha asymmetry scores of electrode pairs F3-F4, F7-F8, and P3-P4 were calculated using the above-mentioned formula (ln[right electrode]-ln[left electrode]). Thereafter, the data was analysed using a paired samples t-test for each of the electrode pairs.

RESULTS

Evaluation of music

On average, participants evaluated the threatening music to sound more threatening than the non-threatening music. On a scale from 1 (very threatening) to 9 (very safe) the participants evaluated music selected as threatening to sound somewhat threatening (*M* = 3.47, *SD* = 1.31), while the music selected as non-threatening was evaluated to sound mostly safe (*M* = 7.08, *SD* = 1.49), $t_{(22)} = 18.834$, $p = .023$. Each excerpt of threatening music was evaluated to sound at least a little bit threatening on average, the highest average score (least threatening) of a single music piece being *M* = 4.53, *SD* = 1.46. Similarly, each piece of non-threatening music was evaluated to sound at least somewhat safe, the lowest average score (least safe) of a single music piece being *M* = 6.44, *SD* = 1.54.

On a scale from 1 (very unpleasant) to 9 (very pleasant) the participants evaluated non-threatening music to sound mostly pleasant (*M* = 6.88, *SD* = 1.34), with the highest average score for a music piece being *M* = 7.40, *SD* = 0.94 and the lowest average score being *M* = 6.03, *SD* = 1.87. Threatening music was evaluated to sound not as pleasant, but not that unpleasant either (*M* = 5.44, *SD* = 2.15), with the highest average score for a music piece being *M* = 7.00, *SD* = 1.72 and the lowest average score being *M* = 4.10, *SD* = 1.94. Overall, threatening music was on average evaluated to sound less pleasant than non-threatening music ($t_{(22)} = 5.432$, $p = .024$).

Task-related frontal alpha asymmetry during the music condition

Analyses of the frontal alpha asymmetry scores calculated from the data recorded during the Executive RT test when music was playing, resulted in a main effect of music ($F_{(1, 33)} = 5.183$, $p = .029$, $\eta^2G = .136$) for the electrode pair F3-F4. Threatening music led to a decreased alpha asymmetry score, in other words less relative left frontal cortical activity in comparison to non-threatening music. For the visual distractor stimuli, no main effect was observed ($F_{(1, 33)}$, = 0.525, $p = .474$, $\eta^2G = .016$). Furthermore, there was no significant interaction effect between the music and the visual stimuli ($F_{(1, 33)}$, = 3.032, $p = .091$, $\eta^2G = .084$). However, further pairwise analyses were conducted since the interaction effect was close to being statistically significant. Pairwise analyses showed that when the music was threatening, the mean alpha asymmetry scores were significantly smaller for the threatening than for the neutral visual distractor ($F_{(1, 33)} = 4.608$, $p = .039$, $\eta^2G = .123$). In turn, when the music was non-threatening, there was no significant difference in the mean alpha asymmetry scores between the visual distractor stimuli ($F_{(1, 33)} = 0.659$, $p = .423$, $\eta^2G = .020$).

For the electrode pair F7-F8, there was no main effect of music ($F_{(1, 31)} = 2.450$, $p = .128$, $\eta^2G = .073$). However, there was a main effect of visual distractor stimuli ($F_{(1, 31)} = 4.245$, $p = .048$, $\eta^2G = .120$). Seeing a threatening visual distractor stimulus led to a decreased alpha asymmetry score in comparison to seeing a neutral visual stimulus. There were no interactions between the music and the visual stimuli for the F7-F8 electrode pair ($F_{(1, 31)} = 0.795$, $p = .795$, $\eta^2G = .002$).

Analysis for the electrode pair P3-P4 resulted in no main effect of music ($F_{(1, 33)} = 0.026$, $p = .872$, $\eta^2G = .001$) or visual stimuli ($F_{(1, 33)} = 0.028$, $p = .868$, $\eta^2G = .001$). Furthermore, no interaction between the main effects was observed for the electrode pair P3-P4 ($F_{(1, 33)} = 1.888$, $p = .179$, $\eta^2G = .054$).

See Figure 3 for illustration of these results.

