

Personality affects musical emotion processing: An fMRI-study

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Tiivistelmä - Referat - Abstract <p>Music has an important role in our everyday lives. It is a powerful way of conveying and inducing emotions. It is even described as the language of emotions. Still, the research on the processing of musical emotions and its variations among individuals is scarce. In addition, it is not known whether the same or different neural pathways are recruited when musical emotions are processed with or without conscious awareness (i.e., implicitly or explicitly). The central aims of this thesis are 1. to examine the neural basis of the processing of musical emotions, namely happy, sad and fearful, 2. to determine the neural networks underlying the implicit and explicit processing of musical emotions and 3. to discern the effects of personality on this processing.</p> <p>31 participants (mean age 27.4 years, 9 men) attended the study. Functional magnetic resonance imaging (fMRI) was used to assess the brain activation as the participants listened to musical excerpts expressing three emotions: sadness, happiness, and fear. In the implicit paradigm, participants estimated how many instruments they heard in the stimulus (one, two or many). In the explicit paradigm, participants chose the emotion that best described the stimulus (happy, sad, or fearful). Personality was evaluated using two personality questionnaires, NEO-FFI and S5.</p> <p>Each of the three emotions studied activated different brain regions. Processing of happy music activated the auditory cortex, processing of sad music activated the limbic and frontal areas, and processing of fearful music activated areas of the limbic system, the frontal cortex and the motor cortex. As was expected, implicit processing of musical emotions recruited both cortical and subcortical regions whereas explicit processing activated mainly cortical regions. In addition, personality traits of neuroticism, extraversion and openness affected the processing of musical emotions. Neuroticism correlated with increased activation in the temporal and frontal lobe in response to music expressing negative emotions, and in the subcortical areas in response to happy music. Extraversion correlated with decreased activation in the limbic areas in response to happy music. Openness correlated with activations in the occipital regions in response to happy and sad music. These results highlight the importance of individual differences in the processing of musical emotions and offer perspectives on the applied use of music in health care and educational settings.</p>		
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<p>Tiivistelmä - Referat - Abstract</p> <p>Musiikki on osa jokapäiväistä elämäämme. Musiikilla on myös erityisen vahva rooli tunteiden tulkinnessa ja välittämisessä. Musiikillisten tunteiden prosessoinnista hermoston tasolla sekä siinä ilmenevistä yksilöllisistä eroista tiedetään kuitenkin hyvin vähän. Emme myöskään tiedä, aktivoiko musiikillisten tunteiden prosessointi eri aivoalueita kun prosessointi tapahtuu ilman tietoista kontrollia (implisiittisesti) tai tietoisesti (eksplisiittisesti). Tämän tutkielman tavoitteena on tarkastella 1. musiikillisten tunteiden, erityisesti ilon, surun ja pelon, prosessoinnin aivoperustaa, 2. musiikin tietoisien ja tiedostamattoman prosessoinnin mahdollisia erillisiä hermoverkostoja, sekä 3. persoonallisuuden vaikutusta musiikillisten tunteiden prosessointiin.</p> <p>Toiminnallisella magneettikuvauksella (fMRI) suoritettuun tutkimukseen osallistui 31 koehenkilöä (keski-ikä 27.4 vuotta, 9 miestä). Kokeen aikana koehenkilöt kuuntelivat kolmea tunnetilaa (ilo, suru, pelko) kuvaavia musiikkinäytteitä. Tiedostamattoman prosessoinnin koeasetelmassa koehenkilöiden tehtävänä oli tunnistaa näytteessä kuultujen soitinten lukumäärä (yksi, kaksi, useampi). Tietoisien prosessoinnin koeasetelmassa koehenkilöitä pyydettiin tunnistamaan musiikkinäytteen tunnetila (ilo, suru, pelko). Koehenkilöiden persoonallisuutta arvioitiin kahden kyselylomakkeen, NEO-FFI:n ja S5:n, avulla.</p> <p>Jokainen tutkituista tunteista tuotti toisistaan eriäviä aivoaktivaatioita. Iloisen musiikin prosessointi aiheutti lisääntyntä aktivaatiota kuuloaivokuorella, surullisen musiikin prosessointi limbisillä ja otsalohkon alueella, ja pelottavan musiikin prosessointi limbisillä, otsalohkon sekä liikeaivokuoren alueilla. Kuten oletettiin, tiedostamaton musiikillisten tunteiden prosessointi aktivoi sekä aivokuoren että aivokuoren alaisia alueita. Tiedostettu prosessointi sen sijaan aktivoi pääasiassa alueita aivokuorella. Persoonallisuuden piirteistä neuroottisuudella, ulospäin suuntautuneisuudella ja avoimuudella huomattiin olevan yhteyttä musiikillisten tunteiden prosessointiin. Neuroottisuus oli yhteydessä lisääntyneeseen aktivaatioon ohimolohkon ja otsalohkon alueilla prosessoitaessa negatiivisia tunteita, sekä aivokuoren alaisten alueiden aktivaatioon prosessoitaessa iloista musiikkia. Ulospäin suuntautuneisuus sen sijaan oli yhteydessä vähentyneeseen aktivaatioon limbisillä alueilla prosessoitaessa iloista musiikkia. Avoimuus oli yhteydessä takaraivolohkon aktivaatioon prosessoitaessa iloista ja surullista musiikkia. Nämä tulokset korostavat yksilöllisten erojen tärkeyttä musiikin prosessoinnissa sekä tarjoavat näkökulmia musiikin soveltavaan käyttöön esimerkiksi terveydenhoidossa ja opetuksessa.</p>			
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1 Introduction

