Master Degree Project

UNIVERSITY OF SKÖVDE

Can Frontal Alpha Asymmetry Predict the Perception of Emotions in Music?

Master Degree Project in Cognitive Neuroscience
One year Advanced level 30 ECTS
Spring term 2016

Katharina Rischer

Supervisors: Oskar MacGregor
Sakari Kallio
Examiner: Antti Revonsuo

Rischer, Katharina:
Can Frontal Alpha Asymmetry Predict the Perception of Emotions in Music?
Master Thesis Cognitive Neuroscience
University of Skövde
Period: 18/01/2016 - 10/06/2016

Abstract

Resting frontal alpha asymmetry was measured with an electroencephalogram in 28 volunteers to predict the evaluation of emotions in music. Sixteen music excerpts either expressing happiness, sadness, anger or fear were rated by the participants with regard to conveyed mood, pleasantness and arousal. In addition, various variables of music background were collected. The experiment started with the assessment of current mood, followed by the evaluation of the music excerpts, and finished with the assessment of the participants' approach and withdrawal behaviour. The results showed that each music excerpt was specific for the intended mood except for music of the category anger which obtained also high ratings for fear. These music excerpts were also the only ones for which a difference in ratings between relatively more left-active and right-active participants could be observed. Partly against expectations, left-dominant volunteers perceived music excerpts of the category anger to express more fear and anger than right-active participants. Results are interpreted within the behavioural inhibition and approach model of anterior brain asymmetry.

Keywords: alpha asymmetry, resting state, emotions in music, motivational direction

Acknowledgements

This piece of work would not have been the same without the advices of my supervisors, Oskar MacGregor and Sakari Kallio, and the suggestions put forward by my examiner, Antti Revonsuo. I would particularly like to thank Oskar MacGregor for the time he took to read again and again through my thesis and for the thoughtful comments he gave. I would also like to thank my family for their constant support - especially for spreading the word about my online questionnaire. Furthermore, I would like to thank all the volunteers who participated in this study, often very enthusiastically, and Pilleriin Sikka for providing me with the EEGLab scripts. Last but not least, I would like to thank Renout Schoen with whom I collected the data and who would deserve a master's degree for his patience alone with which he disentangled the wires after a long day of recording sessions.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

> *The brain is the last and grandest biological frontier, the most complex thing we have yet discovered in our universe. It contains hundreds of billions of cells interlinked through trillions of connections. The brain boggles the mind.*
>
> James D. Watson

James Watson's famous foreword for the book *Discovering the Brain* published by Ackerman (1992) puts in a nutshell what motivated many researchers to explore the brain. For a long time neuroscientists were mostly restricted to the observation of behavioural changes caused by brain damage and the autopsy of the brains of deceased individuals in order to draw any conclusions about the organization and function of the human brain. First the development of techniques that were able to capture brain activity in the living individual allowed researchers to eventually gain insight into cognitive and emotional processes in the brain. One of these techniques is the electroencephalogram (EEG). It captures changes in voltage caused by the firing of neurons by means of electrodes that are attached on the scalp (Gazzaniga, Ivry, & Mangun, 2009). In his pioneering work on human electrocardiogram activity, Berger (1929) discovered that neurons fire in different frequencies. He observed that the prevailing oscillatory pattern in the human scalp lies between 8 and 13 Hz and termed the pattern *alpha* rhythm (Berger, 1929).

Around the same time as the EEG became established, Goldstein (1995) noted that persons suffering from damage to the right or left prefrontal cortex (PFC) processed positive and negative emotions differently. But only three decades later, a team of researchers around Richard Davidson could corroborate this finding using the EEG (Davidson, Schwartz, Saron, Bennett, & Goleman, 1979). They observed that individuals showed relatively higher alpha power over the right frontal hemisphere when they watched video tapes designed to elicit positive emotions whereas participants showed relatively higher alpha power over the left frontal hemisphere when they watched video tapes with negative content (Davidson et al., 1979). Considering that alpha power is negatively correlated with cortical activity (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998; B. Schmidt & Hanslmayr, 2009), this means that positive emotions were accompanied by relatively more cortical activity in the left frontal hemisphere and negative emotions were accompanied by more brain activity in the right frontal hemisphere. Following the discovery of *frontal alpha asymmetry (FAA)*, researchers explored thoroughly the relationship between alpha power and affect. In doing so, they also revealed that resting FAA could predict the responses to emotional stimuli. Harmon-Jones and Allen (1998) and others found that the crucial factor was less the valence of the stimuli, but rather the motivational direction associated with the stimuli.

In one of the experiments on alpha asymmetry, B. Schmidt and Hanslmayr (2009) found that FAA recorded during resting state predicted the evaluation of the expressed mood of three different music pieces that were intended to sound negative, neutral or positive. However, they also found that participants with relatively more left frontal cortical activity enjoyed the negative music excerpt most. Possibly, because participants associated the music primarily with anger - a negatively valenced, but approach-related emotion.

Primary aims of the present study are therefore

(i) to test the assumption that motivational direction can better predict the evaluation of emotions in music than affective valence alone
(ii) to rule out that current mood and motivation have a major influence on the evaluation of emotions in music
(iii) to explore the specificity and robustness of frontal alpha asymmetry

Chapter 2 provides background knowledge on research in frontal brain asymmetry, followed by Chapter 3 that reviews studies on the neural processing of music. Thereafter, the methods of the present experiment are described in Chapter 4. Subsequently, the results of the music experiment are presented in Chapter 5 and discussed in Chapter 6. Thereupon, the results of various methodological analyses are stated in Chapter 7 and reviewed in Chapter 8. Finally, a brief conclusion is given in Chapter 9.

Chapter 2

Frontal Alpha Asymmetry

This chapter focuses on the theoretical assumptions which are underlying research on frontal alpha asymmetry. In the first part, several theoretical frameworks are described that have been proposed to account for the relation between FAA and the processing of emotions, followed by contemporary paradigms of FAA. Subsequently, various methodological issues that are associated with research on anterior brain asymmetry are explained and confounding variables are specified.

2.1 Models

Various models have been put forward to explain how FAA is linked to affect. Among the most discussed ones is the *motivational direction* model which was developed by Richard Davidson (Davidson, 1984; Wacker, Heldmann, & Stemmler, 2003). Motivational direction refers in this case to approach or withdrawal behaviour towards appetitive stimuli, or away from aversive stimuli, respectively (Spielberg, Stewart, Levin, Miller, & Heller, 2008). Another theoretical framework, the *affective valence* model, was devised by Heller (1990) and others. The underlying assumption of this model is that emotions are either positively or negatively valenced, meaning that they are perceived either as pleasant or unpleasant (Spielberg et al., 2008). Later, Heller incorporated the dimension of arousal in her model; here referred to as *valence and arousal* model (Heller, 1993). Further, brain asymmetry was postulated to rely on the *behavioural inhibition and approach systems (BIS/BAS)*; the latter system is also often called behavioural activation system (Wacker et al., 2003). Besides this, it was proposed that FAA is based on *behavioural activation* (Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2004) or *asymmetry inhibition* (Grimshaw & Carmel, 2014). Behavioural approach refers to the activity of a physiological system that regulates approach behaviour whereas the behavioural inhibition system is engaged in avoidance behaviour (Wacker et al., 2003). *Behavioural activation* in this context designates the activation of either the BIS or BAS (Hewig et al., 2004), and the expression *asymmetry inhibition* specifies executive control mechanisms which inhibit the activity of specific neural networks (Grimshaw & Carmel, 2014).

Although the models are partly related, they make different predictions with regard to the activity of the left or right hemisphere for the four basic emotions happiness, sadness, anger and fear as can be seen in Table 2.1. It should be noted that the expressions *mood* and *emotion* are used interchangeably in the present study. Admittedly, emotions are often described as being directed towards a specific object whereas mood is conceived of as lasting, undirected affect (Vuoskoski, 2012). However, it is unclear in how far mood and emotions are distinct phenomena (Vuoskoski, 2012). Moreover, the articles reviewed for this study made no differentiation between emotions and mood with regard to the neural mechanisms they rely on.

Table 2.1: Predictions of Different Models of FAA

Model	Happiness	Sadness	Anger	Fear
Affective Valence	LH	RH	RH	RH
Valence and Arousal	LH	RH	RH	RH
Motivational Direction	LH	RH	LH	RH
BIS/BAS	independent of emotion	independent of emotion	independent of emotion	independent of emotion
Behavioural Activation	both	both	both	both
Asymmetry Inhibition	blocked by right dlPFC	blocked by left dlPFC	blocked by left dlPFC	blocked by left dlPFC

Note. The table depicts which hemisphere is predicted to be relatively more active during the experience of four basic emotions according to different models of frontal alpha asymmetry (FAA). LH = left hemisphere; RH = right hemisphere; dlPFC = dorsolateral prefrontal cortex.

Affective Valence The affective valence model states that positive emotions such as happiness are reflected in increased left frontal EEG activity whereas the processing of negative emotions such as fear, anger and sadness is accompanied by relatively more right-sided frontal activity (Harmon-Jones, 2003). However, the model struggles to account for the finding that anger is often accompanied by enhanced left frontal activity (Harmon-Jones & Allen, 1998; Harmon-Jones, 2003; Spielberg et al., 2008). Tomarken, Davidson, Wheeler, and Doss (1992) found that stable FAA predicted scores of positive affect measured with the PANAS, a questionnaire developed by Watson, Clark, and Tellegen (1988). On the other hand, Sutton and Davidson (1997) and Harmon-Jones and Allen (1998) found no significant correlation between affect quantified with the PANAS and FAA.

Valence and Arousal The valence and arousal model is based on the assumptions of the affective valence model, but additionally states that the right parietotemporal area modulates autonomic and behavioural arousal (Heller, 1993). Evidence that right posterior regions might be involved in emotion perception or comprehension has been found in several studies (Papousek & Schulter, 2006; Wacker et al., 2003; Zhang & Zhou, 2014).

Motivational Direction The motivational direction model holds that relatively more left frontal activity reflects a system that facilitates approach behaviour and is probably involved in goal-directed planning whereas relatively more right frontal activity indicates the activity of a system that facilitates withdrawal behaviour (Davidson, 1984, 2004; Davidson & Fox, 1982; Harmon-Jones, 2003).

According to Harmon-Jones (2003) anger is an approach-related emotion. As evidence he adduced that participants, who showed more anger in reaction to an unsolvable task, had more approach motivation to solve the following cognitive task (Harmon-Jones, 2003). Moreover, anger was found to be related to optimistic expectations and trait anger correlated with more assertiveness and competitiveness (Harmon-Jones, 2003). The assumption that anger is an approach-related emotion renders the motivational direction model a better predictor of the observed association between anger and increased left frontal activity than the valence model. Sutton and Davidson (1997) suggested that the sensitivity of one's approach and withdrawal systems could be measured with a questionnaire developed by Carver and White (1994), referred to as ***behavioural inhibition and activation scales*** or ***sensitivity (BIS/BAS)***. A correlation analysis showed that EEG asymmetry accounted for more than 25% of the variance of the BIS-BAS strength (Sutton & Davidson, 1997).

The neuroanatomical basis of the approach system is considered to be the left dorsolateral and medial PFC and the basal ganglia (Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2006). On the other hand, the withdrawal system is assumed to rely on the right dorsolateral PFC, the right temporal polar region, the amygdala, the basal ganglia and the hypothalamus (Hewig et al., 2006). However, an association between the sensitivity of the BIS and higher activity in the right PFC is controversial (De Pascalis, Cozzuto, Caprara, & Alessandri, 2013; Hewig et al., 2006). For instance, Poole and Gable (2014) found that frontal-lateralized late positive potentials (f-LPPs) to approach-positive and approach-negative pictures were larger in left frontal regions compared to right frontal areas whereas the f-LPPs in response to withdrawal-negative pictures did not differ between frontal sites. Also a study by Coan, Allen, and Harmon-Jones (2001) provided ambiguous results. In their study, facial configurations of fear and sadness associated with withdrawal tendencies resulted in relatively less left frontal activation whereas facial expressions of disgust, joy and anger were less supportive of the motivational direction model. Since the changes in the left hemisphere (LH) were more pronounced than in the right hemisphere (RH), the authors concluded that the LH might be the main contributor to FAA (Coan et al., 2001).

Behavioural Approach and Inhibition This model is based on the theory of Gray and McNaughton (2000) that behaviour is regulated amongst others by the behavioural approach (or activation) system (BAS) and the behavioural inhibition system (BIS). The BIS was conceptualized as a mechanism that modulates responses to aversive events and is sensitive to punishment, non-reward and unfamiliarity (Carver & White, 1994). The BAS, on the other hand, is sensitive to reward, non-punishment and involved in goal-directed behaviour (Carver & White, 1994).

Wacker et al. (2003) extended this conceptualization to explain FAA. In their view, behavioural facilitation-mobilisation controlled by the BAS is associated with relatively more left frontal brain activity and independent of emotions or motivational direction. This means that the BAS is assumed to also be active when the behavioural goal is to avoid an aversive event (Wacker et al., 2003). Behavioural inhibition is thought to interrupt goal-directed behaviour whenever the individual has to decide between two comparable appetitive, but conflicting goals and is associated with relatively more right-sided brain activity (Wacker et al., 2003). It is noteworthy to mention, that the conception of the behavioural approach and inhibition model of anterior brain asymmetry by Wacker et al. (2003) is not the same as what the BIS/BAS questionnaire developed by Carver and White (1994) measures. The BIS/BAS scales are based on the assumption that one's behavioural inhibition sensitivity reflects one's proneness to anxiety whereas one's behavioural approach/activation sensitivity indicates one's tendency to goal-directed behaviour (Carver & White, 1994).

Behavioural Activation The behavioural activation model strongly resembles the behavioural approach and inhibition model. However, it holds that the withdrawal and approach system are subsystems of the behaviour activation system (Hewig et al., 2004). The model predicts that high activity of the activation system should become evident in increased bilateral frontal activity. This claim is supported by a study in which the resting EEG activity of 59 subjects was measured on four occasions separated by four weeks each (Hewig et al., 2004). The results showed that greater bilateral frontal cortical activity was accompanied by higher BAS scores whereas no significant relationship between greater right anterior cortical activity and BIS scores was found (Hewig et al., 2006).

Asymmetry Inhibition The asymmetry inhibition model was postulated by Grimshaw and Carmel (2014). The authors suggest that EEG asymmetries reflect executive control mechanisms inhibiting interference from irrelevant emotional stimuli, so that relevant information is prioritized and kept in working memory (Grimshaw & Carmel, 2014). In more detail, they state that mechanisms in the left dorsolateral prefrontal cortex (dlPFC) block negatively valenced distractions whereas the right dlPFC is involved in the inhibition of positive stimuli (Grimshaw & Carmel, 2014). Evidence for this model is given by a study showing that subjects with relatively low left frontal activity found it more difficult to turn their attention away from angry faces, but not happy ones (Grimshaw & Carmel, 2014).

2.2 Paradigms of Frontal Brain Asymmetry

In most experiments FAA is either recorded at baseline and then subsequently correlated with behavioural and physiological measures or measured during the exposure to specific stimuli. In short, FAA is either treated as an independent trait-like predisposition or as a state-dependent measure (B. Schmidt & Hanslmayr, 2009).

2.2.1 Resting EEG Asymmetry

Hagemann, Naumann, Thayer, and Bartussek (2002) evaluated which of these two conceptually different paradigms has more explanatory power. For this, they recorded resting FAA of 59 participants on four occasions and subsequently analysed the temporal course of 15 participants who were extreme stable and 15 participants who were extreme unstable with regard to changes in brain asymmetry. Employing the *latent state-trait theory*, they showed that about 60% of the observed variance of asymmetry could be ascribed to individual differences on a temporally stable-latent trait whereas the remaining 40% were found to be due to occasion-specific fluctuations (Hagemann et al., 2002).

This finding corroborates the assumptions of the so-called *diathesis/stress model* postulated by Davidson (Davidson, 1993). The model states that shifts in FAA in response to physiological changes evoked by emotions are superimposed upon rather stable trait-like differences in anterior activation (Davidson, 1993). According to this conceptualization, brain asymmetry at baseline indicates an individual's vulnerability and tendency to experience certain positive and negative emotions, also described as *affective style* (Davidson, 1998). In favour of the conceptualization of FAA as trait is also the finding that resting FAA shows acceptable test-retest stability and excellent internal consistency reliability (Tomarken, Davidson, Wheeler, & Kinney, 1992). Moreover, resting FAA assessed in 14 month old children correlated with asymmetry scores computed at 83 months (B. C. Müller, Kühn-Popp, Meinhardt, Sodian, & Paulus, 2015). Further, alpha power was revealed to be highly heritable at frontal sites (Anokhin, Heath, & Myers, 2006).

Various studies have found evidence that stable brain asymmetry at baseline correlates with different physiological and behavioural measures. For example, relatively higher activity in the LH has been linked to dispositional optimism and higher levels of psychological wellbeing (De Pascalis et al., 2013; Urry et al., 2004). Individuals assessed to exhibit extreme and stable left-sided frontal EEG activity over several recording sessions were also found to report increased generalized positive affect and less negative affect compared to persons with stable right-sided frontal activity (Tomarken, Davidson, Wheeler, & Doss, 1992). Moreover, increased left-sided frontal activity has been associated with an effective coping style, i.e. conscious effort to solve one's problems, and quick recovery from aversive situations (Davidson, 2004; Jackson et al., 2003; Papousek & Schulter, 2006). Experiments even provide evidence that relatively more left-sided brain activity is related to a resilient profile of peripheral neuroendocrine and immune functions, i.e. better adaptation to stress (Davidson, 2004). For instance, it was revealed that individuals with increased activity in the LH had lower levels of the stress hormone cortisol and more natural killer cells, both at baseline and in response to aversive events than individuals with relatively more right-sided activity (Davidson, Coe, Dolski, & Donzella, 1999; Kalin, Larson, Shelton, & Davidson, 1998; Kang et al., 1991). What is more, patients suffering from spinal cord injury thought about their pain in less catastrophic ways if they exhibited relatively greater left than right anterior activity (Jensen, Gianas, Sherlin, & Howe, 2015).

In contrast to this, relatively less left-sided activity has been linked to depression (Harmon-Jones, 2003; Henriques & Davidson, 1991). For instance, left anterior brain lesions were associated with the development of major depression whereas right anterior brain lesions were linked to the occurrence of mania (Harmon-Jones & Allen, 1998). However, Davidson (1993) emphasized that an individual exhibiting hypoactivation of the left frontal hemisphere is not depressive per se, but rather more prone to become depressive when confronted with negative life events. For instance, participants selected from a normal sample based on their left frontal hypoactivation did not report more depressive symptoms than individuals with more left-sided activity, but showed more dispositional negative affect (Davidson, 1993).

Importantly, not all experiments on the relationship between relatively more right-sided frontal activation or activity and increased negative affect or withdrawal tendencies obtain clear-cut results; for instance only 14 of 33 studies reviewed by Hagemann et al. (2002) demonstrated a clear association. The same is true for the relation between more left-sided anterior cortical activation or activity and increased positive affect or the strength of behavioural activation; here, Hagemann et al. (2002) found only four of 12 studies to provide unambiguous results.

2.2.2 State-Dependent EEG Asymmetry

Challenging for the conception of FAA as a stable trait is the finding from Coan and Allen (2004) on the influence of trait and state effects on the variance of FAA. In an experiment, Coan et al. (2001) asked the participants to show facial expressions of anger, joy, disgust, fear and sadness. When Coan and Allen (2004) analysed the data, they found that trait accounted only for approximately 8% of the variance, state for circa 10% and the interaction between trait and state for roughly 11% of variance. Interestingly, they found that state-elicited changes were rather robust and occurred regardless of the person's trait predispositions (Coan & Allen, 2004). Therefore they concluded that FAA might be better conceptualized as state-dependent than as temporally stable trait. In favour of this concept are findings from Davidson and Fox (1982) that 10 month old children showed increased left frontal activation in response to film clips with a smiling actress compared to sad expressions. Besides this, Ekman and Davidson (1993) found that smiles of enjoyment were accompanied by increased left frontal activation, and Coan et al. (2001) demonstrated that voluntary facial expressions of fear led to relatively less left frontal EEG activity. L. A. Schmidt and Trainor (2001) observed that happy music excerpts were accompanied by more left-sided frontal activity whereas fearful and sad music excerpts were accompanied by relative more right-sided frontal activity. The same pattern could be observed for various other studies on affect in music (see Chapter 3).