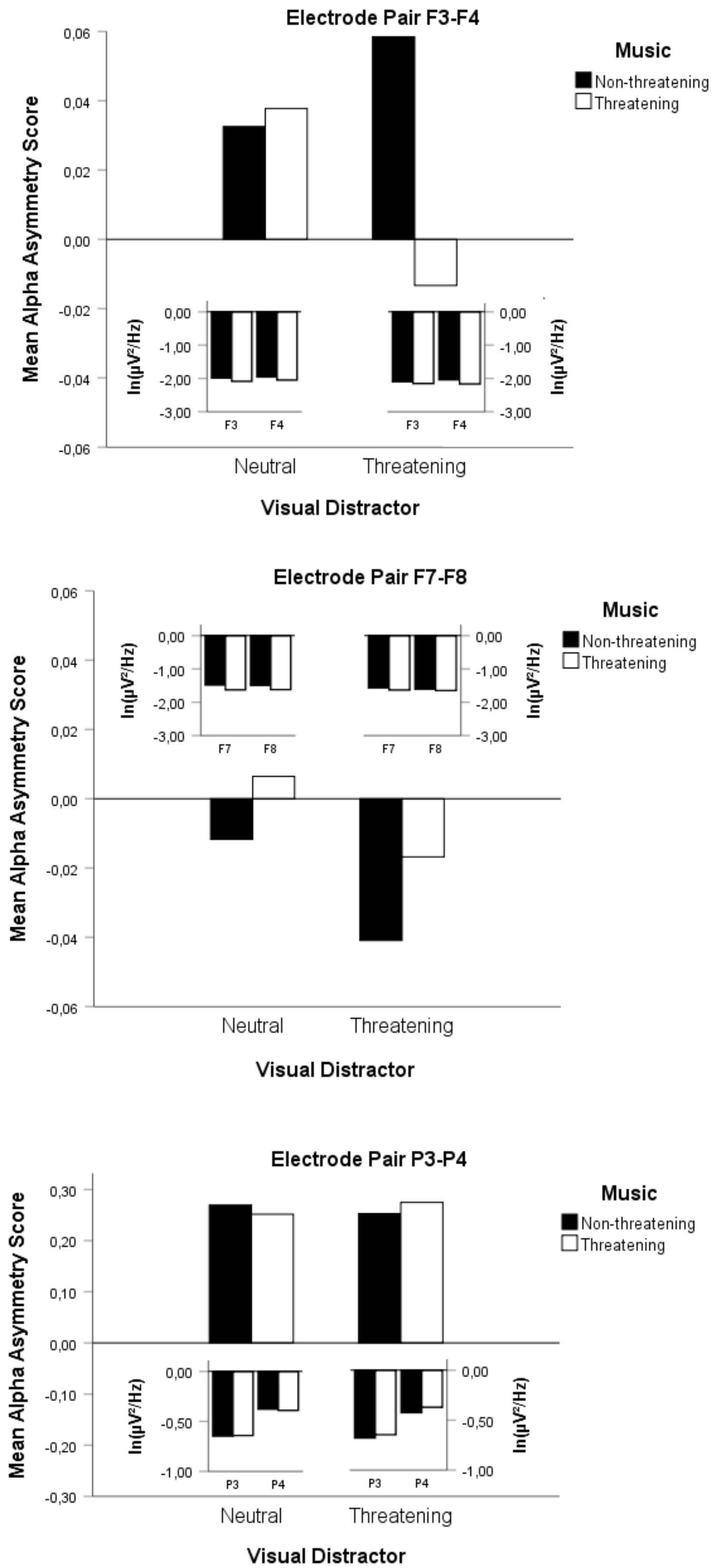

Figure 3. Mean task-related alpha asymmetry scores during the music condition for electrode pairs F3-F4, F7-F8, and P3-P4.

Task-related frontal alpha asymmetry during the preceding music condition

Analyses of the frontal alpha asymmetry scores calculated from the data recorded during the Executive RT test when there was no music playing, resulted in a main effect of visual stimuli ($F_{(1, 33)} = 64.022$, $p < .001$, $\eta^2G = .660$) for the electrode pair F3-F4. The frontal alpha asymmetry scores were smaller when the visual distractor stimulus was neutral than for when it was threatening. No main effect of preceding music was observed ($F_{(1, 33)} = 0.338$, $p = .565$, $\eta^2G = .010$). There was an interaction between visual distractor stimuli and preceding music ($F_{(1, 33)} = 14.525$, $p < .001$, $\eta^2G = .306$). To investigate this interaction, pairwise analyses were done. The pairwise analyses showed that when the preceding music was non-threatening, the mean alpha asymmetry scores were significantly smaller for the neutral than for the threatening visual distractor ($F_{(1, 33)} = 99.642$, $p < .000$, $\eta^2G = .751$). In turn, when the preceding music was threatening, there was no significant difference in mean alpha asymmetry scores between the visual distractor stimuli ($F_{(1, 33)} = 0.037$, $p = .849$, $\eta^2G = .001$).