Music has an essential role in our everyday lives. We hear it in shops, cafes, offices, films and concerts. Historically music has had an important role in the construction and reinforcement of national identities, in group cooperation, religion and also in major life events, such as births, deaths, marriages and acts of worship. We use music to induce specific types of moods: we play romantic music at dates or weddings, relaxing music at the dentist's office, scary music in movies. Music is even used to reduce pain. Still, it is a mystery why music is so important to us, even though it does not seem to have any implications for our life goals. How is it that these "mere sounds" impact our emotions so strongly?

While searching for the answer to the mystery of music, researchers have turned to the theory of evolution. Darwin suggested that music preceded language as a primary way of communicating (Darwin, 1871/1981). Before language, our ancestors might have used pitch, tempo, melody, loudness, repetition and rhythm to communicate emotional messages (Mithen, 2005). To this day caregivers around the world sing to their babies, intuitively using music as a means to regulate the infants' state or the quality of interaction (review: Trehub & Nakata, 2002). Caregivers speak to infants in a singsong manner, using a variety of musical elements (such as slower tempo and higher pitch) to reflect emotional expressiveness (review: Trehub & Nakata, 2002). It may be that through music's emotional messages we can rapidly convey levels of love, devotion and empathy, for example, that would be hard to achieve any other way (Panksepp & Bernatzky, 2002).

Indeed, music seems as natural to humans as language (Peretz, 2006). This is supported by the notion that perception of emotions in music seems to be effortless and natural to humans, both adults and children (review: Peretz, 2010). We use the same sound features to judge the emotions in speech that we use to determine emotions in music (review: Juslin & Sloboda, 2010a). Also, there is invariance in expressing emotions across cultures, that is, people are able to understand the emotional cues from the music of musical cultures they are not accustomed to (Fritz et al., 2009).

There is a compelling line of evidence from brain lesion studies that cognitive processes may not be essential for music to arouse emotions (Panksepp & Bernatzky, 2002). This implies that music could arouse emotions by activating lower subcortical regions, though many higher neural systems would be involved in various other aspects of music information processing and music appreciation (Panksepp & Bernatzky, 2002). Interestingly, the existence of automatic, implicit (unconscious) processing and controlled, explicit (conscious) processing of emotions in music has not been extensively studied. If emotions are automatically processed from musical stimuli, it would mean that we would register in the lower parts of our brains the emotional content of the music of our everyday life even without paying attention to it. This is important considering that music alters the way we perceive the world (Jolij & Meurs, 2011), our memory (Vuoskoski & Eerola, 2012) and our mood (Kempf, Searight, & Ratwik, 2012). In addition, even though the effect of music varies depending on the individual features of the listener (Garrido & Schubert, 2011; Juslin, Liljeström, Västfjäll, Barradas, & Silva, 2008; Sopchak, 1955), research on the individual variations in the affective processing of music is still scarce.