2.2.3 Mode of Operation

Despite the quantity of studies exploring FAA it is still unclear which processes alpha asymmetry reflects. Coan and Allen (2004) formulated two possible modes of action (example i and ii) and two modes of impact (example iii and iv) and exemplified them as following:

(i) An individual with a disposition to relatively more right-sided frontal cortical activity in resting state is more sensitive to fear signals or responds more intensively to the signals since greater right frontal cortical activity is associated with withdrawal behaviour.
(ii) An individual only has the tendency to withdraw during a fear experience if the brain systems are active that constitute FAA.
(iii) An individual with relatively more left-sided resting frontal cortical activity evaluates both negative and positive stimuli as more positive.
(iv) An individual with relatively more left-sided resting frontal cortical activity

perceives only positive stimuli as more positive.

In example (i) FAA gradually regulates the processing of emotions, hence playing the role of a moderator. In contrast to this, in example (ii) FAA reflects the activity of neural networks processing affect, hence playing the role of a mediator (Coan & Allen, 2004). Studies on FAA yield different results in relation to the impact of alpha asymmetry on perception.

On the one hand, Tomarken, Davidson, and Henriques (1990) found that individuals with relatively more right-sided frontal activity during baseline reacted with more negative affect to fear- and disgust-inducing films. Further, Wheeler, Davidson, and Tomarken (1993) demonstrated that individuals with stable left frontal asymmetry responded with more intense positive affect to positive film clips whereas individuals with stable right-sided frontal asymmetry reacted with more intense negative emotions to negative films (as example iv exemplifies). Moreover, Davidson and Fox (1989) revealed that 10 month old infants were more likely to cry when separated from their mothers if they showed relatively more right frontal EEG activity at baseline. Besides this, Harmon-Jones and Allen (2001) demonstrated that participants with relatively increased right frontal EEG activity rated familiar stimuli as more likeable than unfamiliar ones, leading the authors to conclude that right-sided brain activity at baseline might be related to more anxiety toward novel stimuli. Furthermore, participants showed a shift to relatively more right-sided cortical activity when they were exposed to a stressful speech condition resulting in more attention to angry faces and avoidance of happy faces (Pérez-Edgar, Kujawa, Nelson, Cole, & Zapp, 2013).

On the other hand, B. Schmidt and Hanslmayr (2009) found that participants with greater left frontal activity evaluated both positive and negative valenced musical stimuli as more positive and enjoyable than more right-active participants (as example iii illustrates).

The present study is based on the assumption that FAA can be conceptualized as a temporally stable trait and can thus predict the perception of emotions in music as well as enjoyment and arousal (B. Schmidt & Hanslmayr, 2009). An aim of the study is also to further examine the mode of impact of FAA, in particular with regard to music since the outcome of the experiment from B. Schmidt and Hanslmayr (2009) is in contrast to other findings.

2.3 Methodological Issues

In addition to open questions with regard to the constituting mechanisms of FAA, researchers deal with various methodological problems.

One problem is that the EEG is only able to capture signals from the cortex, but allows no inferences on the activity of subcortical areas (Davidson, 2004). Moreover, alpha power has been found to be primarily inversely correlated with activity in the dorsal frontoparietal network coordinating activity between the dorsolateral prefrontal cortex and the posterior parietal cortex whereas the activity of other structures involved in the processing of emotions, such as the orbitofrontal cortex, is almost not reflected in EEG signals (Davidson, 2004; Grimshaw & Carmel, 2014).

Further, the choice of the reference electrode is problematic since e.g. even slight variations in the impedance of linked ears or mastoid reference electrodes can distort the signal (Davidson, 2004). Related to this problem is the common use of the vertex (Cz) as position for the reference electrode in previous studies since it has the worst signal-to-noise ratio (Hagemann, 2004). Besides this, it is still insufficiently explored which role other frequency bands than the alpha band play in emotion processing. With regard to this, one can also pose the question to what degree the alpha frequency band reflects cortical activity (Davidson, 2004). Moreover, the expression of the asymmetry index as the log-transformed alpha power of the LH and RH does not allow to infer whether the differences are due to hyperactivation or hypoactivation of one hemisphere or both (Papousek & Schulter, 2006).

Furthermore, Klimesch (1999) emphasized that power measurements are influenced by various individual variables such as the thickness of the skull, age and arousal. In addition to this, he pointed out that frequency bands vary for each individual, and differ between recording sites (Klimesch, 1999). Moreover, recordings at resting state are relatively uncontrolled, meaning that each individual might engage in different mental processes (Allen, Coan, & Nazarian, 2004).

Another issue is that most studies on FAA and emotions rely on the self-reported measures of emotions, which are unlikely to reveal the mechanisms constituting them (Davidson, 2004). Further, most studies investigating emotional processes do not sufficiently differentiate between the perception of emotional information and the production of emotions as Davidson (1993) criticized.

Besides this, it has been demonstrated that 35% of participants in one experiment moved from more right-sided asymmetry to more left-sided asymmetry or vice versa when the dorsolateral frontal activation was measured twice under identical recording conditions (Papousek & Schulter, 2006). Therefore Papousek and Schulter (2006) suggested to define relatively more left-active and right-active individuals in comparison to the remaining sample e.g. by median split. Importantly, alpha asymmetry is not exclusively related to frontal brain areas, but was also observed in temporal regions in response to emotional stimuli varying in valence (see e.g. Davidson, Ekman, Saron, Senulis, & Friesen, 1990; N. A. Jones & Fox, 1992; Park et al., 2011). Moreover, other researchers found that alpha asymmetry recorded at parietal regions was linked to the processing of emotions (see e.g. Bruder, Tenke, Warner, & Weissman, 2007; Stewart, Towers, Coan, & Allen, 2011).

2.4 Confounding Variables

Frontal alpha asymmetry is potentially influenced by various confounding variables.

Knott and Harr (1997) and Jorm et al. (1998) revealed that elderly adults exhibited greater theta and alpha power in the LH and scored lower on the BIS/BAS scales than younger age groups; in fact, Knott and Harr (1997) could observe increased theta and alpha scores in the RH in young adults. This data points to the need to carefully design studies on FAA if different age groups participate. The study from Jorm et al. (1998) also revealed specific gender effects for the BIS/BAS questionnaire developed by Carver and White (1994); females scored higher on the BIS scales and on the *reward responsiveness* subscale of the BAS questionnaire whereas males scored higher on the drive subscale of the BAS questionnaire. Also Davidson, Schwartz, Pugash, and Bromfield (1976) found gender-specific differences; in the study females exhibited significantly greater activation in the RH during emotional versus non-emotional trials and showed better control of asymmetrical patterns in a biofeedback training task. However, it is important to notice that most studies have not found significant gender effects related to FAA.

Another potential issue is that the unilateral contraction of one hand led to an increased activation of the contralateral hemisphere, resulting in greater left frontal activity at mid-frontal sites when contracting the right hand (Harmon-Jones, 2006). Also handedness might influence brain asymmetry. Brookshire and Casasanto (2012) found that stronger approach motivation was related to more activity in the LH in 34 right-handers whereas it was associated with more activity in the RH in 12 left-handers. Another study, analysing the correlation of FAA and handedness in 10 to 11 month old infants, revealed that left-sided asymmetry was characteristic for right-handers whereas left-handed and ambidextrous infants showed a more bilateral pattern of activity (Stroganova, Pushina, Orekhova, Posikera, & Tsetlin, 2004).

Moreover, it should be taken into account that stress and anxiety can alter or reverse measures of hemispheric specialization, possibly due to a cognitive overload in the specialized hemisphere (Papousek & Schulter, 2006). Besides this, findings of Peterson and Harmon-Jones (2009) indicated that relatively more right frontal activity is greatest during autumn mornings, probably because levels of the stress hormone cortisol are highest during autumn and winter and lowest during spring (Harmon-Jones, Gable, & Peterson, 2010). Velo, Stewart, Hasler, Towers, and Allen (2012), on the other hand, considered that the observed effects relied rather on distal sources projecting to frontal sites and being picked up when one uses conventional reference montages than on seasonal or circadian factors.

It is also controversial whether EEG recordings should be made with open or closed eyes. In a study examining this issue, Barry, Clarke, Johnstone, and Brown (2009) revealed that the opening of one's eyes led to reductions of absolute delta, theta, alpha and beta power. Consequently, they argued for the use of mean alpha power recorded under eyes-closed and eyes-open conditions in order to obtain a valid measure of resting-state activity (Barry et al., 2009). A similar finding was obtained by Boytsova and Danko (2010) when comparing the power of various frequency bands between open and closed eyes in darkness. Since the observed changes could not be elicited by visual stimuli, the authors suggested that the observed changes might reflect a shift from internally directed attention under the closed eyes condition to externally directed attention under the open eyes condition (Boytsova & Danko, 2010).

Last but not least, a study on anaesthetised rats indicated that caffeine intake might affect alpha activity and asymmetry (Voiculescu et al., 2015). In the experiments the rats exhibited a decrease of alpha activity when having taken in 150 mg of caffeine per kilogram body weight compared to controls. Moreover, the intake of a low dose of 1.5 mg per kilogram body weight led to relatively more left-sided activity in the alpha frequency range (Voiculescu et al., 2015).

Chapter 3

Music and Emotions

Music is a powerful stimulus with the potential to elicit spontaneous emotions and modulate arousal (Blood, Zatorre, Bermudez, & Evans, 1999; Mikutta, Altorfer, Strik, & Koenig, 2012). Therefore it is not surprising that the neural foundations of music perception and processing have been thoroughly explored, in particular in relation to the interplay of music and emotions. This chapter gives a brief overview of the factors underlying the perception of music, followed by a description of the neural processing of emotions in music.

3.1 Perception of Music

3.1.1 Cognition and Affect

The recognition of musical qualities, such as rhythm and tonality, and the appreciation of a music piece itself seem to be dissociable processes. By comparing the performance of a patient with severe deficits in music processing with a group of healthy controls in several music related tasks, Peretz, Gagnon, and Bouchard (1998) discovered that the patient was only impaired in non-emotional tasks that required her to detect changes or errors in music pieces that did not concern mode or tempo.

In a subsequent study, Gagnon and Peretz (2000) extended this finding to healthy participants. In the experiment participants listened to melodies either conforming to the rules of the Western tonal system or deviating from it. While one group evaluated the tonality, another group judged whether the melodies sounded pleasant or not (Gagnon & Peretz, 2000). Comparing the reaction times, Gagnon and Peretz (2000) discovered that subjects displayed a right ear advantage when listening to the tonal melodies, and a left ear advantage when presented with atonal melodies. Remarkably, this effect was only found for the group rating the pleasantness of the melodies (Gagnon & Peretz, 2000).

In line with the implications of the experiments by Gagnon and Peretz (2000) and Peretz et al. (1998), Blood et al. (1999) showed that participants were able to evaluate the emotional content of musical pieces without recognizing or identifying the melody. In the study participants listened to six versions of the same novel musical piece varying in degree of dissonance while their brain activity was analysed with positron emission tomography (PET) (Blood et al., 1999). Results revealed that increasing dissonance led to more activity in the right parahippocampal gyrus and the right precuneus regions. In contrast to this, increasing consonance correlated negatively with activity in the bilateral orbitofrontal and medial subcallosal cingulate and the right frontopolar cortex (Blood et al., 1999).

3.1.2 Perceived and Felt Emotions

Music researchers usually distinguish between perceived and felt emotions. Perceived emotions refer to the expressed mood which a music piece conveys and require cognitive judgements (Kreutz, Ott, Teichmann, Osawa, & Vaitl, 2007). Basic emotions, such as happiness, sadness, anger or fear, can be already discriminated by four to six year old children (Johnson-Laird & Oatley, 2008). In contrast, felt emotions comprise psychophysiological changes induced by music (Kreutz et al., 2007). Although even lay persons can clearly distinguish between both concepts, a clear-cut separation is difficult (Scherer, 2004). According to Gabrielsson (2002), perceived and induced emotions could possibly have four kinds of relationships that he exemplified as following:

(i) Perceived happiness induces happiness and perceived sadness induces sadness.
(ii) Perceived happiness induces sadness and perceived sadness induces sadness.
(iii) Perceived happiness and sadness do not induce any emotion or perceived happiness induces varying emotions for different listeners.
(iv) There is no relation between perceived and induced emotions.

3.1.3 Music Properties

Emotions in music are often conveyed by specific arrangements of acoustic cues including universal cues such as tempo and loudness and cultural-specific cues such as scales and tonality (Kreutz et al., 2007). Fritz et al. (2009) demonstrated that participants of the African Mafa population and Western countries both relied on a combination of mode and tempo to identify the expressed mood of music pieces, indicating that the recognition of emotions in music is culturally independent. The expression of fear was found to be primarily dependent on timing whereas sadness was revealed to rely to a large degree on articulation.

Anger, in contrast, is mediated particularly by loudness, and happiness depends on a combination of loudness and timing (Madison, 2000).

In an experiment Trochidis and Bigand (2013) examined the influence of major and minor mode and tempo on emotions evoked by a music piece and came to the conclusion that mode decisively modulates affective valence whereas tempo is implicated in emotional arousal. In their study, Trochidis and Bigand (2013) recorded the EEG activity of participants while those listened to music excerpts varying in mode and tempo. Subsequently, the participants evaluated the music pieces with regard to their emotional content. Examining the relationship between mode and FAA, they discovered that major mode was accompanied by increased activation of the RH (Trochidis & Bigand, 2013). Furthermore, faster tempi were found to induce stronger feelings of happiness and anger, resulting in increased frontal activation in the LH (Trochidis & Bigand, 2013). Slow tempi, on the contrary, were associated with a reduction in frontal activation in the LH (Trochidis & Bigand, 2013). In addition to this, high arousal was found to be accompanied by right frontal suppression of lower alpha band activity (Mikutta et al., 2012).

A similar ambiguous finding with regard to the lateralized processing of emotions in music made Khalfa, Schon, Anton, and Liégeois-Chauvel (2005) in a functional magnetic resonance imaging (fMRI) study. Similar to Trochidis and Bigand (2013), Khalfa et al. (2005) varied mode and tempo of a music excerpt. They found that affective processes involved subcortical and neocortical brain structures; in particular, musical excerpts in minor mode were accompanied by activity in the left orbitofrontal and mid-dorsolateral frontal cortices (Khalfa et al., 2005). Similarly, Lee, See, Chen, and Liang (2013) found that the presentation of a sad music video led to an inclination to more left frontal activity, even if the subject showed a relatively more active RH in the beginning.

Taken together, the findings indicate that the processing of emotions in music might be more complicated than predicted by the motivational direction or valence model. However, all experiments confirm the assumption that the various emotions conveyed by music are processed differently.

3.2 Influencing Factors

Music is a cultural phenomenon and thus experiments on the perception of music have to take various influencing factors into account.

Musical preference and experience decisively influence emotional responses to music (Kreutz et al., 2007). For instance, Van Den Bosch, Salimpoor, and Zatorre (2013) revealed that the self-reported familiarity of a music piece resulted in significantly increased pleasure. Besides this, Kreutz et al. (2007) found that a preference for classical music predicted the intensity of emotion induction best. Moreover, musical training can strengthen the perception of subtle changes through improved cognitive processing of musical cues and might result in higher activation ratings (Kreutz et al., 2007).

Emotional responses to music listening are also influenced by personality traits e.g. by modulating the sensitivity to music and the intensity of listening (Kreutz et al., 2007). Extroversion keenly correlates with the perception of positive affect in music whereas neuroticism was associated with susceptibility to negative affect in music (Vuoskoski & Eerola, 2011). Agreeableness moderated the enjoyment of happy and tender-sounding music and predicted a dislike of music that sounded angry and fearful in a study by Vuoskoski and Eerola (2011). Furthermore Eerola and Vuoskoski (2010) found that the personality trait openness to experience correlated with increased ratings of anger and valence whereas extroversion was accompanied by decreased ratings of tension. Negative mood as assessed with the *Profile of Mood States* questionnaire led to increased ratings of sadness (Eerola & Vuoskoski, 2010).

What is more, Altenmüller, Schürmann, Lim, and Parlitz (2002) found that differences in activation patterns in their experiment became far more evident in the female participants, raising the question of gender-related differences in emotional processes.

Further, Chang et al. (2015) discovered that participants rated music pieces as more pleasant or more positively valenced when they listened to the music with open eyes. Another experiment showed that listening to music with closed eyes led to increased judgements of emotionality in music, in particular for negative music (Lerner, Papo, Zhdanov, Belozersky, & Hendler, 2009). Furthermore, participants exhibited greater activity in the amygdala when they listened with closed eyes to music (Lerner et al., 2009).

3.3 Neural Basis of Music Processing

3.3.1 Processing of Emotions

According to Grimshaw and Carmel (2014) the generation of an emotional response is based on subcortical structures that are sensitive to behaviourally important cues, direct attention to the stimuli and activate a sequence of physiological reactions that prime the individual to approach or withdrawal behaviour. In this process at least four different brain structures are involved: The orbitofrontal cortex, a structure that receives input from subcortical structures and the sensory cortex, determines whether the stimulus is perceived as a reward or a threat (Grimshaw & Carmel, 2014). The anterior insula integrates this information with afferent projections from the body, raising awareness of the stimulus (Grimshaw & Carmel, 2014). Emotional experience is regulated by the ventromedial prefrontal cortex whereas the dorsolateral PFC is involved in cognitively mediated emotion regulation (Grimshaw & Carmel, 2014).

3.3.2 Processing of Emotions in Music

The processing of music relies on an interplay of neural pathways in both hemispheres (Tramo, 2001); primarily in frontotemporal areas (Omar et al., 2011; Sammler, Koelsch, & Friederici, 2011; L. A. Schmidt & Trainor, 2001). Omar et al. (2011) showed that patients with frontotemporal lobar degeneration had difficulties in recognizing emotions in music, most likely due to grey matter loss in a network consisting of the insula, the orbitofrontal cortex, the anterior cingulate and medial PFC, the anterior temporal, posterior temporal and parietal cortices as well as the amygdala and the subcortical mesolimbic system. Interestingly, damage in the amgydala correlated only with impaired emotion recognition for music stimuli, but not for the recognition of facial expressed emotions. The authors conjectured that the processing of emotions in music might rely more keenly on subjective arousal than the processing of other emotional stimuli. In another study, Sammler et al. (2011) revealed that patients with lesions in the left inferior frontal gyrus, also known as Broca's area, exhibited an abnormal scalp distribution of an electrophysiological marker indicating musical syntax processing in response to music stimuli. This led the authors to suggest that Broca's area is not only involved in the processing of syntax in language, but also in music.

In a variety of experiments researchers have explored which neural structures process the emotional content of music, and in doing so, have revealed a clear difference between neural patterns activated in response to positively and negatively valenced music excerpts. However, the studies do not narrow down to a specific core neural pattern, but rather include various structures that are possibly implicated in the processing of affect in music (see Table 3.1 and Table 3.2).

Evidence that emotions evoked by music are processed differently in the hemispheres is provided by an EEG study by Altenmüller et al. (2002) in which participants listened to short sequences taken from jazz, rock-pop, classical music and sounds from the environment. After each sequence the participants were asked to evaluate the pieces according to their emotional valence on a 5-point Likert scale. During listening, the participants exhibited a broad bilateral activation of frontotemporal areas, but when correlating the ratings with brain activity, an increase in left temporal activation could be observed for positive emotional attributions whereas negative judgements correlated with an increase in the right frontotemporal cortex, but to a lesser extent than for the positively judged excerpts. In contrast to this, musical sequences rated to be neutral resulted in a

Table 3.1: Neural Correlates of Affect in Music

Study	Music	Method	Activated Brain Areas
Blood and Zatorre (2001)	self-selected music eliciting chills	PET	activation of ventral striatum, midbrain, amygdala, orbitofrontal cortex and the ventral medial PFC with increasing intensity of 'chills'
Brown, Martinez, and Parsons (2004)	passive listening to pleasant music	PET	subcallosal cingulate gyrus, prefrontal anterior cingulate, retrosplenial cortex, hippocampus, anterior insula, nuclues accumbens, primary and secondary auditory areas, temporal polar areas
Chang et al. (2015)	positive music	EEG	posterior temporal parietal, middle prefrontal regions
Flores-Gutiérrez et al. (2007)	pleasant music	fMRI and EEG	posterior temporal parietal, occipital and middle prefrontal regions
Flores-Gutiérrez et al. (2007)	unpleasant music	fMRI and EEG	activation of right frontopolar and paralimbic areas
Lerner, Papo, Zhdanov, Belozersky, and Hendler (2009)	negative music	fMRI	amygdala, locus ceruleus, ventral PFC
Menon and Levitin (2005)	pleasant music	functional and effective connectivity analyses	nucleus accumbens, ventral tegmental area, hypothalamus, insula
Mitterschiffthaler, Fu, Dalton, Andrew, and Williams (2007)	happy music	fMRI	ventral and dorsal striatum, anterior cingulate, parahippocampal gyrus, auditory association areas
Mitterschiffthaler, Fu, Dalton, Andrew, and Williams (2007)	sad music	fMRI	insula and auditory association areas
L. A. Schmidt and Trainor (2001)	joyful music	EEG	mesolimbic and mesocortical pathways
L. A. Schmidt and Trainor (2001)	scary music	EEG	amygdala; pathway between visual cortex and superior parietal lobe

Note. fMRI = functional magnetic resonance imaging; PET = positron emission tomography; PFC = prefrontal cortex.