For the electrode pair F7-F8, there was a main effect of visual stimuli ($F_{(1, 31)} = 35.696$, $p < .001$, $\eta^2G = .535$); the mean alpha asymmetry scores were smaller when the visual distractor stimulus was neutral than when it was threatening. There was no main effect of preceding music ($F_{(1, 31)} = 0.103$, $p = .751$, $\eta^2G = .003$) nor interactions observed ($F_{(1, 31)} = 0.033$, $p = .857$, $\eta^2G = .001$).

For the electrode pair P3-P4, there was a main effect of preceding music ($F_{(1, 33)} = 127.506$, $p < .001$, $\eta^2G = .794$); the mean alpha asymmetry scores were smaller when the preceding music was threatening in comparison to when it was non-threatening. There was no main effect of visual distractor stimuli ($F_{(1, 33)} = 0.011$, $p = .916$, $\eta^2G < .001$) nor interactions observed ($F_{(1, 33)} = 0.082$, $p = .776$, $\eta^2G = .002$).

See Figure 4 for illustration of these results.

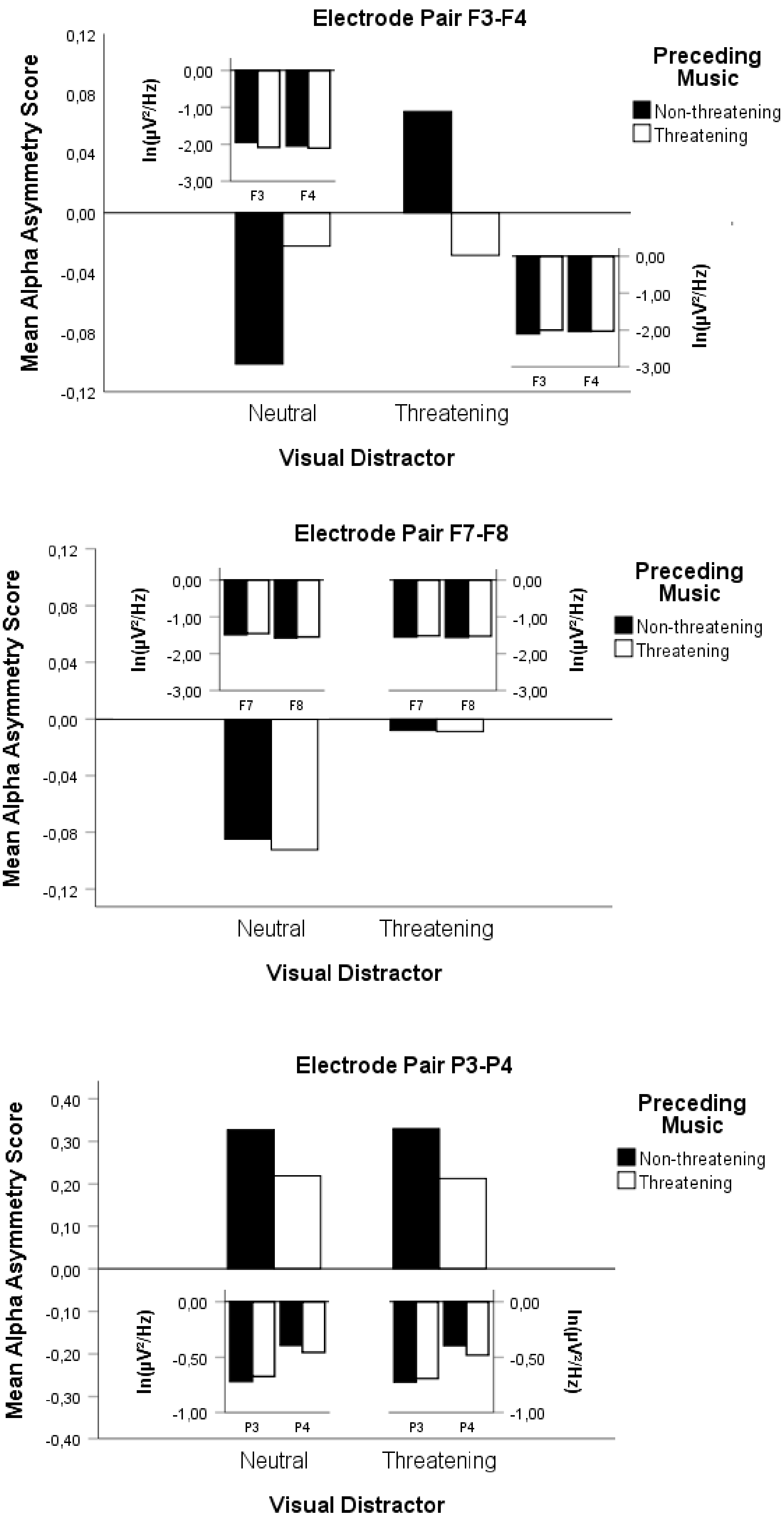

Figure 4. Mean task-related alpha asymmetry scores during the preceding music condition for electrode pairs F3-F4, F7-F8, and P3-P4.

Resting state alpha asymmetry

Analyses of the frontal alpha asymmetry scores, calculated from the data recorded during a resting state, resulted in no significant differences between threatening and non-threatening music for the electrode pairs F3-F4 ($t_{(18)}$ = -1.392, p = .181), F7-F8 ($t_{(17)}$ = -0.387, p = .704), and P3-P4 ($t_{(18)}$ = -0.073, p = .943).

DISCUSSION

The main purpose of the current study was to investigate whether simultaneous or preceding threatening music could modulate the frontal alpha asymmetry evoked by seeing a threatening visual stimulus. This was done by having the participants attend to a computer-based reaction time task that challenges multiple cognitive processes simultaneously. During each trial of the task, participants briefly saw a distractor stimulus that was either neutral or threatening. These trials were presented to the participants during two different conditions. In the music condition, there was either threatening or non-threatening music playing from participants' headphones while they were attending to the task. In the preceding music condition, the music was also either threatening or non-threatening, but the music did not continue playing during the task trials. Thus, altogether there were eight different combinations of visual stimuli (neutral, threatening) and simultaneous or preceding music (non-threatening, threatening).

The main hypothesis was that both the threatening visual stimulus and the threatening music would evoke more relative right frontal cortical activation in comparison to their non-threatening counterparts. Furthermore, it was hypothesized that if the music playing, or the music previously heard playing, was threatening, there would be more relative right frontal cortical activation evoked by the threatening visual stimuli than in the case of the non-threatening music, thus indicating a priming effect. Additionally, it was investigated whether there would be a difference in resting state frontal alpha asymmetry when the participants were listening to threatening music, compared to when they were listening to non-threatening music. The hypothesis was that there would be more relative right frontal cortical activation when the music was threatening.