This thesis aims at understanding the neural basis of different musical emotions and determining the neural networks underlying the implicit and explicit processing of these musical emotions. In addition, the study concentrates on the impact of personality in the processing of musical emotions. Our hypothesis is that implicit and explicit processing of emotional music stimuli activate different neural circuits, and that personality influences the processing of musical emotions. This study was conducted with functional magnetic resonance imaging (fMRI) because of its noninvasiveness and high spatial resolution.

This thesis begins with a brief introduction to the principles of fMRI as a method of studying music and emotions. We continue with reviewing the most relevant findings of brain circuits underlying musical emotions, implicit and explicit processing of emotional stimuli and the influence of personality on the processing of emotions. Then we introduce the hypotheses of this thesis. In Chapters 2 and 3 we describe the methods and results of the present study. Chapter 4 contains the general discussion and conclusion.

1.1 The principles of fMRI in music studies

Functional magnetic resonance imaging (fMRI) is based on the notion that changes of the blood flow in the brain are a delayed function of brain cell activity: if neurons are active, their consumption of oxygen increases (review: Koelsch, Siebel, & Fritz, 2010). There are two blood types in human circulation: oxygenated blood, in which oxygen is attached to haemoglobin molecules (oxyhaemoglobin), and deoxygenated blood, in which haemoglobin has dispensed its oxygen (deoxyhaemoglobin). Importantly for fMRI, oxyhaemoglobin and deoxyhaemoglobin have different magnetic properties. Oxyhaemoglobin is diamagnetic (that is, it creates a magnetic field in opposition to an external magnetic field and is repelled by magnetic fields) and therefore exerts little influence on the local magnetic field, whereas deoxyhaemoglobin is paramagnetic (that is, it is attracted to an external magnetic field) and causes a decrease in the intensity of the MRI image (Heeger & Ress, 2002; review: Koelsch et al., 2010). These changes in the concentration of deoxyhaemoglobin are called the blood-oxygen-level dependent (BOLD) contrast, which is the fMRI method most commonly used in studies (review: Heeger & Ress, 2002).

In fMRI, a strong, static magnetic field of the MRI-system is used to align the hydrogen nuclei in the brain with the magnetic field (Amaro Jr & Barker, 2006). When suitable radiowave pulses are used to excite the hydrogen isotopes, they create a brief, faint signal that can be detected by the MRI system (Amaro Jr & Barker, 2006). Spatial encoding relies on supplementary, gradient magnetic fields that allow the magnetic field to be altered precisely (Amaro Jr & Barker, 2006; review: Koelsch et al., 2010).

If safety precautions are followed, fMRI is a very safe procedure (review: Koelsch et al., 2010). Compared to other neuroimaging techniques, the advantage of fMRI in addition to noninvasiveness is its high spatial resolution (Amaro Jr & Barker, 2006). However, fMRI has its disadvantages. Firstly, electric currents interacting with the main magnetic field cause vibrations that are audible as loud noise (review: Koelsch et al., 2010). This noise affects the processing of auditory information (Novitski, Maess, & Tervaniemi, 2006; Novitski et al., 2003), and makes it challenging to perform experiments inside the fMRI scanner using musical stimuli. Secondly, fMRI has a relatively gross temporal resolution (Logothetis, 2003). Lastly, fMRI does not measure brain activity directly but through

haemodynamics (the local control of blood flow and oxygenation) (review: Heeger & Ress, 2002). The way haemodynamics and brain activity are related is still unclear: hence the validity of studies using fMRI depend on the assumption that fMRI signal is proportional to the local neuronal activity (review: Heeger & Ress, 2002; Logothetis, 2003).