Table 3.2: Physiological Correlates of Affect in Music

Study	Music	Changes in Physiology
Blood and Zatorre (2001)	self-selected music pieces eliciting 'chills'	changes in cerebral blood flow, heart rate, muscle tension and respiration
Krumhansl (1997)	happy music	largest changes in respiration
Krumhansl (1997)	sad music	largest changes in heart rate, blood pressure, skin conductance and temperature
Krumhansl (1997)	scary music	largest changes in blood transit time and amplitude
Sammler, Grigutsch, Fritz, and Koelsch (2007)	unpleasant music compared to pleasant music	significant decrease of heart rate

bilateral activation of frontotemporal areas (Altenmüller et al., 2002). Interestingly, only the affective valence of the musical excerpts influenced the activation patterns whereas the music genre had no effect.

In another experiment, L. A. Schmidt and Trainor (2001) examined whether FAA was capable to distinguish between valence and intensity of musical pieces. For this, they presented 59 subjects with four musical excerpts chosen to represent fear (intense/unpleasant), joy (intense/pleasant), happiness (calm/pleasant) and sadness (calm/unpleasant) while recording their brain activity with EEG (L. A. Schmidt & Trainor, 2001). Similar to the findings of Altenmüller et al. (2002), positively valenced music excerpts were associated with greater left frontal brain activity whereas negatively valenced music was related to relatively greater right frontal brain activity (L. A. Schmidt & Trainor, 2001). Besides this, intense music excerpts were associated with significantly less overall frontal EEG power (L. A. Schmidt & Trainor, 2001).

Employing the assumption that positively valenced music is accompanied by an increase in left hemispheric activation, researchers also investigated whether musical therapy might shift frontal asymmetry in depressives from more right-sided to more left-sided activity. In one of these studies, Field, Martinez, Nawrocki, and Pickens (1998) compared the brain activity and cortisol levels of a group of depressed female adolescents listening to rock music for a 23 minute session with a control group which was asked to simply relax instead. Surprisingly, results revealed that the observed and reported mood did not change, but that relative right frontal activation was significantly attenuated during and after being exposed to the music. All in all, the frontal alpha laterality ratios of the music-group shifted significantly to a more bilateral activity pattern (Field et al., 1998).

Frontal alpha asymmetry is not only modulated by music, but also affects the evaluation of music pieces as a study by B. Schmidt and Hanslmayr (2009) demonstrated. In their experiment participants listened to positively, negatively and neutrally valenced musical excerpts. Subsequently, they rated the mood expressed by the music excerpts and how much they enjoyed the pieces on 5-point Likert scales. The ratings of the subjects were then correlated with their FAA scores. The correlation analyses revealed that the left-active participants evaluated all three music pieces to be significantly more positive than the right-active participants. Moreover, the left-active group enjoyed all three music excerpts significantly more than the right-active participants; this became in particular evident for the negatively valenced music excerpt.

Chapter 4

Experiment

4.1 Point of Departure

The starting point of this study was an experiment conducted by B. Schmidt and Hanslmayr (2009). In their study they hypothesised that participants with relatively greater left-sided frontal cortical activity perceive the music excerpts as more positive and enjoy them more than participants with relatively greater right-sided frontal activity who were assumed to perceive the music as more negative and enjoy it less.

In accordance with their assumptions, B. Schmidt and Hanslmayr (2009) found a significant main effect of the asymmetry score on expressed mood ratings ($F_{1,14}$ = 10.82, $p < .001$). A correlation analysis revealed that a higher asymmetry score, indicating relatively more left-sided activity compared to right-sided activity, correlated significantly with more positive ratings on the expressed mood of all three music stimuli, r_{sp} = .80, $p < .001$. The differences in ratings became evident in effect sizes of *d*(neutral) = .89, *d*(positive) = 1.01, *d*(negative) = 1.45 (the effect size d states the difference between the mean ratings of both groups divided by the standard deviation SD).

In addition to this, B. Schmidt and Hanslmayr (2009) found a significant main effect of the asymmetry score on enjoyment ratings ($F_{1,15}$ = 10.73, $p < .01$). However, the asymmetry score also interacted significantly with the music stimuli ($F_{2,28} = 8.53, p < .001$), becoming evident in an effect size of *d*(negative) = 2.28 for the negatively valenced music excerpt, *d*(positive) = 1.21 for the positive music excerpt and *d*(neutral) = .02 for the neutral excerpt. A Spearman correlation revealed that the alpha asymmetry scores predicted enjoyment of the negatively valenced music piece best (r_{sp} = *.60*, $p < .01$) compared to the positive music excerpt (r_{sp} = *.44*, $p < .05$) and the neutral music excerpt for which the correlation yielded no significant results.

Remarkably, the results contrast with findings of other studies which indicated that greater left-sided activity is associated with more intense positive affect to positively valenced stimuli whereas greater right-sided activity correlates with more intense negative affect to negatively valenced stimuli (Harmon-Jones & Allen, 2001; Pérez-Edgar et al., 2013; Tomarken et al., 1990; Wheeler et al., 1993). Opposite to this, the ratings on the expressed mood scale obtained by B. Schmidt and Hanslmayr (2009) indicate a general reinforcement of positive perception across all three stimuli types for participants displaying relatively more left-sided frontal activity. Moreover, the interaction effect between enjoyment ratings and stimuli type indicates that especially negatively valenced music is enjoyed more by participants with more left-sided activity. What makes this finding so surprising is that participants in the left-active group enjoyed the negative music excerpt even more than the positive music - possibly because participants linked the negative music excerpt implicitly to anger.

This would weaken the explanatory power of the valence model that underlies the experimental design of B. Schmidt and Hanslmayr (2009) while corroborating the validity of the motivational direction model. The primary aim of this study is therefore to test which model accounts better for the relationship between FAA and the evaluation of emotions in music.

4.2 Pilot Study

Before the actual start of the experiment, a pilot study was conducted in order to consolidate the assumption that the music piece used by B. Schmidt and Hanslmayr (2009) to express negative affect was primarily associated with anger. In addition to this, the pilot experiment was used to assess the expressed mood of several music pieces which were initially considered as stimulus material. The study was carried out in form of a web based questionnaire, designed with *psytoolkit.org*. All in all, 33 individuals (18 females) rated how happy, sad, angry and fearful seven different music excerpts, each one and a half to two minutes long, sounded (six individuals only completed the short version of the questionnaire, rating *Harmageddon* by Apocalyptica, *Halloween* by Ives and *Night on Bald Mountain* by Moussorgsky). The stimulus material consisted of the three music excerpts from B. Schmidt and Hanslmayr (2009) which the authors kindly provided and four music pieces employed in a mood induction study by Mayer, Allen, and Beauregard (1995).

In the questionnaire, participants first listened to the YouTube video of the various music pieces and subsequently rated the expressed mood. In doing so, participants started the music piece themselves by clicking on the time indicated in a description above the video. This study design was chosen due to copyright restrictions, but occasionally led to the fact that individuals listened to the whole music piece. Notwithstanding the problem that the web based study was not controllable, it still indicates to what degree each music piece was considered to express a specific mood. Median ratings for the music excerpts are depicted in Table 4.1.

A Friedman test was run to test for significant differences in the ratings of the emotions conveyed by *Harmageddon* from Apocalyptica (the negatively valenced music excerpt from B. Schmidt and Hanslmayr (2009)). Results showed that anger was only significantly different from happiness (χ^2_3 = 20.365, $p < .001$). However, the median ratings suggest that participants associated the music excerpt particularly with anger. This finding points in the direction that motivational direction accounts better for the perception of emotions in music than the factor valence alone.

Another finding is that the enjoyment of *Harmageddon* was strongly dependent on age. Participants were divided into two age groups comprising either individuals (N = 20) of age 21 to 30 (M = 23.80 $\pm$ 2.38) or participants (N = 13) of age 40 to 57 (M = 51.38 $\pm$ 4.89). Young people enjoyed the music piece significantly more (M = 2.90 $\pm$ 1.33, $\tilde{x}$ = 2.50) than the senior participants (M = 1.92 $\pm$ 1.04, $\tilde{x}$ = 2.00) as a Mann-Whitney U-test revealed (U = 75.5, z = -2.111, p = .043).

Against the background of this finding, it stands to reason that participants in the study of B. Schmidt and Hanslmayr (2009) might have also enjoyed the negative music piece more than the other two excerpts because the genre *(cello rock)* was more appealing to them than the classical music excerpts. This observation underlines the necessity to use music stimuli of the same genre for experiments exploring emotions in music and to control for listening habits.

4.3 Hypotheses

Three different assumptions were tested in the experiment. Firstly, the influence of the current mood on the evaluation of the music was assessed in order to rule out situational mood effects. Secondly, the predictive power of frontal alpha asymmetry on the perception of emotions in music was determined. Besides this, it was explored which effect the music background (music preference, hours of listening, music proficiency) had on the perception of emotions in music. Thirdly, the strength of the behavioural inhibition and approach system of each participant was tested with the aim to examine whether it correlates with FAA as demonstrated in previous studies e.g. by Sutton and Davidson (1997) or even directly influences the perception of emotions in music.

Based on studies of Kreutz et al. (2007) and Vuoskoski and Eerola (2011), the affective state was assumed to play only a moderate role, without displaying systematic effects on the evaluation of music. Momentary positive affect was ex-

Table 4.1: Median Ratings in the Pilot Study

Music Excerpt	Category	Happiness	Sadness	Anger	Fear
Harmageddon by Apocalyptica	negative	1	3	4	3
Fantastic Symphony by Berlioz	neutral	4	2	3	3
Violin Concerto D-major by Tschaikowsky	positive	4	3	2	2
Opus 28 No. 6 by Chopin	sad	2	5	1	2
Halloween by Ives	fearful	1	2	4	4
Mazurka from Coppelia by Delibes	happy	4	1	1	1
Night on Bald Mountain by Mussorgsky	angry	3	2	4	3

Note. The table states the median ratings of all seven music pieces rated in the study. The first three excerpts are taken from B. Schmidt and Hanslmayr (2009), the last four excerpts are taken from Mayer, Allen, and Beauregard (1995).

pected to mildly intensify the perception of happiness whereas negative affect was expected to correlate positively with ratings of sadness and fear. No correlation between current mood and alpha asymmetry scores were assumed.

In accordance with the motivational direction model, the perception of approach- and withdrawal-related emotions in music was expected to be modulated by FAA. Based upon this, it was hypothesized that participants with relatively more left-sided activity perceive happiness and anger as stronger than participants with relatively more right-sided activity. In contrast, the latter group should be more susceptible to the perception of fear and sadness, resulting in higher ratings on these emotion categories. Furthermore, FAA was expected to influence enjoyment and arousal. Left-dominant participants were anticipated to become more activated by music that represents happiness or anger and to enjoy it more than right-dominant participants. Opposite to the left-dominant group, right-active participants should be more aroused by fearful- or sad-sounding music excerpts, but enjoy them less.

Music background was assumed to moderately influence the perception of music. Familiarity and preference for classical or film music should result in higher ratings of enjoyment, but have no major impact on arousal (Kreutz et al., 2007; Van Den Bosch et al., 2013). The hours an individual listens to classical or film music per day should lead to increased enjoyment ratings. Moreover, musical expertise was assumed to correlate with higher activation ratings (Kreutz et al., 2007).

In line with previous studies which demonstrated a correlation between the sensitivity of the behavioural approach system and FAA, a positive finding was expected whereas the behavioural inhibition system was assumed to only correlate moderately with FAA, if at all (De Pascalis et al., 2013; Hewig et al., 2006). Moreover, the strength of behavioural approach as conceptualized by Carver and White (1994) was hypothesized to correlate positively with more arousal as well as increased perception of happiness and anger in music.

4.4 Methods

The present study was part of a battery of tasks examining the relationship between FAA and the perception of emotions in music, decision making and the empathic response to emotionally arousing pictures of people. In the first part of the experiment resting brain activity was recorded with an EEG. In the second part participants completed the three behavioural tasks in alternating order.

4.4.1 Participants

Forty-eight individuals completed the EEG recording and the music experiment. After exclusion of three volunteers that misunderstood instructions and defective data sets, the data of 13 female and 15 male volunteers (M = 24.54 ± 4.02) was analysed. Exclusion criteria were left-handedness, psychological or neurological disorders and uncorrected visual or auditory impairments. During recruitment participants were asked to abstain from caffeine consumption at least three hours prior to the experiment. All participants were naive to the goal of the experiment and provided informed consent before start in which they were informed of their right to withdraw from the study at any time. Most participants had an international background coming from Finland, Germany, Greece, Ireland, Lithuania, Portugal, South Korea, Spain, Sweden or Venezuela.

4.4.2 Materials

Musical Stimuli

Musical stimuli consisted of 16 film music excerpts (each approximately 15 seconds long) which were taken from a study by Eerola and Vuoskoski (2010) in which they systematically compared perceived emotions in music. In their experiment 116 non-musicians rated the expressed mood of 110 film music excerpts. For the present study the 16 music excerpts with the highest ratings for the categories *happiness*, *sadness*, *anger* and *fear* were selected (four for each category). Film

Table 4.2: Order of Musical Stimuli Taken from Eerola and Vuoskoski (2010)

Emotion	Album Name	*Track*	*Excerpt*	*Index*
Tender	Oliver Twist	2	00 : 00 – 00 : 29	050
Happiness 1	Batman	18	00 : 55 – 01 : 15	022
Fear 1	Batman Returns	5	00 : 09 – 00 : 25	011
Anger 1	Lethal Weapon 3	8	04 : 15 – 04 : 29	001
Sadness 1	Big Fish	15	00 : 55 – 01 : 11	034
Fear 2	Hannibal	1	00 : 40 – 00 : 54	015
Happiness 2	Man of Galilee CD1	2	03 : 02 – 03 : 18	024
Sadness 2	Man of Galilee CD1	8	01 : 20 – 01 : 37	035
Anger 2	The Alien Trilogy	9	00 : 03 – 00 : 18	003
Sadness 3	The English Patient	7	00 : 00 – 00 : 31	040
Anger 3	The Fifth Element	19	00 : 00 – 00 : 20	005
Happiness 3	Shallow Grave	6	02 : 02 – 02 : 17	023
Fear 3	JFK	8	00 : 08 – 00 : 25	013
Happiness 4	The Rainmaker	3	02 : 55 – 03 : 13	021
Sadness 4	The Portrait of a Lady	9	00 : 00 – 00 : 22	033
Anger 4	Cape Fear	1	02 : 15 – 02 : 30	004
Fear 4	The Alien Trilogy	5	00 : 26 – 00 : 41	014

Note. The excerpt labelled *Tender* was presented for loudness adjustment. *Index* refers to the index of the musical excerpts in the original study of Eerola and Vuoskoski (2010).

music excerpts were chosen to serve as musical stimuli since listeners are frequently exposed to film music, rendering this genre relatively neutral with regard to musical preferences, familiarity and cultural background (Eerola & Vuoskoski, 2010). Another reason was that film music is especially composed to express a specific mood (Eerola & Vuoskoski, 2010). The music excerpts contained no vocals since this might strongly influence the perception of the expressed mood (Brattico et al., 2011).

Table 4.2 lists the music stimuli that served as stimulus material in this study. The music excerpts were presented in two pseudo-randomized counterbalanced orders. Care was taken that no music excerpts from the same emotion category followed each other. The order of *Version 1* is depicted in Table 4.2; for *Version 2* stimuli were displayed in the reversed order.

Questionnaires

Current Affect Momentary mood was assessed with the Positive and Negative Affect Schedule (PANAS) developed by Watson et al. (1988). The PANAS consists of 20 items assessing positive and negative affect and can be either used to compute scores for general affect or momentary affect. Participants rated on a 5-point Likert scale, ranging from *very slightly/not at all* to *extremely*, how they currently felt.

Behavioural Inhibition and Approach The strength of the participant's behavioural inhibition and approach system was measured using the Behavioural Inhibition and Behavioural Approach Scales (BIS/BAS) developed by Carver and White (1994). The questionnaire consists of 24 statements that are rated on a 4-point Likert scale, ranging from *very true for me* to *very false for me* with no neutral response (Carver & White, 1994).

Music For each music excerpt participants had to rate to what degree they agreed that the excerpt expressed *happiness*, *sadness*, *anger* and *fear* on 5-point Likert scales ranging from *strongly disagree* to *strongly agree*. Additionally, they rated how much they enjoyed the music excerpt and how arousing the music was on 5-point Likert scales ranging from *not at all pleasant* to *very much pleasant*, or *not at all arousing* to *very much arousing*. (Note that the experiment was not designed to induce emotions. The possibility to rate *arousal* and *pleasantness* was primarily given to facilitate the differentiation between perceived and felt emotions. Therefore only moderate effects were expected for arousal ratings.) Participants also indicated whether the music excerpt sounded *unfamiliar* or *familiar*. The last page of the questionnaire contained questions assessing the music background of the participant. They were asked to list what kind of music they normally listen to, how many hours they listen to music on average per day and how they would judge their own music knowledge. Here, they could choose between four different answers: (1) *Non-musician*, (2) *Occasional playing musical instruments (only for fun)*, (3) *Amateur (serious interest, but non-professional)* or (4) *Semi-professional or professional (as an occupation)*.

The construction of the questionnaire was based on the music questionnaire used by Kreutz et al. (2007). As in their questionnaire, instructions on the questionnaire stated that unmarked boxes would be rated as *strongly disagree*, *not at all pleasant* or *unfamiliar*.

4.4.3 EEG Set-Up

All participants completed two resting EEG sessions of two minutes with eyes open and closed. Two minutes of recording were demonstrated to be enough to maintain internal consistency reliability of FAA (Allen, Urry, Hitt, & Coan, 2004; Papousek & Schulter, 2006). Conditions (start with eyes closed or eyes open) were alternated between participants. If the recorded data was considered to be heavily distorted by artefacts, participants were asked for a third or fourth session. Verbal instructions were given prior to recording to minimize artefacts. During the recording with open eyes participants were asked to fixate at a fixation cross presented on a screen.

Brain activity was recorded using 34 active Ag/AgCl electrodes positioned according to the international 10/20 placement system. Active electrodes have an ultra-low noise pre-amplifier implemented so that artefacts and signal noise caused by high impedance are reduced ("g.tec's active and passive biosignal electrodes for g.GAMMAcap," n.d.). In addition to the 19 standard electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, O2) ("Recommended EEG standard electrode configurations," n.d.), frontal activity was recorded with eight more electrodes (AF3, AF4, AF7, AF8, FC3, FC4, FC5, FC6). Besides this, two electrodes were attached on the left and right mastoids (LM, RM). Ocular movements were captured by attaching electrodes supra- and suborbit of the right eye and at the external canthi of each eye. Electrodes were placed using a stretchable electrode cap (g.GAMMAcap2) and conductivity was ensured by applying gel. All electrodes were initially referenced to Fz. During processing of the data, electrodes were offline re-referenced to the left and right mastoids. AFz served as ground electrode. EEG was amplified by g.USBamp amplifier (g.tec). Signals were recorded with a sampling rate of 256 Hz and a bandpass filter of .1 to 60 Hz.

4.4.4 Experimental Design

The evaluation of the music excerpts was based on a within-subject design since each participant rated all music pieces. Moreover, each volunteer rated each music excerpt on various categories e.g. happiness, fear, arousal, enjoyment. Thus a repeated-measures design underlay the evaluation of emotions in music. Since participants either listened to *Version 1* or to the reversed order, *Version 2*, the design was also counterbalanced. The analysis of the relationship between frontal alpha asymmetry and the evaluation of emotions in music falls into the category of independent measures designs since each participant was either classified as relatively more *left-active* or *right-active*. Independent variables in this experiment were the music stimuli and alpha asymmetry scores as well as the positive and negative affect scores and the behavioural approach and inhibition scores that were calculated analysing the PANAS and the BIS/BAS questionnaire. Dependent variables, on the other hand, were the ratings of the music excerpts.