The effect of threatening music on task-based and resting state frontal alpha asymmetry

In this study, there was a main effect of music on task-based alpha asymmetry observed for the electrode pair F3-F4. Listening to threatening music resulted in significantly more relative right frontal cortical activity than listening to non-threatening music. Thus, the results are in line with the hypotheses as well as with previous studies investigating the effect of emotional music on frontal alpha asymmetry (e.g. Flores-Gutiérrez et al., 2007; Schmidt & Trainor, 2001; Tsang et al., 2001). However, the main effect of music was not observed for the electrode pair F7-F8. This difference between the two frontal electrode pairs was unexpected. Even though both of these electrode pairs have previously been used for studying frontal alpha asymmetry (Reznik & Allen, 2018), the F3-F4 pair is still far more frequently used than the F7-F8 pair (Thibodeau et al., 2006; van der Vinne et al., 2017). Hence, it is difficult to interpret why the results of the F3-F4 pair and the F7-F8 pair differed from each other.

It is important to keep in mind that all of the previous studies have examined the effects of music in resting state, not task-based, frontal alpha asymmetry. This is relevant, as the two paradigms are different; task-based alpha asymmetry is averaged from short single segments of evoked alpha activity, while resting state alpha asymmetry is averaged from longer periods of data that have been evenly segmented (Smith et al., 2017). Thus, task-based alpha asymmetry is more related to how one reacts to and regulates emotional stimuli when attentional capacity is limited, as suggested by the capability model (Coan et al., 2006). These differences can be seen in the results of this study, as listening to threatening music had no effect on resting state frontal alpha asymmetry for either of the frontal electrode pairs when compared to listening to non-threatening music. Keeping the capability model in mind, the threatening music affecting only the task-based frontal alpha asymmetry could be explained by the reaction time task demanding simultaneous use of multiple cognitive functions, and therefore the participants not being able to regulate reactions to the threatening stimuli as well as in a resting state. In other words, during a resting state there is not a similar need to regulate the threat music evokes, because it does not interfere with performance in a meaningful task and does not capture one's limited attentional resources (Goodman et al., 2013). Furthermore, it is completely possible that during a resting state one's mind wanders to thoughts of varying emotional valence, which may influence frontal alpha asymmetry (Allen & Cohen, 2010). A few studies have shown that when comparing healthy participants to depressed ones, the task-based method is better for observing differences in frontal alpha asymmetry (Perez-Edgar et al., 2013; Stewart et al., 2014). Therefore, it is possible that the task-based method gives us better information concerning the effect of music on frontal alpha asymmetry than the resting state method.