These limitations should be kept in mind when planning research using fMRI. By using carefully designed studies some of these disadvantages can be overcome. Firstly, heavy ear protections can be used to filter most of the noise from the machine. Music can be conducted to ears through earplugs so that the music stimulus is as clearly audible to participants as possible. Secondly, the length and timing of the stimulus should be chosen so that temporal resolution is adequate. Indeed, when the limitations of the method are understood, fMRI offers a powerful tool to advance our understanding of the neural basis of music processing in the healthy brain safely and precisely (see the reviews by Brattico, Bogert, & Jacobsen, 2013; Koelsch, 2010)

1.2 Musical emotions and the brain

1.2.1 Discrete and dimensional models of emotions

In the research literature concerning emotions, there are two broad perspectives of emotion categorization, namely discrete and emotional theories. Discrete theories of emotions assume that there are a set of emotions that are innate and fundamentally distinguishable from one another (Eerola & Vuoskoski, 2013; Ekman & Cordaro, 2011). These emotions correspond to a unique profile in experience and behavior (Mauss & Robinson, 2009). A small subset of these emotions is called the basic emotions, which are proposed to be the most elemental, adaptive and culturally universal emotions (Hamann, 2012). The basic emotions often include happiness, sadness, anger, fear, and disgust (Eerola & Vuoskoski, 2013). In contrast, dimensional theories assert that there are a few fundamental dimensions that organize emotional responses (Mauss & Robinson, 2009). These dimensions include most commonly valence (pleasure vs. displeasure), arousal, and approach-avoidance (Mauss & Robinson, 2009).

Both of these theories have attracted contradicting results. It is clear from previous research that the idea of basic emotions mapping to unique brain areas is too simplistic and insufficient (Hamann, 2012; Lundqvist, Carlsson, Hilmersson, & Juslin, 2009). Still, there are an increasing number of neuroimaging studies associating specific brain circuits with basic emotions (Hamann, 2012; Vytal & Hamann, 2010). On the other hand, studies concentrating on autonomic nervous system responses have found support for the dimensional model of emotions as well (review: Mauss & Robinson, 2009). Recent hybrid models have tried to merge these two aspects by suggesting that emotions consist of core affects, that is, dimensional inner feelings, which are cognitively interpreted as basic emotions (Russell, 2003). Thus, labels of basic emotions would be more relevant in conscious processing, rather than in the physiological stage of emotional processing.

In this thesis the main focus is on musical emotions. This concept entails generally all emotions that are induced by music, without further implications about the nature of the emotions (Juslin & Sloboda, 2010b). In regards to musical emotions, comparison of the dimensional and categorical perspectives has revealed a large correspondence between these two models (Eerola & Vuoskoski, 2011). Basic emotions, especially happiness, sadness, and fear, are cross-culturally and reliably distinguishable musically induced emotions (Balkwill & Thompson, 1999; Balkwill, Thompson, & Matsunaga, 2004; Fritz et al., 2009) that are among the easiest to communicate and recognize in music (Peretz, 2010). Therefore these emotions will be the focus of this thesis.

1.2.2 Brain bases of musical emotions

Both subcortical and cortical structures have a role in the processing of musical stimuli. Of subcortical areas, the nucleus accumbens has been found to activate when listening to music (Menon & Levitin, 2005; review: Peretz, 2010) as well as while doing other pleasurable things (review: Peretz, 2010). The amygdala has been shown to activate during the perception of unpleasant music and deactivate during music-evoked “chills” (i.e. intense pleasurable experience in response to music or other experiences of beauty involving sensations of shivers down the spine) (review: Koelsch, 2010). Of cortical areas, the orbitofrontal cortex and the ventromedial prefrontal cortex are key brain systems in processing musical emotions (review: Peretz, 2010). The role of mode and tempo in

discriminating emotions relies mostly on the orbitofrontal and cingulate cortices (Khalifa, Schon, Anton, & Liégeois-Chauvel, 2005).

Though much is known about the neural structures of musical processing, the neuroimaging studies concerning the brain circuits of distinct musical emotions are scarce and the findings vary. Khalifa et al. (2005) studied brain reactions to excerpts from Western classical music representing happiness or sadness. They found activation in the limbic structures (posterior cingulate cortex) and in the left orbito- and mid-dorsolateral frontal cortex when participants listened to sad music compared to happy music. Listening to happy music did not activate any differing brain areas to those active while listening to sad music.