4.4.5 Procedure

At the beginning of each experiment participants signed an informed consent and answered questions about their age, gender, their caffeine intake prior to the experiment and the exclusion criteria on a questionnaire. For the experiment participants took place in a comfortable chair positioned in front of a screen (HP Z23i IPS Display) with two loudspeaker boxes (Logitech Z523) placed on each side of the screen and the subwoofer placed on the floor. First, EEG was prepared and brain activity was recorded, taking approximately 30 minutes. Thereafter the order of the tasks was explained and participants received the music questionnaire in paper form. Furthermore, participants were instructed how to change the volume of the loudspeakers. After having clarified final questions, researchers left the room without entering in between the behavioural tasks. The completion of the behavioural tasks took on average 45 to 60 minutes. Ten volunteers completed the music task directly after the recording, eight completed it as second task and the remaining ten participants completed it at last. All in all, participants needed between 15 and 20 minutes to complete the music experiment.

The music experiment consisted of three components. In the first component participants filled in questionnaire to assess their current mood and in the third component they answered a questionnaire to quantify the strength of their behavioural inhibition and approach systems. Both questionnaires were designed in E-Prime 2.0 and presented on the screen.

In the second component participants listened to the music excerpts and rated them on a paper questionnaire. They their asked to read the instructions on the questionnaire before listening to the first music excerpt. The component started with the presentation of a moderately tender music excerpt taken from the study by Eerola and Vuoskoski (2010) so that participants could adjust the volume of the loudspeakers to their personal comfort level (Kreutz et al., 2007; B. Schmidt & Hanslmayr, 2009). Afterwards participants listened successively to 16 different music excerpts either presented in the order in which they are listed in Table 4.2 (Version 1) or in the reversed order (Version 2). Instructions on the screen asked them to listen first to the whole excerpt with open eyes before rating the music piece on the paper questionnaire. Each participant could decide when the next excerpt should be displayed by pressing *Enter* on the keyboard.

4.4.6 Data Analysis

EEG Data

The recorded EEG data was processed using the toolbox EEGLAB 13.5.4b (Delorme & Makeig, 2004) in MATLAB R2014a. For cleaning and computation of the asymmetry scores scripts from a previous study on resting alpha asymmetry provided by Pilleriin Sikka from the Universities of Skövde and Turku were adapted. In the first step, data was filtered at .05 Hz and 45 Hz. In addition to this, the data was re-referenced offline to the left and right mastoids. Subsequently, continuous data was visually inspected for artefacts. Sequences containing eye movements and muscle artefacts or otherwise artefact-like events were rejected. In order to automatically remove parts exceeding a threshold of $\pm$ 75 μV that are most likely caused by ocular artefacts, the data was epoched (2000 ms), the baseline for the period before 1000 ms was removed and overlapping epochs of 50% were created (Montefusco-Siegmund, Maldonado, & Devia, 2013). Datasets that contained no more than 20 epochs after epoch rejection were excluded from further analysis.

For calculation of the alpha power, a fast-Fourier-Transformation (FFT) was applied to the remaining epochs using a Hanning window function. Power within the alpha frequency range was computed for electrodes at mid-frontal sites (F3/F4). An alpha frequency range of 8 to 12 Hz was used since alpha asymmetry effects were revealed to be strongest in the lower alpha band (Wacker et al., 2003). For computation of the alpha asymmetry score, power values for open and closed eyes recordings were averaged for each electrode and the logarithm was taken. The score was computed with the following equation (Allen, Coan, & Nazarian, 2004):

$$\text{Asymmetry Score} = \ln(\text{Power}_{\text{right}}) - \ln(\text{Power}_{\text{left}})$$

Positive asymmetry scores reflect relatively more right-sided power i.e. more left-sided cortical activity since the relationship between alpha power and brain activity is inverse (B. Schmidt & Hanslmayr, 2009). Vice versa, negative values indicate more left-sided power i.e. more right-sided cortical activity.

Participants were assigned to the *left-active* or *right-active* group based on two procedures. In one procedure, participants were divided based on positive or negative scores (labelled henceforth *sign split*). Additionally, participants were divided into two groups by median split so that possible effects of unequal group sizes could be estimated. For this, the median asymmetry score was calculated and participants were either classified as relatively more left-active or right-active depending on whether their score was higher or lower than the median. Division by median split is frequently used in studies on alpha asymmetry e.g. by Anokhin et al. (2006), Gotlib (1998), Nash, Inzlicht, and McGregor (2012) and recommended by Papousek and Schulter (2006).

In order to examine the robustness of alpha asymmetry, the data of 22 participants was additionally cleaned using independent component analysis (ICA) in EEGLAB. The resulting independent components reflect stereotyped patterns like eye blinks or alpha activity. Removal of the components leads to a flattening of the concerned parts in the data. However, often components do not clearly reflect one pattern, but are mixed. Against the background of this difficulty, datasets were cleaned with two different approaches. Once, only the components that clearly reflected eye movements were removed (labelled *ICA Basic*). The other time, also components that pointed to non eye-movement-related artefacts were rejected (labelled *ICA Extensive*). After artefact correction with ICA, both data sets were epoched and epochs containing extreme values $\pm$ 75 μV were removed.

Subsequently, four different alpha asymmetry scores were computed, differing in frequency range and electrode sites. The decision to compare four scores was motivated by the fact that research on FAA is not consistent with respect to the electrodes used to compute the score and the frequency cut-points chosen. Some researchers focus primarily on the mid-frontal area (F3/F4) (see e.g. L. A. Schmidt & Trainor, 2001; Sutton & Davidson, 1997) whereas others include the lateral frontal area (F7/F8) in their analysis as well (see e.g. Altenmüller et al., 2002; Coan & Allen, 2003b; Fachner, Gold, & Erkkilä, 2013; Gollan et al., 2014). Besides this, several publications about alpha asymmetry are based on an alpha frequency band of 8 to 12 Hz (see e.g. Chang et al., 2015; Gollan et al., 2014) whereas others employ a frequency band reaching from 8 to 13 Hz (see e.g. Coan et al., 2001; Davidson & Schwartz, 1977; Poole & Gable, 2014). Some researchers on the other hand use no integers at all, but borders such as 7.8 to 12.5 Hz (Bruder et al., 1997) or 8.29 to 11.71 Hz (B. Schmidt & Hanslmayr, 2009). Consequently, alpha asymmetry scores were computed for F3/F4 as well as F7/F8 with either a boundary of 8 to 12 Hz or 8 to 13 Hz.

Further, the assumption that only the alpha frequency band yields significant results for the evaluation of emotions in music was tested by computing asymmetry scores for the delta (2-4 Hz), theta (4-8 Hz), beta (14-30) and gamma (30-40 Hz) frequency bands (Åkerstedt & Gillberg, 1990; Benoit, Daurat, & Prado, 2000; Niedermeyer, 1993; Steriade, Amzica, & Contreras, 1996). Scores were computed for all 28 participants based on the manually cleaned dataset, using the same procedure as for the calculation of alpha asymmetry.

Statistical Analyses

The relationship between frontal alpha asymmetry and the behavioural variables was tested with non-parametric tests in SPSS 22. This decision was made since Levene's test revealed that various variables were not normally distributed. Moreover, it is highly controversial among researchers whether 5-point Likert scales are on interval or ordinal scale. The proponents of the ordinal scale argue that equal distance between the response categories cannot be assumed, so that the mean has no informative value (Jamieson, 2004). The third reason was that groups were partly very unequal in size e.g. high music expertise was relatively uncommon among the examined sample. Music excerpts were either tested individually or the average ratings for all four music pieces of one category were computed, depending on the relationship that was tested. The significance level for all tests was set to p = .05.

The evaluation of the music excerpts was screened for outliers using boxplots. However, it was decided not to remove outliers. The reason is that in contrast to e.g. reaction times, a diverging perception of emotions in music from the norm cannot be ascribed to anticipation or concentration issues, but might very well be related to the investigated differences in cortical activity.

The main hypothesis that left-active participants rate anger and fear to be higher than right-dominant participant, who, on the other hand, perceive fear and sadness more intensely was tested by averaging the ratings for all four music pieces of one category. This was done to rule out effects of music properties and expected to result in more reliable and robust findings.

A Friedman test was run to determine the specificity of the music excerpts for the mood which the excerpt was intended to express. Friedman test is the non-parametric equivalent for a repeated measures analysis of variance (ANOVA). This test was chosen since each participant rated each music excerpt for different categories so that the independence of responses cannot longer be assumed. Group differences between left-active and right-active groups with respect to the evaluation of the music excerpts were assessed with a Mann-Whitney U-test, corresponding to the independent t-test. This test was selected since the alpha asymmetry groups were not related. For continuous data, Bonferroni corrected Spearman or Pearson correlation were used e.g to assess the relationship between the asymmetry scores which were based on different cleaning methods.

Chapter 5

Results of the Music Experiment

This study explored the relationship between resting frontal alpha asymmetry and the perception of emotions in music. In addition to this, the study included measurements of current positive and negative affect to rule out situational mood effects, and an assessment of the strength of the behavioural inhibition and approach system that was shown to be associated with frontal alpha asymmetry in previous studies e.g. by Sutton and Davidson (1997). Participants included in the analysis were 28 volunteers, often with an international background. In the experiment they listened to 16 music pieces of the categories *Happiness*, *Sadness*, *Anger* and *Fear* and subsequently rated the expressed mood, pleasantness and arousal of each excerpt on 5-point Likert scales.

Based on the motivational direction model, it was hypothesized that participants with relatively more left-sided frontal activity should perceive the emotions anger and happiness as more pronounced in music than more right-active participants. These participants, on the other hand, were predicted to perceive fearful- and sad-sounding music pieces as more intense. In this chapter the primary results of the study are presented.

5.1 Music

5.1.1 Specificity of Emotions in Music

The specificity of each music excerpt to express its intended mood was tested with a Friedman test. This statistical test was chosen since each subject rated each music excerpt on four different emotion categories. For all 16 music excerpts the Friedman test confirmed that there was a significant difference in the ratings of the expressed mood. Non-parametric post hoc analysis with a Bonferroni correction revealed that each intended mood was significantly different from the

Table 5.1: Evaluation of the Music Excerpts

Category (a priori)	Excerpt	Happiness		Sadness		Anger		Fear		Arousal		Enjoyment	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Happiness	1	4.18	.82	1.25	.84	1.89	1.13	1.61	1.13	3.32	1.02	3.79	.88
	2	4.50	.64	1.11	.42	1.32	.67	1.18	.48	3.25	1.11	3.68	1.25
	3	4.86	.36	1.00	.00	1.04	.19	1.00	.00	3.43	1.20	3.89	1.07
	4	4.71	.54	1.18	.48	1.14	.59	1.04	.19	3.21	1.07	4.14	.76
Sadness	1	1.68	.67	4.14	.97	1.25	.65	1.75	.97	2.43	.92	3.29	.98
	2	1.86	1.15	3.79	1.00	1.64	.78	2.14	1.18	2.93	.98	3.54	.96
	3	1.32	.72	4.68	.61	1.39	.79	2.07	1.09	2.89	1.29	3.29	.85
	4	1.39	.74	4.46	.69	1.50	.92	1.82	.95	2.82	1.09	3.54	1.07
Anger	1	1.57	.92	1.86	1.04	3.86	1.08	3.46	1.20	3.36	1.10	2.68	1.25
	2	1.11	.32	1.21	.42	4.43	.57	3.00	1.33	2.93	.81	2.82	.91
	3	1.61	.83	2.07	1.18	4.04	.88	2.96	1.48	3.00	.98	3.07	.98
	4	1.07	.26	2.04	1.14	3.96	1.0	3.39	.96	3.14	1.15	2.50	1.04
Fear	1	1.25	.70	2.18	1.09	2.54	1.17	4.57	.63	3.29	1.15	2.04	1.14
	2	1.07	.26	2.07	1.05	1.93	.94	4.14	1.11	2.71	1.08	1.96	.92
	3	1.29	.54	1.71	.94	2.29	1.15	4.00	.94	3.00	.98	2.79	.88
	4	1.14	.45	1.93	1.12	2.89	1.23	4.54	.64	2.89	1.23	2.11	1.10

Note. The table states mean (*M*) and standard deviation (*SD*) for all 16 music pieces that were rated in the study. Note however, that Friedman test is based on the median. *M* and *SD* are only stated to illustrate more subtle differences.

other emotion categories except for three music pieces intended to express anger. These music excerpts were perceived similarly angry as fearful e.g. *Anger 1* was rated comparably angry (M = 3.86 ± 1.08, *Median*= 4) and fearful (M = 3.46 ± 1.20, *Median* = 4) with p = 1.00. Likewise, *Anger 3* and *Anger 4* were rated to express as much anger as fear. *Anger 3* was perceived to represent anger on average with M = 4.04 ± .88, *Median* = 4, and fear on average with M = 2.96 ± 1.48, *Median* = 3. Similarly, *Anger 4* was rated to be likewise angry (M = 3.96 ± 1.00 *Median* = 4) and fearful (M = 3.39 ± .96, *Median* = 3). P-values of p = .067 for *Anger 3* and p = 1.00 for *Anger 4* indicated that the perception of the two moods is not different. Mean scores for each music excerpt for each rated category are listed in Table 5.1.

In a second step the average ratings of all four music excerpts that expressed the same mood were tested for specificity with a Friedman test. Consistent with the results of each music piece, each Friedman test yielded significant results, but fear and anger in *Anger* excerpts were again closely related as a post hoc analysis with Bonferroni correction showed. Although anger was rated slightly higher (M = 4.07 ± .50, *Median*= 4) than fear (M = 3.21 ± .83, *Median*= 3.375), a p-value of .067 indicated non-significance.

5.1.2 Influencing Factors

Music Background

A Mann-Whitney U-test was conducted in order to assess whether a preference for classical or film music influenced the evaluation of the music pieces. All in all, eight participants stated that they normally listened to classical music or soundtracks while the remaining 20 participants did not listen regularly to this genre. No significant difference in the evaluation of the music pieces between the two groups could be found. Only the music pieces expressing anger activated the participants without preference for classical music more (M = 3.29 ± .68, *Median* = 3.378) than the group preferring classical music (M = 2.66 ± .53, *Median* = 2.75) with U = 37.5, z = -2.176, p = .028.

A Spearman correlation was run to assess the relation between hours of music consumption per day and arousal as well as enjoyment. However, results were all non-significant.

For each music piece the participants had to fill in whether the excerpt sounded familiar or not. Only three participants forgot occasionally to mark the box, resulting in four unknown familiarity ratings (*Happiness 1, Fear 1, Fear 1, Anger 2*). A relation between familiarity and enjoyment and arousal was tested with a Mann-Whitney U-test for all 16 music pieces. In general, no clear association could be observed; only one significant result was obtained. Participants were differently strong activated by *Anger 4* depending on the familiarity. When the excerpt was rated to be familiar (N = 4), arousal ratings were significantly higher (M = 4.25 ± .50, *Median* = 4) than for unfamiliarity ratings (M = 2.96 ± 1.12, *Median* = 3), U = 80.5, z = 2.23, p = .029.

Approximately half of the participants judged themselves as *non-musician* (N = 13) whereas seven stated that they *occasionally play music instruments (only for fun)* and six rated themselves to be amateurs, meaning that they have a *serious interest, but play non-professionally.* Two of the participants make either *semi-professionally or professionally music*, that is, earn money with it. In order to balance the group sizes as far as possible the two professionals were classified as amateurs. A Kruskal-Wallis test was conducted to assess possible differences between the groups with regard to the ratings of the music pieces, but yielded no significant results.

Order

All 16 music excerpts were presented in two counterbalanced pseudo-randomized orders. Mann-Whitney U-tests were run to test for possible order effects. A significant difference occurred only for the average ratings of the music pieces representing *happiness* for the categories happiness, anger and arousal. Further analysis revealed that the difference for happiness ratings resulted from a significant discrepancy for *Happiness 1*, displayed as the first music piece in Version 1 and the last one in Version 2. Participants rated the music excerpt as significantly more happy (M = 4.18 ± .82, *Median* = 5) when it was presented in the end compared to when it was the first piece (M = 3.69 ± .86, *Median* = 4) with U = 156, z = 2.908, p = .006. In a similar way, ratings on anger for *Happiness 1* differed between participants. Ratings were higher (M = 2.77 ± 1.09, *Median* = 3) when participants listened to the music piece in the beginning in comparison to the end (M = 1.13 ± .35, *Median* = 1 with U = 20, z = -3.905, $p < .001$). Besides this, *Happiness 2* activated the groups differently strong dependent on the version they listened to. Version 1 yielded higher arousal ratings (M = 3.92 ± .64, *Median* = 4) compared to Version 2 (M = 2.67 ± 1.11, *Median* = 3) with U = 35, z = -3.017, p = .003.

Gender

Thirteen females and 15 males participated in the experiment. A possible influence of gender on the evaluation of the music excerpts was assessed with a Mann-Whitney U-test. Only the arousal level of the averaged ratings of the four anger pieces correlated with gender, U = 50.5, z = -2.18, p = .029. Female participants tended to be more aroused (M = 3.37 ± .60, *Median* = 3.5) than the males (M = 2.88 ± .72, *Median* = 2.75). Interestingly, this effect did not become

Table 5.2: Descriptive Statistics of BIS and BAS Scores

Scale	*Number*	*M*	*SD*
BIS	27	19.30	3.77
BAS	26	39.35	5.64
BAS Drive	28	10.50	2.46
BAS Fun Seeking	27	12.26	2.78
BAS Reward Responsiveness	27	16.63	1.80

Note. BAS Drive, BAS Fun Seeking and BAS Reward Responsiveness are subscales of the BAS. Adding the scores of the subscales yields the score of the BAS.

apparent on the level of each music excerpt i.e. first averaging the ratings over all four pieces representing anger rendered the differences significant.

Mood and Personality

After the music evaluation, participants filled in a questionnaire assessing the strength of their behavioural inhibition system (BIS) and their behavioural approach system (BAS). Three participants missed to fill out one item, resulting in 27 participants for whom the BIS strength could be computed, and 26 participants with BAS scores. In Table 5.2 the mean and standard deviation for all scales are noted, corresponding in general to the mean scores of a large sample (N = 732) of college students tested by Carver and White (1994). With a Spearman correlation it was tested whether these two motivational systems could directly predict the evaluation of the music excerpts since e.g. the personality traits neuroticism and extroversion were shown to do so (Vuoskoski & Eerola, 2011). However, the correlation yielded only non-valid results. Further, a possible influence of gender on BIS/BAS strength as reported by Jorm et al. (1998) was excluded using a Mann-Whitney U-test.

The current mood was assessed with the PANAS, a questionnaire measuring positive and negative affect, for 19 participants (due to a software error not all scores could be retrieved) directly before the music evaluation task. Table 5.3 presents the mean and standard deviation of the present study and compares them to another study in which 660 individuals participated (Watson et al., 1988). As can be seen in the table, participants reported less negative affect in the present study. Bonferroni-corrected Spearman correlation was conducted to estimate the effect of the current mood on the music evaluation. Momentary positive affect was significantly correlated with the perception of happiness in happy-sounding music excerpts as well as with the perception of sadness and enjoyment of music

Table 5.3: Descriptive Statistics of Positive and Negative Affect

Momentary Affect	Present Study		Watson et al. (1988)	
	M	SD	M	SD
Positive	29.28	6.80	29.7	7.9
Negative	12.67	3.63	14.8	5.4

Note. In the present study the scores for 19 participants were computed. In the study of Watson, Clark, and Tellegen (1988) the scores of 660 persons were analysed.

pieces representing fear. The perception of happiness was negatively correlated with positive affect, $r_{s,17}$ = -.516, *p* = .028. Further, higher positive affect predicted more enjoyment of fearful-sounding music excerpts, $r_{s,17}$ = .678, *p* = .002. Also the perception of sadness in fear expressing music excerpts correlated positively with positive affect, $r_{s,17}$ = .632, *p* = .005.

5.2 Alpha Asymmetry

Alpha asymmetry scores were computed for an alpha frequency band ranging from 8 to 12 Hz at mid-frontal sites (F3/F4). This decision was motivated by the fact that previous research has shown that effects are strongest for the lower alpha band (Wacker et al., 2003) and researchers mainly focus on alpha activity recorded at mid-frontal sites (see e.g. L. A. Schmidt & Trainor, 2001; Sutton & Davidson, 1997; Wacker et al., 2003). Based on the alpha asymmetry scores each participant was either classified as relatively more left-active or right-active. However, assigning the participants to the left-active group when they had positive scores, and classifying participants with negative scores as right-active resulted in very unequal group sizes; 22 participants were classified as left-active and only six participants were in the right-active group. Therefore, also median split was used to divide participants into two groups of equal size. This procedure is frequently used in research on alpha asymmetry (see e.g. the discussion in Section 4.4.6).