It is interesting that in this study, the results of resting state alpha asymmetry analyses differ from previous studies investigating unpleasant music (Altenmüller et al., 2002; Arjmand et al., 2017; Schmidt & Trainor, 2001; Tsang et al., 2001). However, most of these previous studies have not concentrated on threatening music. For example, Tsang et al. (2001) used sad music to evoke negative affect, whilst Arjmand et al. (2017) created unpleasant music excerpts by manipulating the music participants enjoyed and making it dissonant. In addition, Altenmüller et al. (2002) focused on music that the participants personally disliked. Furthermore, Flores-Gutiérrez et al. (2007) observed differences in frontal alpha activation between threatening and pleasant music, but did not report any alpha asymmetry for the electrode pairs F3-F4 or F7-F8, as their analysis did not concentrate on typical alpha asymmetry scores calculated from opposite electrodes. Thus, the only previous study that observed differences in resting state frontal alpha asymmetry between threatening and pleasant music was by Schmidt and Trainor (2001). However, it is to be noted that in their study the differences in frontal alpha asymmetry between threatening and pleasant music were smaller compared to the differences between pleasant and sad music. In any case, the previous literature concerning threatening music and resting state frontal alpha asymmetry is minimal.

The effect of visual distractor stimuli on frontal alpha asymmetry

The current study yielded mixed results regarding the effect of threatening visual distractor stimuli on frontal alpha asymmetry. In the music condition, as expected, the visual stimuli did have a main effect on frontal alpha asymmetry for the electrode pair F7-F8, as there was more relative right frontal cortical activation for a threatening visual stimulus compared to a neutral one. However, this effect was not observed for the electrode pair F3-F4. During the preceding music condition, the visual stimuli had a main effect on both the frontal electrode pairs F3-F4 and F7-F8. The neutral visual distractor stimuli evoked more relative right frontal cortical activation in comparison to the threatening one, hence the result being the opposite of what was hypothesized. This was unexpected, because stimuli that are associated with withdrawal motivation have previously been reported to evoke more right frontal cortical activity than neutral or pleasant stimuli (Reznik & Allen, 2018). This effect has also been observed with threatening stimuli (Grimshaw et al., 2014; Perez-Edgar et al., 2013), meaning that in this respect, the results of the current study are at odds with those of previous studies.

However, not all previous studies have observed unambiguous differences between frontal alpha asymmetry evoked by pictures of different valence. For example, there was no difference in the frontal alpha asymmetry evoked by anger-inducing pictures compared to that evoked by pictures of positive or neutral affect in the studies of Harmon-Jones et al. (2006) and Harmon-Jones (2007). Yet, the trait anger of participants was related to how much left frontal cortical activation these pictures elicited. Similarly, while Adolph et al. (2017) observed no differences in frontal alpha asymmetry between threatening and non-threatening pictures, the alpha asymmetry scores were related to the participants' self-rated valence of the pictures. These results could suggest that the individual frontal alpha asymmetry scores are related to how one responds to certain pictures, and not to the pre-defined affective contents (for example threatening, joyful) of these pictures. Furthermore, neither of the two previous studies that used the present Executive RT test to study frontal alpha asymmetry observed a main effect for the visual distractor stimuli (Sun, Peräkylä, Holm, et al., 2017; Sun, Peräkylä & Hartikainen, 2017). However, a study by Sun, Peräkylä, Holm, et al. (2017) resulted in an interaction between visual distractor stimuli and vagus nerve stimulation (VNS), as the VNS influenced frontal alpha asymmetry only in the case of threatening visual distractors. Therefore, it is reasonable to question if it is purposeful to investigate the effect of the visual distractor stimuli on frontal alpha asymmetry as such, since the results of its main effect have been conflicting.