Like Khalifa et al. (2005), Mitterschiffthaler, Fu, Dalton, Andrew and Williams (2007) studied Western classical music representing happiness or sadness, but used longer sections of music and familiarized participants to the stimuli beforehand. Interestingly, in this study listening to sad music did not result in any significant activation when contrasted to happy music, whereas the opposite contrast of happy over sad music revealed activation in the left superior temporal gyrus. When comparing sad music to neutral music, Mitterschiffthaler et al. (2007) did find activation that was partly overlapping with the previous study. Listening to sad music was associated with activation in the limbic structures (left posterior cingulate gyrus and right hippocampus/amygdala), left medial frontal gyrus, temporal cortex (bilaterally in the primary auditory cortex and right auditory association area), and the left cerebellum. Still, partly the same areas were found to activate while participants listened to happy music contrasted with neutral music (left posterior and anterior cingulate, left parahippocampal gyrus, left superior and medial frontal gyrus, bilateral primary auditory cortex, bilateral ventral striatum, left nucleus caudate, and left precuneus) (Mitterschiffthaler et al., 2007). This implies that these areas are not selectively activated in response to specific musical emotions, but could be involved in more general processing of musical emotions.

In another study by Green et al. (2008), activation was found in the left medial frontal gyrus and the limbic structures (left parahippocampal gyrus and bilateral ventral anterior cingulate cortex) when contrasting sad music to happy music. Compared to previous studies, the stimuli used were novel sad and happy melodies. Like Khalifa et al. (2005),

Green et al. (2008) found no significant activation when contrasting happy over sad stimuli.

Lyrics are an important part in conveying the emotional message of modern music. In a study by Brattico et al. (2011), the brain responses to happy and sad music with and without lyrics were compared to study the significance of lyrics in music. Sad music with lyrics seems to induce more negative emotions and wider brain activation than sad instrumental music (Brattico et al., 2011). Sad music with lyrics recruited subcortical areas, such as the parahippocampal gyrus, amygdala, claustrum and putamen, as well as cortical areas, such as the precentral gyrus, medial and inferior frontal gyri, and auditory cortex when compared to sad music without lyrics (Brattico et al., 2011). On the contrary, happy music without lyrics is more powerful in conveying positive emotions and recruits wider brain areas than happy music with lyrics (Brattico et al., 2011). Happy music without lyrics activates structures in the limbic and emotion-related frontal areas, such as the left anterior cingulate, right insula, left middle frontal gyrus, precentral gyrus and superior frontal gyrus, whereas the opposite contrast between happy music with versus without lyrics activated only auditory regions (Brattico et al., 2011).

Contrary to sad and happy, knowledge of the brain circuits involved in processing fear from musical stimuli is limited. Lesion studies show that patients who had an amygdala resection were impaired in the recognition of scary music (Gosselin et al., 2005). This implies that amygdala would be necessary in the perception of musical suspense. This same pattern has been observed in a neuroimaging study of music (Park et al., 2013), and it is in accordance with studies of other domains, where amygdala activity has been found to correlate with phobias (Åhs et al., 2009), recognition of fear from faces (Adolphs et al., 2005) and fear conditioning (review: LeDoux, 2003).

1.3 Implicit and explicit processing of emotional stimuli

There are two distinct paths of emotional processing: implicit (unconscious) and explicit (conscious) (Lane, 2008). Implicit processing is automatic and does not require conscious, cortical processing, whereas explicit processing requires higher levels of processing.

Implicit processing of emotions is potentially crucial in life-threatening situations because of the time saved by having behaviour directed straight by implicit processes without time consuming explicit processing (Lane, 2008). Implicit processes are also older in the evolutionary history of humans (Lane, 2008). On the other hand, capacity for explicit processing, such as reflection, deliberation, delay of impulses and planning, are arguably more important in modern society, where success and intellectual capital are valued more than ever (Lane, 2008).

Implicit and explicit processing of emotional visual stimuli has been studied extensively with facial expressions. There are some controversies in the literature concerning these two processes, since the brain activity during processing of emotional content is dependent not only on the path of emotional processing but also on the type of stimulus (Keightley et al., 2003). Still, there are some conclusions that can be made.