The mean number of epochs left after cleaning the data for the recording with closed eyes was M = 97.11 $\pm$ 77.79, *min* = 21, *max* = 336 whereas the average number for open eyes was M = 107.79 $\pm$ 67.15, *min* = 23, *max* = 275.

5.2.1 The Relation between Alpha Asymmetry and Motivation

A Spearman correlation was run to assess the relationship between the BIS and BAS scales and FAA at mid-frontal sites. However, the correlation provided no significant results. Interestingly, a preliminary analysis of the last 19 participants revealed a correlation for the BAS subscale *Reward Responsiveness* and alpha asymmetry scores. However, this correlation was no longer apparent when taking the whole sample into account.

5.2.2 The Relation between Alpha Asymmetry and Music

A possible relationship between alpha asymmetry groups and rating of expressed mood, enjoyment or anger was tested with Mann-Whitney U-tests. However, no systematic relationship could be observed. Instead only three variables were rated differently by the two groups. The mean scores of each group for the observed effects can be found in Table 5.4. Interestingly, two of the observed effects did not meet the expectations. Left-active participants found music of the category anger to express significantly more fear than right-active participants irrespective of the splitting method (median split: U = 39.5, z = -2.704, p = .006; sign split: U = 25, z = -2.309, p = .020). Furthermore, groups split by sign differed significantly in the perception of fear in sad-sounding music excerpts (U = 30, z = -2.032, p = .045) whereas groups split by median showed no difference in ratings (U = 63, z = -1.621, p = .114). In line with the hypotheses, left-active participants rated angry-sounding music as more angry than right-active volunteers, also irrespective of the splitting method (median split: U = 53, z = -2.110, p = .039; sign split: U = 23, z = -2.457, p = .014).

Table 5.4: Differences in Music Perception Mediated by FAA

Rating	Category	Group	Median Split			Sign Split		
			M	SD	$Median$	M	SD	$Median$
Fear	Anger	left	3.64	.59	3.75	3.40	.75	3.50
		right	2.77	.82	2.50	2.50	.76	2.40
Anger	Anger	left	4.27	.54	4.13	4.19	.48	4.00
		right	3.88	.39	3.88	3.63	.34	3.63
Fear	Sadness	left	2.21	.90	1.88	2.09	.80	1.75
		right	1.68	.58	1.63	1.42	.52	1.25

Note. M = mean; SD = standard deviation.

Further analysis of the results revealed that only *Anger 3* contributed to differences in the perception of fear and anger between the alpha asymmetry groups that were split by sign (anger: U = 25.5, z = -2.44, p = .020; fear: U = 23.5, z = -2.428, p = .014). *Anger 3* was also the driving factor for differences in fear ratings if groups were split by median (U = 46, z = -2.438, p = .016). However, *Anger 2* was the only music excerpt that contributed to differences in the perception of anger for groups split by median (U = 54.5, z = -2.269, p = .044). It is noteworthy that three participants in the right-active group rated *Anger 2* as significantly more angry than on average, so that these participants were marked as outliers. Post hoc tests that were run to identify the music excerpts that contributed to differences in ratings of fear in sad-sounding music, revealed that no music excerpt yielded significant differences between the two groups on its own.

What concerns *Anger 3*, participants with positive scores perceived the music excerpt to express much more anger (M = 4.27 $\pm$ .70, *Median* = 4) than participants with negative asymmetry scores (M = 3.17 $\pm$ .98, *Median* = 3.5). An even larger gap occurred when participants with positive scores rated fear in *Anger 3* (M = 3.32 $\pm$ 1.43, *Median* = 3.5) compared to the ratings of participants with negative scores (M = 1.67 $\pm$ .82, *Median* = 1.5). Fear was also rated to be more pronounced in *Anger 3* by the 14 participants with more left-sided activity (M = 3.64 $\pm$ 1.22, *Median* = 4) compared to the participants with more right-sided activity (M = 2.29 $\pm$ 1.44, *Median* = 2).

Chapter 6

Discussion of the Music Experiment

The analysis of the results revealed that music excerpts were in general specific for the mood they were intended to express. Only music pieces which represented anger were perceived to convey as much fear as anger. Current positive and negative affect only showed unsystematic influences on the evaluation of the music excerpts. Also, music background played only a minor to moderate role with regard to the perception of the expressed mood in music. No correlation could be observed between BIS/BAS scores and the perception of music or FAA.

The tight interrelation between anger and fear became also apparent in the analysis of asymmetry scores and ratings of expressed mood. Angry-sounding music resulted in significantly different ratings between left- and right-active participants. In line with the predictions, left-active participants perceived music of the category anger to be more intense. Unexpectedly, this group also rated the music to express more fear than right-active participants.

In this chapter the results of the music experiment will be discussed following the outline set in Chapter 5, with the focus on the music evaluation in the first part, and the focus on the alpha asymmetry scores in the second part.

6.1 Music

6.1.1 Specificity of Emotions in Music

The confusion of anger and fear in music is frequently observed in music research (Dolgin & Adelson, 1990; Mayer et al., 1995; Terwogt & Van Grinsven, 1988; Robazza, Macaluso, & D'Urso, 1994) and also emerged in the pilot experiment. A reason for the apparent interrelation of anger and fear could be that participants felt threatened by angry music and consequently ascribe this emotion to the music (Mayer et al., 1995). In contrast to fear and anger, sadness and happiness are more easily recognized. In an emotion recognition study on music, Robazza et al. (1994) found that happy and sad music excerpts were correctly classified by 77.5% and 75.7% of 80 participants whereas angry and frightening-sounding excerpts where only recognized by 28.2% and 39.4% of the participants. Almost 50% of participants mistook anger for fear and vice versa (Robazza et al., 1994). Another contributing factor might be that it is very difficult to differentiate between perceived and felt emotions. Even if participants are only asked to evaluate the perceived emotion, their judgement might be influenced by the emotions they felt while listening (Gabrielsson, 2002; Scherer, 2004). Another factor could be that anger and fear are both negatively valenced whereas happiness and sadness, for instance, can be clearly differentiated based on their valence. Further, people are primarily exposed to happy and sad melodies in media whereas fearful and aggressive-sounding music occurs mostly in specific genres, or is composed for specific purposes e.g. in order to accompany horror or battle film scenes.

6.1.2 Influencing Factors

The findings on the influence of music background are in line with the hypotheses that music expertise and preference have only a moderate influence on the evaluation of the music excerpts. Interesting is the finding that participants who stated that they regularly listen to classical or film music were significantly less activated by the four music excerpts expressing anger. Probably classical music listeners are simply more habituated and thus react more relaxed to arousing music (Iwanaga, Ikeda, & Iwaki, 1996). In contrast to this observation, *Anger 4* activated participants more when they judged the music to sound familiar. Presumably because the excerpt evoked episodic memories related to the content of the film.

An analysis on the influence of order revealed that in particular the very first or last music piece was rated differently among participants. Individuals who listened to *Happiness 1* at the beginning (Version 1) perceived it as more angry and less happy than participants who listened to Version 2 in which *Happiness 1* was presented at the end. This observation is not surprising considering the fact that in Version 2, *Happiness 1* was preceded by *Fear 1*, probably sharpening the contrast between the two moods whereas participants listening to Version 1 had no possibility to compare *Happiness 1* to another music piece. More interesting is the finding that *Happiness 2* aroused the groups differently strong. Possibly the reason is that participants felt still aroused after listening to *Fear 2* in Version 1 whereas they were less aroused by *Sadness 2* that preceded *Happiness 2* in Version 2.

Gender effects became only apparent for arousal ratings of angry-sounding music. The observation that women experienced anger in music as especially intense was also made by Nielzén and Cesarec (1981) who reported that women perceived fraught music as more tense than men. Interesting is that the effect became first apparent when taking the average of all excerpts into account. This indicates that differences between genders were only moderate for each music piece.

Against conjectures the sensitivity of the BIS/BAS as conceptualized by Carver and White (1994) had no significant influence on the evaluation of mood in music. Possibly, because the computation of two scores representing the sensitivity of the motivational systems is not precise enough to account for possible subtle differences in the perception of affect in music between individuals.

Rather difficult to account for is the findings that participants perceived happy-sounding music the more happy the less positive affect they had. An explanation could be that individuals with less positive affect were simply more susceptible to happy-sounding music. However it is also likely that the finding is due to chance and does not represent valid relationships. A complicating factor is that some participants indicated that they were not familiar with some words such as *jittery* or *alert* which were used in the PANAS. Translation problems could therefore have resulted in slightly skewed scores.

6.2 Alpha Asymmetry

Interestingly, alpha asymmetry scores did not correlate with BIS/BAS scores. This finding was somewhat unexpected since the relationship between the sensitivity of the behavioural approach system and alpha asymmetry seems to be quite established in the literature (see e.g. Coan & Allen, 2003a; De Pascalis et al., 2013; Diego, Field, & Hernandez-Reif, 2001; Sutton & Davidson, 1997). However, it should be noted that some participants had problems to translate some statements in their mother tongue, so that translation difficulties might have biased the scores.

The analysis of a possible correlation between alpha asymmetry and the evaluation of affect in music yielded only significant results for music intended to express anger. Further analysis revealed that mainly two music excerpts, *Anger 2* and *Anger 3*, contributed to the findings. However, considering that the differences between the left-active and right-active groups for *Anger 2* are almost non-significant, it seems likely that the effect was only observed by chance. Further, it stands to reason that the observed differences between groups for ratings of fear in music of the category sadness were found by chance since no music excerpt on its own yielded significant differences and the p-value of p = .045 is almost non-significant.

Taking into account that probably only one music excerpt yielded the significant differences between left- and right-active participants concerning the perception fear and anger, it is probable that the observed effects are also due to chance and do not reflect true differences between left-active and right-active volunteers. Moreover, anger and fear perception are closely interrelated in this study rendering it difficult to analyse the results. On the other hand, the effects were so strong that they even became apparent in the average ratings for all four music excerpts of the category anger. It would be interesting to know whether *Anger 3* differs from the other angry-sounding music excerpts in specific music properties like mode or tempo. However, a comparison of the music properties exceeds the limits of this study. Supposed that the findings reflect true differences between alpha asymmetry groups, then it is still necessary to explain why - against expectations - left-active participants rated fear to be higher than right-active volunteers irrespective of the splitting method. This finding is in stark contrast to the effects L. A. Schmidt and Trainor (2001) and B. Schmidt and Hanslmayr (2009) observed when examining the relationship between FAA and music. However, L. A. Schmidt and Trainor (2001) obtained no ratings from their participants and B. Schmidt and Hanslmayr (2009) asked their participants only to rate the valence of the expressed mood, rendering comparisons difficult.

Wacker et al. (2003) explicitly addressed the question to what extent influences of emotion and motivational direction on alpha asymmetry are entangled. For this, they designed for different mood induction scripts that either induced fear or anger in situations associated with approach or withdrawal. Further, they measured alpha asymmetry before and after the mood induction. In line with results of the present study, Wacker et al. (2003) found a strong interrelation of fear and anger, and no pronounced right lateralized changes in alpha asymmetry in the fear groups. Moreover, they observed greater left-sided changes in alpha asymmetry in anger than in fear, but at the same time greater approach ratings for the fear-inducing script than for anger (Wacker et al., 2003). Comparing different models of frontal brain asymmetry, Wacker et al. (2003) drew the conclusion that the *behavioural inhibition and approach* model might best account for the observed changes. The reason is that the BIS/BAS model as they conceptualize it (see Section 2.1) predicts left-sided activation irrespective of the motivational direction e.g also when an aversive event is actively avoided.

The experiment of Wacker et al. (2003) is based upon a state-dependent paradigm of FAA and thus comparisons with the present study should be made with caution. Nevertheless, the BIS/BAS model of frontal brain asymmetry could also explain the results obtained in this study. Possibly, participants with relatively more left-sided frontal brain activity have a more pronounced behavioural approach system that makes them more sensitive towards situations that prompt the approach system to take action such as anger- and fear-evoking events. Consequently, left-active participants might have been more sensitive to fear- and anger cues conveyed by *Anger 3* than right-active volunteers.

Furthermore, it is important to emphasize that participants did not differ in ratings on fear and anger in fearful-sounding music. Thus the finding in the present study is not in direct conflict with studies that found fearful stimuli to be correlated with relatively more right-sided frontal activity or less left-sided activity (see e.g. Coan et al., 2001; L. A. Schmidt & Trainor, 2001). Rather the observed effects point to a very specific interrelation of fear and anger that might not have been covered by the experimental design in other studies.

Taking into consideration that the BAS should be primarily sensitive to real situations, it seems likely that the present study yielded no significant results for the majority of music excerpts because it was not intended to induce emotions. Thus, effects might have only occurred when (music excerpts evoked such strong emotions that) participants mixed their impressions of the expressed mood with their own subjective feelings. Furthermore, individual differences might have been become more apparent if the study had been designed based on a state-dependent paradigm of FAA (Coan, Allen, & McKnight, 2006).

In a nutshell, the present study could not confirm the assumptions which the motivational direction model makes. Also, it was not possible to assess whether FAA influences emotions equally or not (see Section 2.2.3). Rather, results are accounted best by the postulates of the behavioural inhibition and approach model of anterior asymmetry put forward by Wacker et al. (2003). However, a lack of comparable results from other studies points to the need of future research to corroborate the interpretation of the observed effects.

Chapter 7

Results of Methodological Examinations

In the present experiment the evaluation of emotions in music was investigated in relation to resting FAA. As the discussion of the music experiment in Chapter 6 showed, only few unsystematic effects were found. In this chapter, the examination results of various methodological aspects concerning the distribution, specificity and robustness of alpha asymmetry are presented.

7.1 Methodological Aspects of Alpha Asymmetry

7.1.1 Distribution of Alpha Asymmetry

The distribution of alpha asymmetry scores for the mid-frontal sites (F3/F4) resulted in two very unequal group sizes if participants with positive scores (N = 22) were categorized as *left-active* and participants with negative scores (N = 6) were classified as *right-active*. The number of relatively more right-active participants rose to eight if a frequency band of 8 to 13 Hz was chosen. Also alpha activity assessed at lateral frontal sites (F7/F8) resulted in a higher number of right-active participants (N = 10) irrespective of the frequency band ranges. Figure 7.1 and 7.2 depict the distribution of the alpha asymmetry scores for both frequency bands at mid-frontal or lateral frontal sites.

In order to estimate the reliability of the observed effects for groups split by algebraic sign, it was decided to additionally split groups by median. Figure 7.1 illustrates how p-values can differ between groups split by median or sign. As apparent, ratings of fear in music intended to sound angry were significant irrespective of splitting method or frequency cut-points. Ratings of anger in music of the category anger were still significant for three of the four procedures whereas

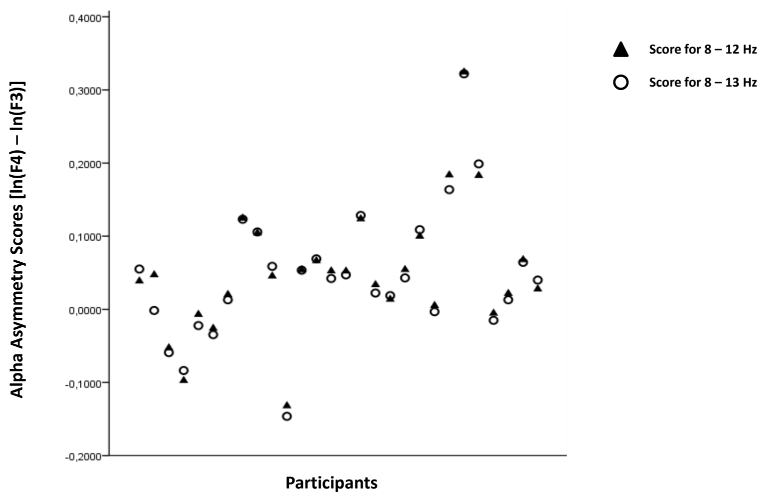

Figure 7.1: Distribution of FAA scores assessed at mid-frontal sites (F3/F4) within a frequency range of either 8 to 12 or 8 to 13 Hz.

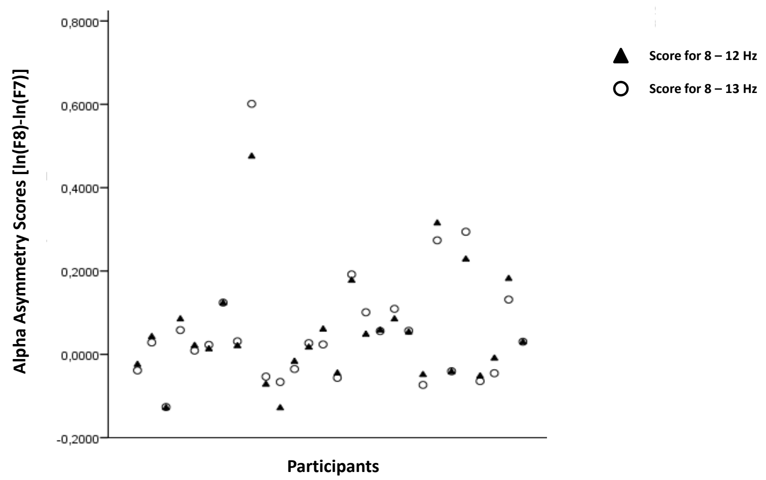

Figure 7.2: Distribution of FAA scores assessed at lateral frontal sites (F7/F8) within a frequency range of either 8 to 12 or 8 to 13 Hz.

Table 7.1: Effect Sizes for Median and Sign Split

Rating	Category	8 - 12 Hz		8 - 13 Hz	
		Median	Sign	Median	Sign
Fear	Anger	.006 **	.020*	.031*	.038*
Anger	Anger	.039*	.014*	.178	.021*
Fear	Sadness	.114	.045*	.265	.328

Note. * $p < .05$, ** $p < .01$.

ratings of fear in sad-sounding music became only significant for participants split by sign and with a frequency band of 8 to 12 Hz.

7.1.2 Specificity of Alpha Asymmetry

The specificity of the found effects to rely solely on the alpha frequency was examined by running a Bonferroni-corrected Spearman correlation for the delta (2-4 Hz) (Benoit et al., 2000), theta (4-8 Hz) (Åkerstedt & Gillberg, 1990), beta (14-30) (Niedermeyer, 1993) and gamma (30-40 Hz) (Steriade et al., 1996) frequency bands. The correlation revealed that two of the three observed effects for the alpha band were also related to delta, theta and beta asymmetry scores, indicating that the found effects are not specific to the alpha frequency band only. Asymmetry assessed at lateral frontal sites (F7/F8) resulted in higher correlation coefficients for ratings of fear in music excerpts of the category sadness for the alpha, beta and delta band. Ratings of fear for angry-sounding music, on the other hand, were better predicted by asymmetric cortical activity at the mid-frontal sites (F3/F4). Table 7.2 contains the correlation coefficients and p-values for all computed asymmetry scores and the ratings in question.

7.1.3 Robustness of Alpha Asymmetry

In order to examine how robust alpha asymmetry scores are with regard to different cleaning procedures, the EEG data of the 22 last participants (including the three participants who did not complete the music task according to instructions) was processed using the three different methods described in 4.4.6. The mean number of epochs left (and used for analysis) after cleaning the data with different procedures is given in Table 7.3. As the table shows, the number of epochs was highest if data is cleaned with the procedure referred to as *ICA Extensive* in the present study. Also *ICA Basic* resulted in a higher number of remaining epochs than EEG data cleaned by manual rejection of artefacts on continuous data. As it becomes apparent in the table, open eyes recordings led always to less rejection

Table 7.2: Asymmetry Effects of Different Frequencies

Score	Frequency	Fear in Anger		Fear in Sadness	
		$r_{s,26}$	*p*	$r_{s,26}$	*p*
Alpha at F3/F4	8-12 Hz	.643	.001**	.316	.102
	8-13 Hz	.609	.001**	.254	.193
Alpha at F7/F8	8-12 Hz	.365	.056	.442	.018*
	8-13 Hz	.408	.031*	.453	.015*
Delta at F3/F4	2-4 Hz	.440	.019*	.466	.012*
Delta at F7/F8	2-4 Hz	.146	.459	.490	.008**
Theta at F3/F4	4-8 Hz	.537	.003**	.419	.026*
Theta at F7/F8	4-8 Hz	.254	.191	.404	.033*
Beta at F3/F4	14-30 Hz	.462	.013*	-.103	.600
Beta at F7/F8	14-30 Hz	.422	.025*	.462	.013*

Note. * $p < .05$, ** $p < .01$. N = 19 participants.

of epochs than closed eyes recordings.