Another possibility is that the need to inhibit any visual distractor in the first place affects frontal alpha activity. Notably, Grimshaw and Carmel (2014) have proposed an alternative model for frontal alpha asymmetry, stating that alpha asymmetry reflects the inhibition of distractors. It differs from the approach/withdrawal model in that it associates left dorsolateral frontal cortical activity with inhibiting threatening distractors, and right dorsolateral frontal cortical activity with inhibiting pleasant distractors. Grimshaw and Carmel argue for their model by presenting some previous studies investigating cortical activity and inhibition (e.g. Compton et al., 2003; Goldstein & Volkow, 2011), but they admit that more research focusing on frontal alpha asymmetry is needed. As a study by Ocklenburg et al. (2017) did not observe an association between frontal alpha asymmetry and inhibition, the validity of the asymmetric inhibition model is still inconclusive.

Priming and frontal alpha asymmetry

In the current study, it was hypothesized that listening to threatening music would modulate the frontal alpha asymmetry evoked by a threatening visual stimulus. The results partly supported this hypothesis. In the music condition, there was no interaction between music and visual stimuli observed for any of the electrode pairs, albeit this result was trending towards significance for the electrode pair F3-F4. However, a further pairwise analysis on the electrodes F3-F4 showed that when the music was threatening, there was more relative right frontal cortical activation for the threatening visual stimulus in comparison to the neutral. This difference was not observed when the music was non-threatening. Overall, the most relative right than left frontal cortical activation was achieved when both the music and the visual stimulus were threatening. Thus, this result is in line with the hypothesis, although it was only observed for the F3-F4 electrode pair and not for the F7-F8 pair.

In the preceding music condition, there was an interaction between the preceding music and the visual distractor stimulus for the electrode pair F3-F4, but not for F7-F8. This interaction was not in line with the hypotheses, as preceding non-threatening music modulated the changes in frontal alpha asymmetry evoked by visual stimuli, but preceding threatening music did not. Moreover, when preceded by non-threatening music, there was more relative right frontal cortical activation when the visual stimulus was neutral in comparison to when it was threatening. Thus, the results of the preceding music condition for electrode pair F3-F4 are almost the complete opposite of what was proposed in the hypotheses. Furthermore, there was more relative right parietal cortical activation for preceding threatening music, compared to non-threatening music, observed for the electrode pair P3-P4. As this electrode pair was selected as a control, these results were unexpected. It is possible, however, that this effect is due to arousal. Threat-related stimuli are known to elicit higher arousal (Steimer, 2002), which has been associated with more relative right than left parietal cortical activity (Metzger et al., 2004).

All in all, the results of the preceding music condition were largely opposite of what was proposed in the hypotheses. However, the results do match the asymmetric inhibition model (Grimshaw & Carmel, 2014) discussed above in relation to the effects of visual stimuli. Keep in mind that this model suggests that left frontal cortical activity is related to inhibiting threatening distractors, while right frontal cortical activity is related to inhibiting pleasant distractors. It is possible that in the current study, the interaction observed between preceding music and visual distractor stimuli is a result of this inhibition. The alpha asymmetry scores for the F3-F4 pair support this model, but only when the preceding music was non-threatening. As the preceding non-threatening music was not expected to influence the alpha asymmetry evoked by the visual stimuli, it may be that these scores solely reflect the inhibition of the visual distractor stimuli. However, it is possible that the threatening music itself is such a powerful emotional stimulus that even when heard prior to seeing the visual distractor stimuli, it modulates the evoked frontal alpha asymmetry by inhibiting emotional visual distractors. Hence, it could be argued that the threatening music had a priming effect on the visual distractor stimuli, just not the one that was hypothesized. However, applying the asymmetric inhibition model (Grimshaw & Carmel, 2014) to explain the results of this study should be done cautiously, as the results of the music condition do not clearly fit the model.

It is also relevant to discuss whether the affective priming paradigm is fit for studying frontal alpha asymmetry. Although past research has shown that the effects of affective priming can be observed in event-related potentials (ERPs) (Baumgartner et al., 2006; Hietanen & Astikainen, 2013; Yang et al., 2011; Zhang et al., 2010), no previous studies have focused on its effect on frontal alpha power between hemispheres. Furthermore, in a study by Baumgartner, Esslen and Jäncke (2006), the simultaneous use of emotional music and pictures evoked more frontal activity, in other words less alpha power, than merely listening to emotional music or viewing emotional pictures alone. The study, however, did not observe a difference between hemispheres, nor the emotional valence of the stimuli, albeit they did not use the common alpha asymmetry paradigm concentrating mostly on electrode pairs F3-F4 and F7-F8.