The robustness of the alpha asymmetry scores was examined using Pearson correlation. Table 7.4 contains the correlation coefficients and *p*-values for asymmetry scores computed for 8 to 13 Hz at mid-frontal and lateral frontal sites. As the table shows, the asymmetry scores for mid-frontal sites (F3/F4) show relatively high correlation coefficients no matter with which procedure the EEG data was cleaned. In contrast to this, the asymmetry scores based on manually cleaned EEG data or *ICA Basic* correlate only with scores based on data that was extensively cleaned with ICA if assessed at lateral frontal sites (F7/F8). Further, scores for mid-frontal and lateral frontal sites showed hardly any significant correlation.

Table 7.3: Number of Epochs For Different Processing Methods

Processing	Recording	*Mean*	*SD*	*Minimum*	*Maximum*
Manual	closed	66.36	37.14	21	153
	open	85.32	47.84	23	173
ICA Extensive	closed	124.59	43.61	73	219
	open	150.23	49.93	64	222
ICA Basic	closed	77.45	31.86	22	141
	open	102.14	40.76	33	177

Note. Open and *closed* refer to recordings made when the participant had the eyes open or closed. N = 22 participants.

Table 7.4: Correlation of Alpha Asymmetry Scores Based on Different Processing Methods

		Mid-Frontal						Lateral Frontal					
		Manual		ICA Extensive		ICA Basic		Manual		ICA Extensive		ICA Basic	
		r_{20}	p	r_{20}	p	r_{20}	p	r_{20}	p	r_{20}	p	r_{20}	p
Mid-Frontal	Manual	1.00	-	.819	$<$ .001***	.863	$<$ .001***	.448	.036*	-.124	.584	-.083	.712
	ICA Extensive	.819	$<$ .001***	1.00	-	.764	$<$ .001***	.226	.312	-.118	.602	-.187	.405
	ICA Basic	.863	$<$ .001***	.764	$<$ .001***	1.00	-	.143	.526	-.455	.033*	-.043	.848
Lateral Frontal	Manual	.448	.036*	.226	.312	.143	.526	1.00	-	.561	.007**	.354	.106
	ICA Extensive	-.124	.584	-.118	.602	-.455	.033*	.561	.007**	1.00	-	.510	.015*
	ICA Basic	-.083	.712	-.187	.405	-.043	.848	.354	.106	.510	.015*	1.00	-

Note. * p $<$ .05, ** p $<$ .01, *** p $<$ .001. Correlation coefficients (r_{20}) and p-values were obtained with Pearson correlation for N = 22 participants.

Chapter 8

Discussion of Methodological Aspects

8.1 Methodological Aspects of Alpha Asymmetry

In this chapter the various observations described in Chapter 7 are discussed and related to the findings of the music experiment. Further, methodological problems that concern the experimental design of the present study are reflected upon.

8.1.1 Distribution of Alpha Asymmetry

The analysis of the distribution of the asymmetry scores revealed that they are partly susceptible to frequency range and scalp sites at which cortical activity was assessed. Taking this into consideration, comparisons between different studies should be made with caution. The surge from six to eight right-active participants if the frequency range was broadened from 12 to 13 Hz indicates that cortical activity at the right frontal site (F4) was particularly strong between 12 and 13 Hz for at least two participants. Further, the observation points to the fact that frequency boundaries differ between individuals as Klimesch (1999) pointed out. However, it exceeded the limits of this study to determine the alpha frequency band for each participant.

It is worth to mention that the distribution of the alpha asymmetry scores was not foreseeable. One reason is that researchers of FAA usually do not publish the distribution of the scores they obtained (at least in the studies reviewed here). Further, they do not explicate why they split participants by algebraic sign or median. In any case, it would be very interesting if future research on FAA addressed explicitly the question of the distribution of alpha asymmetry scores.

Another methodological issue is that the comparison of groups split by median yielded other results than the comparison of groups split by algebraic sign. On the one hand, it is probably a more sensitive method to classify participants on the basis of the plus- or minus-sign of their scores (Gotlib, 1998). On the other hand, groups split by median yield statistically more reliable results since group sizes are equal. Figure 7.1 illustrates how p-values can differ between groups split by median or sign. As apparent, ratings of fear in music intended to sound angry were significant irrespective of splitting method or frequency cut-points. This can be taken as an indicator of a robust effect. Ratings of anger in music of the category anger were still significant for three of the four procedures, also pointing to a relatively robust effect. In contrast, ratings of fear in sad-sounding music became only significant for one method, meaning that the effect was probably found by chance. In general a comparison between different splitting methods seems advisable to obtain an impression of the reliability of the found effects.

8.1.2 Specificity of Alpha Asymmetry

Examining possible effects of other frequency bands revealed that alpha was not the only frequency which was strongly associated with the observed differences in ratings of left- and right-active individuals.

A relation between delta, theta, or beta frequencies and emotions was also found in other studies (see e.g. Davidson, Chapman, Chapman, & Henriques, 1990; Harmon-Jones & Allen, 1998; Marox et al., 2001). However, as Harmon-Jones and Allen (1998) remark, relationships are commonly not reported or rejected as non-significant. Also the gamma rhythm has been associated with the processing of emotions (see e.g. M. M. Müller, Keil, Gruber, & Elbert, 1999). Possibly, the present study yielded no significant results for the gamma frequency range, because boundaries were restricted to 30 to 40 Hz due to filtering adjustments whereas most researchers use boundaries up towards 90 Hz (M. M. Müller et al., 1999) or 100 Hz (Hughes, 2008).

Delta Activity and Emotions

Delta activity designates frequencies below 4 Hz (Niedermeyer, 1993). The delta rhythm becomes especially prominent during *slow-wave sleep*, predominantly at frontal and central scalp sites (Schomer, 2007). Relatively few studies have examined the relation between the delta rhythm and mental activity, probably because delta activity is in particular susceptible to ocular artefacts (Harmony et al., 1996). Despite this, the results of the few experiments on delta activity and cognitive or emotional processes indicate a relation between both factors (Güntekin & Başar, 2015). For instance, looking at pictures of loved persons led to increased delta responses over posterior regions compared to simple light stimulation (Güntekin & Başar, 2015). Moreover, the perception of positive and negative pictures resulted in higher delta responses than images with neutral content (Güntekin & Başar, 2015). Other researchers used differences in the delta frequency band occurring during music listening to classify the emotions conveyed by the music with machine learning algorithms (Lin et al., 2010). Besides this, Yuvaraj et al. (2014) found that patients suffering from Parkinson disease showed less absolute delta power during different emotional states compared to healthy controls.

Further, researchers associated the ratio of slow- and fast-wave activity with the processing of emotions. Putman (2011) observed a negative relationship between delta and beta coherence and the attentional avoidance of images with threatening content. Also Tortella-Feliu et al. (2014) found that delta/beta ratio was related to spontaneous emotion regulation. In their experiment they showed that participants with lower frontal and parietal delta/beta ratios perceived unpleasant pictures as less discomforting (Tortella-Feliu et al., 2014). Besides this, participants with lower delta/beta ratio at parietal sites recovered more quickly from the exposure to the negative pictures (Tortella-Feliu et al., 2014).

However, no article reviewed for this study related delta asymmetry to emotional processes. A potential problem is that delta activity in the present study was computed for a frequency range between 2 and 4 Hz whereas other researchers used lower boundaries such as 1 to 3 Hz (see e.g. Putman, 2011; Tortella-Feliu et al., 2014) or .5 to 3.5 Hz (see e.g Güntekin & Başar, 2015). Therefore it cannot be ruled out that delta asymmetry scores might have in fact partly reflected theta activity, considering the fact that frequency boundaries differ from individual to individual (Klimesch, 1999).

Theta Activity and Emotions

Theta occurs in humans at frequencies between approximately 4 to 7.5 Hz (Klimesch, 1999). Importantly, the frequency at which theta transitions into alpha varies for each individual (Klimesch, 1999). That makes it potentially problematic to compare theta and alpha power between participants if frequency cut-points are not determined for each individual.

Researchers differentiate between two forms of theta. One form becomes apparent during drowsiness and spans the whole scalp whereas the other theta manifests itself in the frontal midline (also referred to as frontal midline theta) and indicates alertness, focused attention and cognitive activity, in particular memory performance (Fachner, Gold, Ala-Ruona, Punkanen, & Erkkilä, 2010; Klimesch, 1999). Small theta power and a rise in theta power synchronization were revealed to reflect good cognitive performance (Klimesch, 1999).

Theta activity was not only associated with cognitive performance, but also with the processing of emotions e.g. with the experience of hedonic states in children (Niedermeyer, 1993). Further, frontal midline theta was associated with anxiety in adults. For instance, individuals with few anxiety symptoms showed increased theta power (Fachner et al., 2010). Moreover, frontal midline theta was employed as a marker for high and low anxious personality and frontal theta was described to regulate attention to emotions. (Fachner et al., 2010). Besides this, frontal midline theta and anterior theta were identified as markers of internalized attention and positive emotional experience in a meditation study (Aftanas & Golocheikine, 2001). Fachner et al. (2010) found that theta power significantly increased in 79 depressive patients after music therapy, in particular for F7/F8 and F3/F4. They also observed that a reduction of anxiety symptoms related to the increase of theta power (Fachner et al., 2010). In line with Fachner et al. (2010), Sammler, Grigutsch, Fritz, and Koelsch (2007) found that frontal midline theta increased significantly when participants listened to pleasant music.

The high correlations between theta asymmetry scores, in particular at mid-frontal sites (F3/F4) and the ratings on the perception of fear in music excerpts that were intended to express anger or sadness corroborate the assumption that theta power is associated with fear. However, a post hoc Pearson correlation that was run to assess a possible correlation between theta power (at locations F3 and F4 separately) and ratings on the perception of fear in angry- or sad-sounding music excerpts yielded no significant results. This is in particular interesting with regard to the fact that studies on theta power and emotions usually use absolute theta power and no asymmetry scores.

Beta Activity and Emotions

Researchers differentiate between four different forms of beta, amongst others, frontal beta and posterior beta (Rangaswamy et al., 2002). Frontal beta is characterized by fast frequencies and posterior beta resembles fast alpha activity (Rangaswamy et al., 2002). Active beta rhythms were associated with cognition, perception and attention (Rangaswamy et al., 2002).

Beta activity was also associated with the processing of emotions, in particular anger. Harmon-Jones and Allen (1998) found that dispositional anger correlated with $r = .48$ and $p < .01$ with asymmetry of the alpha (8 to 13 Hz) and beta (13 to 20 Hz) frequency band as well as with the theta (4 to 8 Hz) frequency band ($r = .41$, $p < .05$). Güntekin and Başar (2010) examined beta responses to pictures depicting negative, neutral or positive facial expressions. They found that participants exhibited significantly higher beta responses for unpleasant pictures, in particular over frontal, central and parietal areas (Güntekin & Başar, 2010). Comparing beta activity for unpleasant and neutral pictures revealed higher beta responses for the negatively valenced pictures over parietal and occipital sides

(Güntekin & Başar, 2010). In another experiment Güntekin and Başar (2007) presented participants with pictures of angry, happy and neutral faces while measuring their brain activity. They observed that very emotional pictures elicited differences in the alpha frequency range (9 to 13 Hz) and the beta frequency range (15 to 24 Hz) for happy and angry expressions (Güntekin & Başar, 2007).

Furthermore, parietal beta asymmetry has been associated with behavioural responses to anger by Schutter, Putman, Hermans, and van Honk (2001). In their experiment they tested whether avoidant or vigilant attention for angry faces in a modified Dot probe task related to parietal beta asymmetry (Schutter et al., 2001). Findings revealed that more right-sided beta (13 to 30 Hz) asymmetry predicted more avoidant responses to angry facial expressions for 24 subjects (Schutter et al., 2001).

In order to assess a possible effect between parietal beta asymmetry and anger ratings, beta asymmetry scores were computed for parietal sides (P3/P4), and correlated with the ratings on anger, but yielded no significant results. With regard to this, it is interesting to observe that beta asymmetry at lateral frontal sides correlated significantly with fear in anger or sadness.

8.1.3 Robustness of Alpha Asymmetry

Frontal alpha asymmetry appears to be very robust. Allen, Coan, and Nazarian (2004) noted for instance, that a significant relation between frontal alpha asymmetry and the dependent variable often occurs independent of the reference scheme used, the frontal sites measured, and the choice of the frequency cut-points (Allen, Coan, & Nazarian, 2004). However, Allen, Coan, and Nazarian (2004) also remarked that this robustness might either truly reflect a manifest representation of a latent variable, or is rather caused by an inflation of Type I errors (Allen, Coan, & Nazarian, 2004). This uncertainty has led many researchers to extensively examine issues of reference scheme, frequency band, or length of recording (see e.g. Allen, Coan, & Nazarian, 2004; Davidson, 1993; Hagemann, 2004; Papousek & Schulter, 2006), but no paper reviewed for this study examined to what extent different cleaning procedures influence the distribution of alpha asymmetry scores.

As it can be seen in Table 7.4, alpha asymmetry scores assessed at mid-frontal sites (F3/F4) were only slightly affected by cleaning procedures whereas scores assessed at lateral frontal sites (F7/F8) showed a much greater vulnerability to cleaning methods, indicated by non-significant correlation coefficients. This observation illustrates how important the examination of methodological issues is in research on frontal alpha asymmetry. Moreover, the finding points to the need to find a consensus on how to assess alpha asymmetry in order to render findings of different studies comparable. Furthermore, the relatively high correlation coefficients obtained for data cleaned with *ICA Extensive* at lateral frontal sites indicate that the number of epochs plays an important role for the reliability and robustness of alpha asymmetry.

8.2 Methodological Aspects of the Experimental Design

The design of the experiment was guided by previous studies, in particular by the experiment by B. Schmidt and Hanslmayr (2009). However, the present study differed from the one by B. Schmidt and Hanslmayr (2009) in various aspects that possibly contributed to the unsystematic findings. Firstly, this experiment was part of a battery of tasks that were completed in an alternating order by all volunteers. Therefore it cannot be completely ruled out that the other tasks - a decision-making task concerning monetary rewards and a task measuring the empathic response to pictures depicting humans in various emotional states - influenced the participants. Moreover, only ten volunteers completed the music evaluation task directly after the EEG recording. Admittedly, resting frontal alpha asymmetry is assumed to be a temporally stable trait (Hagemann et al., 2002). However, as B. Schmidt and Hanslmayr (2009) noted, resting frontal alpha asymmetry cannot be claimed to be a temporally stable trait if it is measured only once. Thus it remains unclear whether the varying time in between EEG recording and completion of the task contributed to unspecific findings.

A second deviation from the study by B. Schmidt and Hanslmayr (2009) is that participants listened in their study to each music excerpt for roughly two minutes whereas music excerpts used in the present study were approximately 15 seconds long. It is possible that a longer presentation of the stimuli results in a better classification of the presented mood, although studies demonstrated that already excerpts over more than one second are enough to elicit emotions and to activate auditory brain areas (Altenmüller et al., 2002; Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005). Further,the participants in the study by B. Schmidt and Hanslmayr (2009) rated the expressed mood on one scale, ranging from *very negative* to *very positive*, so that emotions could not be confused. Future studies on FAA and music might therefore benefit if they ask participants to rate only the most dominant emotion.

In contrast to other studies on FAA, this study was not designed to induce a specific mood, but relied on the perceived mood of the music pieces. This decision was made in order to have the possibility to compare findings of this experiment to the results obtained by B. Schmidt and Hanslmayr (2009). Further, the decision was motivated by the fact that music and emotion researchers disagree to what extent music can induce emotions and whether the induced emotions are comparable to genuine emotions whereas researchers generally agree that music is able to express moods (Vuoskoski, 2012). However, various studies on resting frontal brain asymmetry reviewed in Chapter 2 relied on mood induction (see e.g. Pérez-Edgar et al., 2013; Tomarken et al., 1990; Wheeler et al., 1993), related brain asymmetry to physiological measures (see e.g. Davidson, 2004; Jackson et al., 2003), or behavioural variables (see e.g. Davidson & Fox, 1989; De Pascalis et al., 2013) whereas only few studies related frontal alpha asymmetry to cognitive perception of affective stimuli (see e.g. Papousek, Freudenthaler, & Schulter, 2011; B. Schmidt & Hanslmayr, 2009).

The amount of publications on alpha asymmetry in mood induction studies can be taken as an indicator that frontal alpha asymmetry primarily reflects processes involved in the production of emotions and less the perception of emotions themselves (Davidson, 1993). Consequently, the study might have resulted in more significant results if it had been conceptualized as a mood induction study. Furthermore, mood induction studies have the advantage that they avoid the confusion of anger and fear if participants are explicitly exposed to a specific situation e.g. insulting feedback for a written essay (Harmon-Jones & Sigelman, 2001) or radio tapes in which a tuition fee increase is announced (Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003).

A further problem could be the cultural heterogeneity of the participants. Although film music excerpts were in particular chosen as stimulus material to account for cultural differences (since it can be assumed that the majority of participants are familiar with film music whereas not all are familiar with e.g. classical music), it cannot completely ruled out that the background influenced ratings. Especially the fact that the PANAS and the BIS/BAS questionnaires were only available in English might have sometimes led to misunderstandings when participants did not ask the researchers for the meaning of a specific word they did not understand.

Chapter 9

Conclusion

The present study explored the role of resting frontal alpha asymmetry on the evaluation of emotions in music. Moreover, the study focused on the specificity and robustness of alpha asymmetry scores. The experiment consisted of three parts that took about 15 to 20 minutes to complete. At the beginning, participants filled in a questionnaire assessing their current positive and negative affect in order to rule out situational mood effects. Subsequently, participants listened to 16 different music excerpts taken from a study by Eerola and Vuoskoski (2010). Each music excerpt was approximately 15 seconds long and represented one of four different categories: Happiness, sadness, anger or fear. After each excerpt, participants rated to which degree they agreed that the expressed mood of the music piece was *happy*, *sad*, *angry*, and *fearful* on 5-point Likert scales. In addition to this, they rated how pleasant they found the excerpt and how much it had aroused them on 5-point Likert scales. In order to assess possible influences of familiarity and music background, participants also stated whether the excerpt sounded familiar or not, and answered questions about their music preference, hours of music consumption per day and music skills. The third part of the experiment consisted of a questionnaire assessing the sensitivity of the behavioural inhibition and approach system of each participant. The BIS/BAS questionnaire was included in the experiment to test whether sensitivity scores could directly predict the evaluation of the music excerpts. Besides this, previous studies found a significant relation between BIS/BAS scores and alpha asymmetry. Therefore another aim of the present study was to test this relationship.

The experiment was based on the assumption that resting frontal alpha asymmetry reflects a temporally stable trait that moderates responses to affective stimuli. This relationship was assumed to be accounted best by the *motivational direction* model. This theoretical framework holds that emotions which are associated with approach-behaviour such as anger and happiness are accompanied by relatively more cortical activity in the left frontal hemisphere whereas the processing of emotions which are typically associated with withdrawal-behaviour as e.g. sadness or fear is reflected in relatively more right frontal activity.

Accordingly, the main hypothesis was that participants with relatively more left-sided activity at baseline should perceive happiness and anger in music as more intense and thus rate these emotions higher than right-active participants. These, on the other hand, should rate sadness and fear as higher.

In order to assess the specificity of each music excerpt to express predominantly the intended mood, a Friedman test was run. Results revealed that each music excerpt was specific for the intended mood except for *Anger 1*, *Anger 3*, and *Anger 4* which were perceived equally angry and fearful. Furthermore, the influence of music background and current mood on the evaluation of the music excerpts was tested, but yielded only few, unsystematic effects.

Alpha asymmetry scores were computed for mid-frontal sites (F3/F4) and a frequency range of 8 to 12 Hz. The participants were categorized as either *left-active* or *right-active* based on positive or negative asymmetry scores. Additionally, median split was used to divide participants into two groups since the group sizes obtained with the former method were very unequal in size (22 left-active against six right-active participants). The analysis of the relation between alpha asymmetry groups and ratings revealed only two reliable significant results. In line with the hypotheses, left-active participants rated anger to be higher for the excerpt *Anger 3* than right-active participants irrespective of the splitting method used to divide the groups. However, left-active participants also perceived *Anger 3* to express significantly more fear than right-active participants.

Supposed that this effect was not found by chance, then it cannot be explained with the motivational direction model. Instead it was speculated that - based on the study by Wacker et al. (2003) - relatively more left-active participants might have a behavioural approach system that is more sensitive to cues such as anger and fear that prompt the behavioural approach system to take action. However, this assumption is highly speculative and points to the need of future research in this area. From the methodological viewpoint it might be advisable to design future experiments as mood-induction studies. Besides this, the outcome of the study indicates that a specific combination of music properties might lead to more confusion of fear and anger than other combinations.

Interestingly, alpha power was not the only frequency that could be associated with the dependent variables, but so did delta, theta and beta power. This correlation is not completely surprising since frontal midline theta was associated with anxiety and (parietal) beta was linked to the processing of anger. The observed finding that the alpha frequency band was not specific, highlights the fact that studies on alpha asymmetry should aim to analyse all frequencies for effects. Besides this, research in the field of affective neuroscience might benefit from conducting more studies on the relation between delta, theta, alpha and beta and the processing of emotions in general.

An issue commonly neglected in methodological reviews about frontal alpha asymmetry is the influence of the cleaning method on alpha asymmetry scores. In the present study three different ways of processing the EEG data were compared with each other. The comparison revealed that asymmetry scores for the mid-frontal sites were relatively robust against cleaning procedures whereas alpha asymmetry scores assessed at lateral frontal sites differed more from each other. Therefore it is important to inspect cleaning methods in detail when comparing the results of different studies.

In summary, the present study was not able to corroborate the assumptions of the motivational direction model when film music excerpts were used as stimulus material. Instead the found effects were best accounted by the behavioural approach and withdrawal model of anterior brain asymmetry. All in all, findings point to the need of future research - not only with regard to the relation between alpha asymmetry and affective stimuli, but also with regard to methodological choices.

References

Ackerman, S. et al. (1992). *Discovering the brain.* National Academies Press.

Aftanas, L. & Golocheikine, S. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: High-resolution EEG investigation of meditation. *Neuroscience Letters*, *310*(1), 57–60. doi:10.1016/S0304-3940(01)02094-8

Åkerstedt, T. & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience*, *52*(1-2), 29–37. doi:10.3109/00207459008994241

Allen, J. J., Coan, J. A., & Nazarian, M. (2004). Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion. *Biological Psychology*, *67*(1), 183–218. doi:10.1016/j.biopsycho.2004.03.007

Allen, J. J., Urry, H. L., Hitt, S. K., & Coan, J. A. (2004). The stability of resting frontal electroencephalographic asymmetry in depression. *Psychophysiology*, *41*(2), 269–280. doi:10.1111/j.1469-8986.2003.00149.x

Altenmüller, E., Schürmann, K., Lim, V. K., & Parlitz, D. (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. doi:10.1016/S0028-3932(02)00107-0

Anokhin, A. P., Heath, A. C., & Myers, E. (2006). Genetic and environmental influences on frontal eeg asymmetry: A twin study. *Biological Psychology*, *71*(3), 289–295. doi:10.1016/j.biopsycho.2005.06.004

Barry, R. J., Clarke, A. R., Johnstone, S. J., & Brown, C. R. (2009). EEG differences in children between eyes-closed and eyes-open resting conditions. *Clinical Neurophysiology*, *120*(10), 1806–1811. doi:10.1016/j.clinph.2009.08.006

Benoit, O., Daurat, A., & Prado, J. (2000). Slow (0.7–2 hz) and fast (2–4 hz) delta components are differently correlated to theta, alpha and beta frequency bands during NREM sleep. *Clinical Neurophysiology*, *111*(12), 2103–2106. doi:10.1016/S1388-2457(00)00470-3

Berger, H. (1929). Über das elektrenkephalogramm des menschen. *European Archives of Psychiatry and Clinical Neuroscience*, *87*(1), 527–570.

Bigand, E., Vieillard, S., Madurell, F., Marozeau, J., & Dacquet, A. (2005). Multidimensional scaling of emotional responses to music: The effect of musical expertise and of the duration of the excerpts. *Cognition & Emotion*, *19*(8), 1113–1139. doi:10.1080/02699930500204250

Blood, A. J. & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences*, *98*(20), 11818–11823. doi:10.1073/pnas.191355898

Blood, A. J., Zatorre, R. J., Bermudez, P., & Evans, A. C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature Neuroscience*, *2*(4), 382–387. doi:10.1038/7299

Boytsova, Y. A. & Danko, S. (2010). EEG differences between resting states with eyes open and closed in darkness. *Human Physiology*, *36*(3), 367–369. doi:10.1134/S0362119710030199

Brattico, E., Alluri, V., Bogert, B., Jacobsen, T., Vartiainen, N., Nieminen, S., & Tervaniemi, M. (2011). A functional mri study of happy and sad emotions in music with and without lyrics. *Frontiers in Psychology*, *2*(308), 10–3389. doi:10.3389/fpsyg.2011.00308

Brookshire, G. & Casasanto, D. (2012). Motivation and motor control: Hemispheric specialization for approach motivation reverses with handedness. *PLoS One*, *7*(4), e36036. doi:10.1371/journal.pone.0036036

Brown, S., Martinez, M. J., & Parsons, L. M. (2004). Passive music listening spontaneously engages limbic and paralimbic systems. *NeuroReport*, *15*(13), 2033–2037. doi:10.1097/00001756-200409150-00008

Bruder, G. E., Fong, R., Tenke, C. E., Leite, P., Towey, J. P., Stewart, J. E., ... Quitkin, F. M. (1997). Regional brain asymmetries in major depression with or without an anxiety disorder: A quantitative electroencephalographic study. *Biological Psychiatry*, *41*(9), 939–948. doi:10.1016/S0006-3223(96)00260-0

Bruder, G. E., Tenke, C. E., Warner, V., & Weissman, M. M. (2007). Grandchildren at high and low risk for depression differ in EEG measures of regional brain asymmetry. *Biological Psychiatry*, *62*(11), 1317–1323. doi:10.1016/j.biopsych.2006.12.006

Carver, C. S. & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology*, *67*(2), 319.

Chang, Y.-H., Lee, Y.-Y., Liang, K.-C., Chen, I.-P., Tsai, C.-G., & Hsieh, S. (2015). Experiencing affective music in eyes-closed and eyes-open states: An electroencephalography study. *Frontiers in Psychology*, *6*. doi:10.3389/fpsyg.2015.01160

Coan, J. A. & Allen, J. J. (2003a). Frontal EEG asymmetry and the behavioral activation and inhibition systems. *Psychophysiology*, *40*(1), 106–114. doi:10.1111/1469-8986.00011

Coan, J. A. & Allen, J. J. (2003b). Varieties of emotional experience during voluntary emotional facial expressions. *Annals of the New York Academy of Sciences*, *1000*(1), 375–379. doi:10.1196/annals.1280.034

Coan, J. A. & Allen, J. J. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, *67*(1), 7–50. doi:10.1016/j.biopsycho.2004.03.002

Coan, J. A., Allen, J. J., & Harmon-Jones, E. (2001). Voluntary facial expression and hemispheric asymmetry over the frontal cortex. *Psychophysiology*, *38*(6), 912–925. doi:10.1111/1469-8986.3860912

Coan, J. A., Allen, J. J., & McKnight, P. E. (2006). A capability model of individual differences in frontal EEG asymmetry. *Biological Psychology*, *72*(2), 198–207. doi:10.1016/j.biopsycho.2005.10.003

Cook, I. A., O'Hara, R., Uijtdehaage, S. H., Mandelkern, M., & Leuchter, A. F. (1998). Assessing the accuracy of topographic EEG mapping for determining local brain function. *Electroencephalography and Clinical Neurophysiology*, *107*(6), 408–414. doi:10.1016/S0013-4694(98)00092-3

Davidson, R. J. (1984). Affect, cognition, and hemispheric specialization. In R. B. Z. Carroll E. Izard Jerome Kagan (Ed.), *Emotions, cognition, and behavior* (pp. 320–365). Retrieved from https://books.google.de/books?hl=de&lr=&id=IpY5AAAAIAAJ&oi=fnd&pg=PA320&dq=11+Affect,+cognition,+and+hemispheric+specialization&ots=G1-yf2BwdC&sig=OmJOUfnESLs6pVm7UccVCrRftGM#v=onepage&q=11%20Affect%2C%20cognition%2C%20and%20hemispheric%20specialization&f=false

Davidson, R. J. (1993). Cerebral asymmetry and emotion: Conceptual and methodological conundrums. *Cognition & Emotion*, *7*(1), 115–138. doi:10.1080/02699939308409180

Davidson, R. J. (1998). Affective style and affective disorders: Perspectives from affective neuroscience. *Cognition & Emotion*, *12*(3), 307–330. doi:10.1080/026999398379628

Davidson, R. J. (2004). What does the prefrontal cortex "do" in affect: Perspectives on frontal EEG asymmetry research. *Biological Psychology*, *67*(1), 219–234. doi:10.1016/j.biopsycho.2004.03.008

Davidson, R. J., Chapman, J. P., Chapman, L. J., & Henriques, J. B. (1990). Asymmetrical brain electrical activity discriminates between psychometrically-matched verbal and spatial cognitive tasks. *Psychophysiology*, *27*(5), 528–543. doi:10.1111/j.1469-8986.1990.tb01970.x

Davidson, R. J., Coe, C. C., Dolski, I., & Donzella, B. (1999). Individual differences in prefrontal activation asymmetry predict natural killer cell activity at rest and in response to challenge. *Brain, Behavior, and Immunity*, *13*(2), 93–108. doi:10.1006/brbi.1999.0557

Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. A., & Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: Emotional expression and brain physiology i. *Journal of Personality and Social Psychology*, *58*(2), 330.

Retrieved from http://www-psych.stanford.edu/~knutson/ans/davidson90.pdf

Davidson, R. J. & Fox, N. A. (1982). Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. *Science*, *218*(4578), 1235–1237. doi:10.1126/science.7146906

Davidson, R. J. & Fox, N. A. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology*, *98*(2), 127. doi:10.1037/0021-843X.98.2.127

Davidson, R. J. & Schwartz, G. E. (1977). The influence of musical training on patterns of EEG asymmetry during musical and non-musical self-generation tasks. *Psychophysiology*, *14*(1), 58–63. doi:10.1111/j.1469-8986.1977.tb01156.x

Davidson, R. J., Schwartz, G. E., Pugash, E., & Bromfield, E. (1976). Sex differences in patterns of EEG asymmetry. *Biological Psychology*, *4*(2), 119–137. doi:10.1016/0301-0511(76)90012-0

Davidson, R. J., Schwartz, G. E., Saron, C., Bennett, J., & Goleman, D. J. (1979). Frontal versus parietal EEG asymmetry during positive and negative affect. *Psychophysiology*, *16*(2), 202–203.

De Pascalis, V., Cozzuto, G., Caprara, G. V., & Alessandri, G. (2013). Relations among EEG-alpha asymmetry, BIS/BAS, and dispositional optimism. *Biological Psychology*, *94*(1), 198–209. doi:10.1016/j.biopsycho.2013.05.016

Delorme, A. & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial eeg dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. doi:10.1016/j.jneumeth.2003.10.009

Diego, M. A., Field, T., & Hernandez-Reif, M. (2001). BIS/BAS scores are correlated with frontal EEG asymmetry in intrusive and withdrawn depressed mothers. *Infant Mental Health Journal*, *22*(6), 665–675. doi:10.1002/imhj.1025

Dolgin, K. G. & Adelson, E. H. (1990). Age changes in the ability to interpret affect in sung and instrumentally-presented melodies. *Psychology of Music*, *18*(1), 87–98. doi:10.1177/0305735690181007

Eerola, T. & Vuoskoski, J. K. (2010). A comparison of the discrete and dimensional models of emotion in music. *Psychology of Music*. doi:10.1177/0305735610362821

Ekman, P. & Davidson, R. J. (1993). Voluntary smiling changes regional brain activity. *Psychological Science*, *4*(5), 342–345. doi:10.1111/j.1467-9280.1993.tb00576.x

Fachner, J., Gold, C., Ala-Ruona, E., Punkanen, M., & Erkkilä, J. (2010). Depression and music therapy treatment—clinical validity and reliability of EEG alpha asymmetry and frontal midline theta: Three case studies. In P. S. C. S. M. Demorest S. J. Morrison (Ed.), *Proceedings of the 11th international conference on music perception and cognition (ICMPC 11)*. Seattle, USA. Retrieved from http://users.jyu.fi/~jofachne/Publications_files/MP100080.pdf

Fachner, J., Gold, C., & Erkkilä, J. (2013). Music therapy modulates fronto-temporal activity in rest-EEG in depressed clients. *Brain Topography*, *26*(2), 338–354. doi:10.1007/s10548-012-0254-x

Field, T., Martinez, A., Nawrocki, T., Pickens, J., et al. (1998). Music shifts frontal EEG in depressed adolescents. *Adolescence*, *33*(129), 109. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9583665

Flores-Gutiérrez, E. O., Díaz, J.-L., Barrios, F. A., Favila-Humara, R., Guevara, M. Á., del Río-Portilla, Y., & Corsi-Cabrera, M. (2007). Metabolic and electric brain patterns during pleasant and unpleasant emotions induced by music masterpieces. *International Journal of Psychophysiology*, *65*(1), 69–84. doi:10.1016/j.ijpsycho.2007.03.004

Fritz, T., Jentschke, S., Gosselin, N., Sammler, D., Peretz, I., Turner, R., ... Koelsch, S. (2009). Universal recognition of three basic emotions in music. *Current Biology*, *19*(7), 573–576. doi:10.1016/j.cub.2009.02.058

Gabrielsson, A. (2002). Emotion perceived and emotion felt: Same or different? *Musicae Scientiae*, *5*(1 suppl), 123–147. Retrieved from http://msx.sagepub.com/content/5/1_suppl/123.abstract

Gagnon, L. & Peretz, I. (2000). Laterality effects in processing tonal and atonal melodies with affective and nonaffective task instructions. *Brain and Cognition*, *43*(1-3), 206–210. doi:10.1006/brcg.1999.1135

Gazzaniga, M., Ivry, R., & Mangun, G. (2009). *Cognitive neuroscience: The biology of the mind*. Norton. Retrieved from https://books.google.se/books?id=%5C_B9CGgAACAAJ

Goldstein, K. (1995). *The organism: A holistic approach to biology derived from pathological data in man*. Zone Books. Retrieved from https://books.google.se/books?id=VXwiAQAAMAAJ

Gollan, J. K., Hoxha, D., Chihade, D., Pflieger, M. E., Rosebrock, L., & Cacioppo, J. (2014). Frontal alpha EEG asymmetry before and after behavioral activation treatment for depression. *Biological Psychology*, *99*, 198–208. doi:10.1016/j.biopsycho.2014.03.003

Gotlib, I. H. (1998). EEG alpha asymmetry, depression, and cognitive functioning. *Cognition & Emotion*, *12*(3), 449–478. doi:10.1080/026999398379673

Gray, J. & McNaughton, N. (2000). Retrieved from https://books.google.se/books?id=_M4owh-vs-8C&printsec=frontcover&dq=gray+The+neuropsychology+of+anxiety&hl=de&sa=X&redir_esc=y#v=onepage&q=gray%20The%20neuropsychology%20of%20anxiety&f=false

Grimshaw, G. M. & Carmel, D. (2014). An asymmetric inhibition model of hemispheric differences in emotional processing. *Frontiers in Psychology*, *5*(489), 308. doi:10.3389/fpsyg.2014.00489

Güntekin, B. & Başar, E. (2007). Emotional face expressions are differentiated with brain oscillations. *International Journal of Psychophysiology*, *64*(1), 91–100. doi:10.1016/j.ijpsycho.2006.07.003

Güntekin, B. & Başar, E. (2010). Event-related beta oscillations are affected by emotional eliciting stimuli. *Neuroscience Letters*, *483*(3), 173–178. doi:10.1016/j.neulet.2010.08.002

Güntekin, B. & Başar, E. (2015). Review of evoked and event-related delta responses in the human brain. *International Journal of Psychophysiology*. doi:10.1016/j.ijpsycho.2015.02.001

Hagemann, D. (2004). Individual differences in anterior EEG asymmetry: Methodological problems and solutions. *Biological Psychology*, *67*(1), 157–182. doi:10.1016/j.biopsycho.2004.03.006

Hagemann, D., Naumann, E., Thayer, J. F., & Bartussek, D. (2002). Does resting electroencephalograph asymmetry reflect a trait? An application of latent state-trait theory. *Journal of Personality and Social Psychology*, *82*(4), 619. doi:10.1037/0022-3514.82.4.619

Harmon-Jones, E. (2003). Clarifying the emotive functions of asymmetrical frontal cortical activity. *Psychophysiology*, *40*(6), 838–848. doi:10.1111/1469-8986.00121

Harmon-Jones, E. (2006). Unilateral right-hand contractions cause contralateral alpha power suppression and approach motivational affective experience. *Psychophysiology*, *43*(6), 598–603. doi:10.1111/j.1469-8986.2006.00465.x

Harmon-Jones, E. & Allen, J. J. (1998). Anger and frontal brain activity: EEG asymmetry consistent with approach motivation despite negative affective valence. *Journal of Personality and Social Psychology*, *74*(5), 1310. doi:10.1037/0022-3514.74.5.1310

Harmon-Jones, E. & Allen, J. J. (2001). The role of affect in the mere exposure effect: Evidence from psychophysiological and individual differences approaches. *Personality and Social Psychology Bulletin*, *27*(7), 889–898. doi:10.1177/0146167201277011

Harmon-Jones, E., Gable, P. A., & Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology*, *84*(3), 451–462. doi:10.1016/j.biopsycho.2009.08.010

Harmon-Jones, E. & Sigelman, J. (2001). State anger and prefrontal brain activity: Evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. *Journal of Personality and Social Psychology*, *80*(5), 797. doi:10.1037/0022-3514.80.5.797

Harmon-Jones, E., Sigelman, J., Bohlig, A., & Harmon-Jones, C. (2003). Anger, coping, and frontal cortical activity: The effect of coping potential on anger-induced left frontal activity. *Cognition & Emotion*, *17*(1), 1–24. doi:10.1080/02699930302278

Harmony, T., Fernández, T., Silva, J., Bernal, J., Díaz-Comas, L., Reyes, A., … Rodríguez, M. (1996). EEG delta activity: An indicator of attention to internal processing during performance of mental tasks. *International Journal of Psychophysiology*, *24*(1), 161–171. doi:10.1016/S0167-8760(96)00053-0

Heller, W. (1990). The neuropsychology of emotion: Developmental patterns and implications for psychopathology. In N. L. Stein, B. Leventhal, & T. R. Trabasso (Eds.), *Psychological and biological approaches to emotion* (Vol. 1, pp. 166–188). Retrieved from https://books.google.de/books?hl=de&lr=&id=iZGMWf2-CoAC&oi=fnd&pg=PA167&dq=The+neuropsychology+of+emotion:+%7BD%7Developmental+patterns+and+implications+for+psychopathology&ots=wNZSVuvJaA&sig=On21DnF5oaGah2q693TA7dXuPLk#v=onepage&q=The%20neuropsychology%20of%20emotion%3A%20%7BD%7Developmental%20patterns%20and%20implications%20for%20psychopathology&f=false

Heller, W. (1993). Neuropsychological mechanisms of individual differences in emotion, personality, and arousal. *Neuropsychology*, *7*(4), 476. doi:10.1037/0894-4105.7.4.476

Henriques, J. B. & Davidson, R. J. (1991). Left frontal hypoactivation in depression. *Journal of Abnormal Psychology*, *100*(4), 535. doi:10.1037/0021-843X.100.4.535

Hewig, J., Hagemann, D., Seifert, J., Naumann, E., & Bartussek, D. (2004). On the selective relation of frontal cortical asymmetry and anger-out versus anger-control. *Journal of Personality and Social Psychology*, *87*(6), 926–939. doi:10.1037/0022-3514.87.6.926

Hewig, J., Hagemann, D., Seifert, J., Naumann, E., & Bartussek, D. (2006). The relation of cortical activity and BIS/BAS on the trait level. *Biological Psychology*, *71*(1), 42–53. doi:10.1016/j.biopsycho.2005.01.006

Hughes, J. R. (2008). Gamma, fast, and ultrafast waves of the brain: Their relationships with epilepsy and behavior. *Epilepsy & Behavior*, *13*(1), 25–31. doi:10.1016/j.yebeh.2008.01.011

Iwanaga, M., Ikeda, M., & Iwaki, T. (1996). The effects of repetitive exposure to music on subjective and physiological responses. *Journal of Music Therapy*, *33*(3), 219–230. doi:10.1093/jmt/33.3.219