The complexity of music as a stimulus

When discussing the effect affective music has on frontal alpha asymmetry, it is important to keep in mind that music is ultimately a complex stimulus that may elicit very specific and complicated emotions (Juslin & Laukka, 2003). In addition, the perception of music involves a wide variety of cognitive processes and their underlying brain mechanisms (Koelsch, 2011). As all of the excerpts of music in the current study were classical music, which often involve complex structures and dynamics, it is essential to discuss if the changes in alpha asymmetry may be explained by solely the affective qualities of the music.

The participants of the current study were asked to rate each piece of music for how threatening and how pleasant they thought each excerpt sounded. The results showed that, on average, threatening music was evaluated to sound more threatening and more unpleasant than non-threatening music. On the scale of pleasantness, however, threatening music was evaluated to sound only somewhat unpleasant (*M* = 5.44 on a scale from 1 to 9). Furthermore, not every threatening piece of music was rated more unpleasant than all of the non-threatening music, whilst every threatening music excerpt was rated more threatening than any of the non-threatening music. Thus, explaining the results of differences in alpha asymmetry between two types of music based on how threatening they sounded is justifiable in this study. However, since there was still a significant difference between the types of music regarding how pleasant they were, the option that the differences in alpha asymmetry were caused by the pleasantness of the music cannot be ruled out. In past research, the differences in frontal alpha symmetry have usually been explained by certain structural features that are believed to give certain music specific affective qualities (e.g. Arjmand et al., 2017; Daly et al., 2019). Yet, as previous studies have used different types of music to create negative affect, it is difficult to say for sure if they have all had a similar basis for their effects on frontal alpha asymmetry. However, one could argue that sad, threatening, and dissonant music can all be associated with withdrawal motivation, which for now is the most common explanation for decreased relative right cortical alpha power (Smith et al., 2017). A few studies have argued that the subjective enjoyment, in other words the pleasantness of music, is the reason behind changes in frontal alpha power (Altenmüller et al., 2002; Schmidt & Hanslmayr, 2009). However, Hausmann et al. (2016) argued that this is unlikely, as they observed differences in frontal activation between sad, neutral, and happy music, even though all were rated equally enjoyable.

It is possible that qualities of music which are not directly related to the affective features of the listeners' subjective enjoyment could impact frontal alpha asymmetry scores. Although Altenmüller et al. (2002) observed that the genre of music had no effect on frontal alpha asymmetry, it is possible that more specific elements of music do. In their study, Arjmand et al. (2017) observed that peaks in frontal alpha asymmetry were related to changes in musical features; especially motifs, instruments, and pitches. The peaks were, however, only identified in the pleasant music condition, hence it is uncertain if they would have been different when the music was unpleasant. As the task-based alpha asymmetry data in the current study were recorded in multiple segments of 1400 ms, it is possible that, for example, a change in instruments or pitch during a trial impacted the evoked asymmetry. If some music excerpts included a lot of these changes, it is possible they affected multiple trials and thus the average.

Limitations

One limitation of the current study is that the differences in frontal alpha asymmetry were only analysed by comparing the mean scores of each participant in different conditions, instead of also comparing the individual alpha asymmetry scores of participants to their baselines. It is known from past research that the individual baseline of frontal alpha asymmetry differs from person to person (Coan & Allen, 2004a). Most often, baseline alpha asymmetry values are used in the trait-like resting state alpha asymmetry paradigms (Coan & Allen, 2004b). However, it would also be useful to study how different stimuli change the frontal asymmetries in relation to pre-stimulus baselines with task-based studies. To achieve this, the resting state alpha asymmetry should have been measured while participants were sitting in silence with their eyes closed, which, however, was not done in this study. Therefore, it is possible that participants with either exceptionally high or low baseline alpha asymmetry scores could influence the data greatly. Furthermore, adding a condition without any preceding music could have enabled better analyses of the effects of the preceding music in the preceding music condition.

Another limitation is that the participants' moods were not asked about during the procedure, and therefore it was not controlled for in the analyses. The effect of current mood on frontal alpha asymmetry is not without caveats. Some previous studies suggest that the current mood of a participant may have significant influence on frontal alpha asymmetry (Coan & Allen, 2004a; Palmiero & Piccardi, 2017). However, Adolph and Margraf (2017) showed in their study that self-reported mood did not predict frontal alpha asymmetry. Regardless, controlling for mood may have given a better control for the results of this study. In addition, as all participants performed the Executive RT test with their right hand, it is possible that the slight movement of their hand influenced left frontal cortical activity.