Jackson, D. C., Mueller, C. J., Dolski, I., Dalton, K. M., Nitschke, J. B., Urry, H. L., ... Davidson, R. J. (2003). Now you feel it, now you don't frontal brain electrical asymmetry and individual differences in emotion regulation. *Psychological Science*, *14*(6), 612–617. doi:10.1046/j.0956-7976.2003.psci_1473.x

Jamieson, S. et al. (2004). Likert scales: How to (ab) use them. *Medical Education*, *38*(12), 1217–1218. doi:10.1111/j.1365-2929.2004.02012.x

Jensen, M. P., Gianas, A., Sherlin, L. H., & Howe, J. D. (2015). Pain catastrophizing and EEG-alpha asymmetry. *The Clinical Journal of Pain*, *31*(10), 852–858. doi:10.1097/AJP.0000000000000182

Johnson-Laird, P. N. & Oatley, K. (2008). *Emotions, music, and literature.* Guilford Press New York. Retrieved from https://books.google.de/books?hl=de&lr=&id=uIQQskejGwUC&oi=fnd&pg=PA102&dq=Emotions,+Music,+and+Literature&ots=3OXjPNnfx5&sig=nP3KGLlM5GF7fAUPPXNiNMeqNVU#v=onepage&q=Emotions%2C%20Music%2C%20and%20Literature&f=false

Jones, N. A. & Fox, N. A. (1992). Electroencephalogram asymmetry during emotionally evocative films and its relation to positive and negative affectivity. *Brain and Cognition*, *20*(2), 280–299. doi:10.1016/0278-2626(92)90021-D

Jorm, A. F., Christensen, H., Henderson, A. S., Jacomb, P. A., Korten, A. E., & Rodgers, B. (1998). Using the BIS/BAS scales to measure behavioural inhibition and behavioural activation: Factor structure, validity and norms in a large community sample. *Personality and Individual Differences*, *26*(1), 49–58. doi:10.1016/S0191-8869(98)00143-3

Kalin, N. H., Larson, C., Shelton, S. E., & Davidson, R. J. (1998). Asymmetric frontal brain activity, cortisol, and behavior associated with fearful temperament in rhesus monkeys. *Behavioral Neuroscience*, *112*(2), 286. doi:10.1037/ /0735-7044.112.2.286

Kang, D.-H., Davidson, R. J., Coe, C. L., Wheeler, R. E., Tomarken, A. J., & Ershler, W. B. (1991). Frontal brain asymmetry and immune function. *Behavioral Neuroscience*, *105*(6), 860. doi:10.1037/0735-7044.105.6.860

Khalfa, S., Schon, D., Anton, J.-L., & Liégeois-Chauvel, C. (2005). Brain regions involved in the recognition of happiness and sadness in music. *Neuroreport*, *16*(18), 1981–1984. Retrieved from http://www.brainmusic.org/EducationalActivitiesFolder/Khalfa_emotion2005.pdf

Klimesch, W. (1999). Eeg alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews*, *29*(2), 169–195. doi:10.1016/S0165-0173(98)00056-3

Knott, V. J. & Harr, A. (1997). Aging, smoking and hemispheric EEG asymmetry. *Canadian Journal on Aging/La Revue canadienne du vieillissement*, *16*(04), 647–664. doi:0.1017/S0714980800011016

Kreutz, G., Ott, U., Teichmann, D., Osawa, P., & Vaitl, D. (2007). Using music to induce emotions: Influences of musical preference and absorption. *Psychology of Music*, *36*(1), 101–126. doi:10.1177/0305735607082623

Krumhansl, C. L. (1997). An exploratory study of musical emotions and psychophysiology. *Canadian Journal of Experimental Psychology*, *51*(4), 336. doi:10.1037/1196-1961.51.4.336

Lee, Y. Y., See, A. R., Chen, S. C., & Liang, C. K. (2013). Effect of music listening on frontal EEG asymmetry. In *Applied mechanics and materials* (Vol. 311, pp. 502–506). Trans Tech Publ. doi:10.4028/www.scientific.net/AMM.311.502

Lerner, Y., Papo, D., Zhdanov, A., Belozersky, L., & Hendler, T. (2009). Eyes wide shut: Amygdala mediates eyes-closed effect on emotional experience with music. *PLoS One*, *4*(7), e6230. doi:10.1371/journal.pone.0006230

Lin, Y.-P., Wang, C.-H., Jung, T.-P., Wu, T.-L., Jeng, S.-K., Duann, J.-R., & Chen, J.-H. (2010). EEG-based emotion recognition in music listening. *IEEE Transactions on Biomedical Engineering*, *57*(7), 1798–1806. doi:0.1109/TBME.2010.2048568

Madison, G. (2000). Properties of expressive variability patterns in music performances. *Journal of New Music Research*, *29*(4), 335–356. doi:10.1080/09298210008565466

Marox, E., Rodríguez, H., Yañez, G., Bernal, J., Rodríguez, M., Fernández, T., ... Guerrero, V. (2001). Broad band spectral measurements of EEG during emotional tasks. *International Journal of Neuroscience*, *108*(3-4), 251–279. doi:10.3109/00207450108986517

Mayer, J. D., Allen, J. P., & Beauregard, K. (1995). Mood inductions for four specific moods: A procedure employing guided imagery. *Journal of Mental Imagery*, *19*(1-2), 133–150. Retrieved from http://www.unh.edu/personalitylab/Assets/reprints-public/RP1995-MayerAllenBeauregard.pdf

Menon, V. & Levitin, D. J. (2005). The rewards of music listening: Response and physiological connectivity of the mesolimbic system. *NeuroImage*, *28*(1), 175–184. doi:10.1016/j.neuroimage.2005.05.053

Mikutta, C., Altorfer, A., Strik, W., & Koenig, T. (2012). Emotions, arousal, and frontal alpha rhythm asymmetry during Beethoven's 5th symphony. *Brain Topography*, *25*(4), 423–430. doi:10.1007/s10548-012-0227-0

Mitterschiffthaler, M. T., Fu, C. H., Dalton, J. A., Andrew, C. M., & Williams, S. C. (2007). A functional MRI study of happy and sad affective states induced by classical music. *Human Brain Mapping*, *28*(11), 1150–1162. doi:10.1002/hbm.20337

Montefusco-Siegmund, R., Maldonado, P. E., & Devia, C. (2013). Effects of ocular artifact removal through ICA decomposition on EEG phase. In *2013 6th international IEEE/EMBS conference on neural engineering (NER)* (pp. 1374–1377). IEEE. doi:10.1109/NER.2013.6696198

Müller, B. C., Kühn-Popp, N., Meinhardt, J., Sodian, B., & Paulus, M. (2015). Long-term stability in children's frontal EEG alpha asymmetry between 14-months and 83-months. *International Journal of Developmental Neuroscience*, *41*, 110–114. doi:10.1016/j.ijdevneu.2015.01.002

Müller, M. M., Keil, A., Gruber, T., & Elbert, T. (1999). Processing of affective pictures modulates right-hemispheric gamma band EEG activity. *Clinical Neurophysiology*, *110*(11), 1913–1920. doi:10.1016/S1388-2457(99)00151-0

Nash, K., Inzlicht, M., & McGregor, I. (2012). Approach-related left prefrontal EEG asymmetry predicts muted error-related negativity. *Biological Psychology*, *91*(1), 96–102. doi:10.1016/j.biopsycho.2012.05.005

Niedermeyer, E. (1993). The normal EEG of the waking adult. In E. Niedermeyer & F. Lopes Da Silva (Eds.), *Electroencephalography: Basic principles, clinical applications, and related fields. 5th edition* (pp. 149–173). Retrieved from https://www.researchgate.net/publication/220048971_The_normal_EEG_of_the_waking_adult

Nielzén, S. & Cesarec, Z. (1981). On the perception of emotional meaning in music. *Psychology of Music*. doi:10.1177/030573568192002

Omar, R., Henley, S. M., Bartlett, J. W., Hailstone, J. C., Gordon, E., Sauter, D. A., ... Warren, J. D. (2011). The structural neuroanatomy of music emotion recognition: Evidence from frontotemporal lobar degeneration. *NeuroImage*, *56*(3), 1814–1821. doi:10.1016/j.neuroimage.2011.03.002

g.tec's active and passive biosignal electrodes for g.GAMMAcap. (n.d.). Retrieved from http://www.gtec.at/Products/Electrodes-and-Sensors/g.Electrodes-Specs-Features

Recommended EEG standard electrode configurations. (n.d.). Retrieved from http://www.besa.de/wp-content/uploads/2014/05/Recommended_EEG_Standard_Electrode_Configurations.pdf

Papousek, I., Freudenthaler, H. H., & Schulter, G. (2011). Typical performance measures of emotion regulation and emotion perception and frontal EEG asymmetry in an emotional contagion paradigm. *Personality and Individual Differences*, *51*(8), 1018–1022. doi:10.1016/j.paid.2011.08.013

Papousek, I. & Schulter, G. (2006). Individual differences in functional asymmetries of the cortical hemispheres. Revival of laterality research in emotion and psychopathology. *Cognition, Brain, Behavior*, *10*(2), 269–298. Retrieved from http://www.uni-graz.at/ilona.papousek/CCC_Papousek.pdf

Park, K. S., Choi, H., Lee, K. J., Lee, J. Y., An, K. O., & Kim, E. J. (2011). Emotion recognition based on the asymmetric left and right activation. *International Journal of Medicine and Medical Sciences*, *3*(6), 201–209. Retrieved from http://www.academicjournals.org/app/webroot/article/article1379058569_Park%20et%20al..pdf

Peretz, I., Gagnon, L., & Bouchard, B. (1998). Music and emotion: Perceptual determinants, immediacy, and isolation after brain damage. *Cognition*, *68*(2), 111–141. doi:10.1016/S0010-0277(98)00043-2

Pérez-Edgar, K., Kujawa, A., Nelson, S. K., Cole, C., & Zapp, D. J. (2013). The relation between electroencephalogram asymmetry and attention biases to threat at baseline and under stress. *Brain and Cognition*, *82*(3), 337–343. doi:10.1016/j.bandc.2013.05.009

Peterson, C. K. & Harmon-Jones, E. (2009). Circadian and seasonal variability of resting frontal eeg asymmetry. *Biological Psychology*, *80*(3), 315–320. doi:10.1016/j.biopsycho.2008.11.002

Poole, B. D. & Gable, P. A. (2014). Affective motivational direction drives asymmetric frontal hemisphere activation. *Experimental Brain Research*, *232*(7), 2121–2130. doi:10.1007/s00221-014-3902-4

Putman, P. (2011). Resting state EEG delta-beta coherence in relation to anxiety, behavioral inhibition, and selective attentional processing of threatening stimuli. *International Journal of Psychophysiology*, *80*(1), 63–68. doi:10.1016/j.ijpsycho.2011.01.011

Rangaswamy, M., Porjesz, B., Chorlian, D. B., Wang, K., Jones, K. A., Bauer, L. O., ... Reich, T., et al. (2002). Beta power in the EEG of alcoholics. *Biological Psychiatry*, *52*(8), 831–842. doi:10.1016/S0006-3223(02)01362-8

Robazza, C., Macaluso, C., & D'Urso, V. (1994). Emotional reactions to music by gender, age, and expertise. *Perceptual and Motor skills*, *79*(2), 939–944. doi:10.2466/pms.1994.79.2.939

Sammler, D., Grigutsch, M., Fritz, T., & Koelsch, S. (2007). Music and emotion: Electrophysiological correlates of the processing of pleasant and unpleasant music. *Psychophysiology*, *44*(2), 293–304. doi:10.1111/j.1469-8986.2007.00497.x

Sammler, D., Koelsch, S., & Friederici, A. D. (2011). Are left fronto-temporal brain areas a prerequisite for normal music-syntactic processing? *Cortex*, *47*(6), 659–673. doi:10.1016/j.cortex.2010.04.007

Scherer, K. R. (2004). Which emotions can be induced by music? What are the underlying mechanisms? And how can we measure them? *Journal of New Music Research*, *33*(3), 239–251. doi:10.1080/0929821042000317822

Schmidt, B. & Hanslmayr, S. (2009). Resting frontal EEG alpha-asymmetry predicts the evaluation of affective musical stimuli. *Neuroscience Letters*, *460*(3), 237–240. doi:10.1016/j.neulet.2009.05.068

Schmidt, L. A. & Trainor, L. J. (2001). Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions. *Cognition & Emotion*, *15*(4), 487–500. doi:10.1080/02699930126048

Schomer, D. L. (2007). The normal EEG in an adult. In *The clinical neurophysiology primer* (pp. 57–71). Humana Press.

Schutter, D. J., Putman, P., Hermans, E., & van Honk, J. (2001). Parietal electroencephalogram beta asymmetry and selective attention to angry facial expressions in healthy human subjects. *Neuroscience Letters*, *314*(1), 13–16. doi:10.1016/S0304-3940(01)02246-7

Spielberg, J. M., Stewart, J. L., Levin, R. L., Miller, G. A., & Heller, W. (2008). Prefrontal cortex, emotion, and approach/withdrawal motivation. *Social and Personality Psychology Compass*, *2*(1), 135–153. doi:10.1111/j.1751-9004.2007.00064.x

Steriade, M., Amzica, F., & Contreras, D. (1996). Synchronization of fast (30-40 hz) spontaneous cortical rhythms during brain activation. *The Journal of Neuroscience*, *16*(1), 392–417. Retrieved from http://www.jneurosci.org/content/16/1/392.short

Stewart, J. L., Towers, D. N., Coan, J. A., & Allen, J. J. (2011). The oft-neglected role of parietal EEG asymmetry and risk for major depressive disorder. *Psychophysiology*, *48*(1), 82–95. doi:10.1111/j.1469-8986.2010.01035.x

Stroganova, T. A., Pushina, N. P., Orekhova, E. V., Posikera, I. N., & Tsetlin, M. M. (2004). Functional brain asymmetry and individual differences in hand preference in early ontogeny. *Human Physiology*, *30*(1), 14–23. Retrieved from http://link.springer.com/article/10.1023/B:HUMP.0000013759.88727.01

Sutton, S. K. & Davidson, R. J. (1997). Prefrontal brain asymmetry: A biological substrate of the behavioral approach and inhibition systems. *Psychological Science*, *8*(3), 204–210. doi:10.1111/j.1467-9280.1997.tb00413.x

Terwogt, M. M. & Van Grinsven, F. (1988). Recognition of emotions in music by children and adults. *Perceptual and motor skills*, *67*(3), 697–698. doi:10.2466/pms.1988.67.3.697

Tomarken, A. J., Davidson, R. J., & Henriques, J. B. (1990). Resting frontal brain asymmetry predicts affective responses to films. *Journal of Personality and Social Psychology*, *59*(4), 791. doi:10.1037//0022-3514.59.4.791

Tomarken, A. J., Davidson, R. J., Wheeler, R. E., & Doss, R. C. (1992). Individual differences in anterior brain asymmetry and fundamental dimensions of emotion. *Journal of Personality and Social Psychology*, *62*(4), 676. doi:10.1037//0022-3514.62.4.676

Tomarken, A. J., Davidson, R. J., Wheeler, R. E., & Kinney, L. (1992). Psychometric properties of resting anterior EEG asymmetry: Temporal stability and internal consistency. *Psychophysiology*, *29*(5), 576–592. doi:10.1111/j.1469-8986.1992.tb02034.x

Tortella-Feliu, M., Morillas-Romero, A., Balle, M., Llabrés, J., Bornas, X., & Putman, P. (2014). Spontaneous EEG activity and spontaneous emotion regulation. *International Journal of Psychophysiology*, *94*(3), 365–372. doi:10.1016/j.ijpsycho.2014.09.003

Tramo, M. J. (2001). Music of the hemispheres. *Science*, *291*(5501), 54–56. doi:10.1126/science.10.1126/SCIENCE.1056899

Trochidis, K. & Bigand, E. (2013). Investigation of the effect of mode and tempo on emotional responses to music using EEG power asymmetry. *Journal of Psychophysiology*. doi:10.1027/0269-8803/a000099

Urry, H. L., Nitschke, J. B., Dolski, I., Jackson, D. C., Dalton, K. M., Mueller, C. J., ... Davidson, R. J. (2004). Making a life worth living neural correlates of well-being. *Psychological Science*, *15*(6), 367–372. doi:10.1111/j.0956-7976.2004.00686.x

Van Den Bosch, I., Salimpoor, V. N., & Zatorre, R. J. (2013). Familiarity mediates the relationship between emotional arousal and pleasure during music listening. *Frontiers in Human Neuroscience*, *7*(534), 1–10. doi:10.3389/fnhum.2013.00534

Velo, J. R., Stewart, J. L., Hasler, B. P., Towers, D. N., & Allen, J. J. (2012). Should it matter when we record? Time of year and time of day as factors influencing frontal eeg asymmetry. *Biological Psychology*, *91*(2), 283–291. doi:10.1016/j.biopsycho.2012.06.010

Voiculescu, M., Segarceanu, A., Negutu, M., Ghita, I., Fulga, I., & Coman, O. A. (2015). The effect of caffeine on cerebral asymmetry in rats. *Journal of Medicine and Life*, *8*(4), 476. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4656956/?report=reader

Vuoskoski, J. K. (2012). Emotions represented and induced by music: The role of individual differences.

Vuoskoski, J. K. & Eerola, T. (2011). The role of mood and personality in the perception of emotions represented by music. *Cortex*, *47*(9), 1099–1106. doi:10.1016/j.cortex.2011.04.011

Wacker, J., Heldmann, M., & Stemmler, G. (2003). Separating emotion and motivational direction in fear and anger: Effects on frontal asymmetry. *Emotion*, *3*(2), 167. doi:10.1037/1528-3542.3.2.167

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063.

Wheeler, R. E., Davidson, R. J., & Tomarken, A. J. (1993). Frontal brain asymmetry and emotional reactivity: A biological substrate of affective style. *Psychophysiology*, *30*(1), 82–89. doi:10.1111/j.1469-8986.1993.tb03207

Yuvaraj, R., Murugappan, M., Ibrahim, N. M., Omar, M. I., Sundaraj, K., Mohamad, K., ... Satiyan, M. (2014). On the analysis of EEG power, frequency and asymmetry in Parkinson's disease during emotion processing. *Behavioral and Brain Functions*, *10*(1), 1. doi:10.1186/1744-9081-10-12

Zhang, J. & Zhou, R. (2014). Individual differences in automatic emotion regulation affect the asymmetry of the LPP component. *PloS One*, *9*(2), e88261. doi:10.1371/journal.pone.0088261

Appendix

Subject: Date:

Music Questionnaire

In the following 16 different music excerpts will be presented to you. Your task is to rate

- to what extent they expressed happiness, sadness, anger and fear
- how much you enjoyed listening to them
- how much they aroused you
- whether you knew them from before

Important: Try to differentiate between the mood that the music excerpt expressed and what emotions you felt when you listened to the excerpt!

Example: You listen to a music excerpt and think that it is rather sad and melancholic. But at the same time you find it beautiful and elevating. However, that does not mean that the expressed mood is beauty or elevation. Therefore **please only rate the moods that the music excerpt expressed and not what you felt** in the left box. In the right box you can then state how much you liked the excerpt and whether it aroused you, that is, affected your emotions strongly or not. Besides this, you are asked to state whether you recognized the music excerpt from before or not.

Please

- Listen first to the complete excerpt and then tick the boxes.
- Tick one box for each mood and each question.
- If you do not tick any box, it will be counted as strongly disagree or as not at all pleasant and not at all arousing or as unfamiliar.

Now you can start!

Excerpt 1

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐
not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 2

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 3

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 4

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 5

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 6

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 7

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 8

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 9

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 10

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 11

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 12

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 13

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 14

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 15

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Excerpt 16

The music excerpt expressed:

	strongly disagree				strongly agree
Happiness	☐	☐	☐	☐	☐
Sadness	☐	☐	☐	☐	☐
Anger	☐	☐	☐	☐	☐
Fear	☐	☐	☐	☐	☐

Listening to the music was:

not at all pleasant				very much pleasant
☐	☐	☐	☐	☐

not at all arousing				very much arousing
☐	☐	☐	☐	☐

The music excerpt sounded:

unfamiliar	familiar
☐	☐

Please answer the following questions.

(1) What kind of music do you normally listen to? ____

(2) How many hours do you listen to music on average per day? __________________________________

(3) How would you judge your music knowledge?

- Non-musician ☐
- Occasional playing musical instruments (only for fun) ☐
- Amateur (serious interest, but non-professional) ☐
- Semi-professional or professional (as an occupation) ☐