The small sample size and the need to discard a few participants for bad EEG data also results in a few problems for this study. As the final sample size for the task-based alpha asymmetry data consisted of only 16–17 participants, depending on the electrode pair, the data of a single participant may have a significant effect on the whole data. Furthermore, with a small sample size the risk for both false negatives and false positives increases, thus making it possible that neither significant nor insignificant results reflect true effects (Button et al., 2013). The small sample size also did not allow for meaningful comparison between genders. There is some evidence that gender may moderate the relation of frontal alpha asymmetry and the enjoyment of music (Altenmüller, 2002).

Finally, because there was only one type of threatening visual stimulus used during hundreds of trials, it is possible that there would have been some habituation to the stimulus. It is well known that emotion-related regions of the brain such as the insula, amygdala, and prefrontal cortex habituate to repeatedly seeing specific threatening stimuli (e.g. Denny et al., 2014; Fischer et al., 2003), though it does not appear to have been studied if the habituation effect is similar when measuring alpha asymmetry. Regardless, the frontal alpha asymmetry evoked by a threatening visual stimulus could differ between the earlier and later blocks of the experimental design.

Strengths, practical applications, and future research

The results of the current study broaden the knowledge of the effect of music on frontal alpha asymmetry. To my knowledge, this is the first study to investigate the affective priming paradigm in relation to frontal alpha asymmetries. Although the exact effect remains somewhat unclear, this study demonstrates that simultaneous and preceding threatening music does influence the changes in frontal alpha asymmetry evoked by an emotional visual distractor. This endorses our understanding of music being a powerful emotional stimulus (e.g. Gerrads-Hesse et al., 1994) that can influence the processing of following stimuli (e.g. Goerlich et al., 2012). In addition, results of this study demonstrate that listening to threatening music evokes greater relative right than left frontal activation, similarly to sad music (Tsang et al., 2001) and music people dislike (Altenmüller, 2002). Moreover, this study supports the capability model (Coan et al., 2006), as the difference in frontal alpha asymmetry between threatening and non-threatening music was observed only when participants were performing a reaction time test and not during a resting state. Furthermore, the unexpected effect of visual distractor stimuli on frontal alpha asymmetry gives possible support for the asymmetric inhibition model proposed by Grimshaw and Carmel (2014).

The frontal alpha asymmetry model has been investigated from different perspectives for decades now. However, the full clinical potential of this phenomenon is still unclear. One reason for this has been the dilemma of what the difference in alpha power between frontal hemispheres actually represents. Additionally, the differences in electrode pairs and reference electrodes chosen, as well as the processing of EEG data, have complicated finding consensus (Smith et al., 2017). However, as several studies have evidenced the possibility of frontal alpha asymmetry being a practical biomarker of depression (Allen & Reznik, 2015), and perhaps even more so for anxiety disorders (Adolph & Margraf, 2017), there is a clear demand for further research. The Executive RT test used in the current study has been proposed as one possible approach for studying the effects of the differences in frontal alpha asymmetry between a clinical and a control sample (Sun, Peräkylä, Holm, et al., 2017; Sun, Peräkylä & Hartikainen, 2017). One of its main strengths is that as the visual distractor stimuli are composed of the same line elements, the only difference between the flower and spider images are their emotional content. However, it is still unclear if a threatening visual distractor stimulus alone influences frontal alpha asymmetry. Therefore, it is essential to investigate if evoked frontal alpha asymmetry could be manipulated by other stimuli in order to elicit further subtle differences between participants. If perfected, the Executive RT test could at best be used for separating healthy controls and those at risk by their individual frontal alpha asymmetry scores.

There is still a need for a lot of future research on frontal alpha asymmetry, and how it may be influenced by emotionally relevant music. It is still not certain if the changes in frontal alpha asymmetry are due to the musical elements of the music or the personal enjoyment. Furthermore, the effect of varying music should be extensively researched regarding both resting state and task-based frontal alpha asymmetry. In addition, the affective priming paradigm and frontal alpha asymmetry should be studied further by using simple music excerpts or other affective stimuli as well. As the results of this study gave some support to the asymmetric inhibition model (Grimshaw & Carmel, 2014), there is a need for more studies investigating the inhibition of visual distractors and frontal alpha asymmetry. Further support of this model could lead to a better understanding of the exact nature of hemispheric differences in frontal alpha power. There is also a need for an extensive study that compares the results of frontal alpha asymmetry studies according to the electrode pairs they have used. Finally, future research should pay more attention to the differences between gender, age, and the exact features of complex psychiatric disorders such as depression or anxiety.

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