Implicit processing of faces employs limbic and emotion-related cortical areas, such as the amygdala (Critchley et al., 2000; Lane, 2008; Williams et al., 2006), insula (Critchley et al., 2000; Fusar-Poli et al., 2009), anterior cingulate cortex (Williams et al., 2006), and inferior prefrontal cortex (Critchley et al., 2000). These areas have previously been discovered to be involved in conditional learning (Büchel, Dolan, Armony, & Friston, 1999; Büchel, Morris, Dolan, & Friston, 1998), initiation of emotional, autonomic and hormonal responses (review: Koelsch, 2010), and modulation of motivation and attention (review: Koelsch, 2010; Scheuerecker et al., 2007).

Explicit processing of emotional visual stimuli activates mostly cortical areas. These areas include the middle temporal gyrus (Critchley et al., 2000), an area responding to facial expressions and movements (Puce, Allison, Bentin, Gore, & McCarthy, 1998), and the medial prefrontal cortex (Fusar-Poli et al., 2009; Scheuerecker et al., 2007; Williams et al., 2006), which is related to self-reflective thought (Johnson et al., 2002) and metacognitive evaluations (Johnson et al., 2002; Schmitz, Kawahara-Baccus, & Johnson, 2004). Of subcortical areas, explicit processing activates the hippocampus (Critchley et al., 2000), an area that is necessary for formation and expression of declarative knowledge and memories (Bechara et al., 1995; Eichenbaum, 2000), and bilaterally the amygdala (Fusar-Poli et al., 2009; Habel et al., 2007).

Beyond the visual domain, prosody (“melody of speech”) is a powerful way of conveying emotions. Implicit processing of prosody engages temporal areas, such as the posterior superior temporal gyrus (Frühholz, Ceravolo, & Grandjean, 2012) and the left superior temporal sulcus (Bach et al., 2008). These areas have been previously related to phonological (Buchsbaum, Hickok, & Humphries, 2001) and sentence-level semantic and syntactic processing (Friederici, Rüschemeyer, Hahne, & Fiebach, 2003). In addition, activity has been found in the bilateral inferior frontal gyrus (Frühholz et al., 2012) and clusters in the right superior and inferior parietal lobule (Bach et al., 2008), areas that are involved in multisensory processing and integration (Clower, West, Lynch, & Strick, 2001; Molholm et al., 2006).

Explicit processing of prosody relies on the mid-superior temporal gyrus (Frühholz et al., 2012) and frontal areas, such as the left inferior frontal gyrus (Frühholz et al., 2012), left dorsolateral prefrontal cortex (Bach et al., 2008) and bilateral medial frontal cortex (including anterior cingulate) (Bach et al., 2008; Frühholz et al., 2012). The role of the amygdala is unclear since it has been reported to be activated during both implicit and explicit processing of prosody (Bach et al., 2008; Frühholz et al., 2012).

Musical implicit and explicit processes related to emotion perception and induction are yet to be studied. It has been suggested that emotional responses to music can be aroused in humans as readily as reflexes (Peretz, 2006), that is, through implicit processing. According to Peretz (2006), musical emotions occur with immediacy, through automatic appraisal, and with changes in physiological and behavioural responses. Though many higher neural systems of the brain are involved in processing different aspects of music and in music appreciation, the emotional power may be generated by lower subcortical regions of the brain (Panksepp & Bernatzky, 2002). Hence, musical emotions seem to resemble other classes of biological stimuli, such as facial emotions (Peretz, 2006), although further research needs to be conducted for a definite answer.

1.4 The influence of personality on emotion processing

1.4.1 The five-factor model of personality

In trait psychology, personality can be defined as dimensions of individual differences in tendencies to think, feel and act in a consistent way (McCrae & Costa, 2003). Personality traits provide an outline of human individuality, a recognizable signature that a person tends to express in multiple situations over a long period of time (McAdams & Pals, 2006). In the quest to find these core traits of human personality, researchers turned to folk wisdom. Since personality differences are vitally important in getting along with others and in cooperation, every culture must have evolved words to represent these differences (McCrae & Costa, 2003). So by screening and clustering words describing personality, it should be possible to find the core dimensions of personality (McCrae & Costa, 2003).

By going through thousands of words and tens of thousands of trait ratings made by hundreds of thousands of people, five personality dimensions emerged (review: Rentfrow & McDonald, 2010). These dimensions, which are frequently called *neuroticism*, *extraversion*, *openness to experience*, *agreeableness* and *conscientiousness*, are found in in peer rating scales, self-reports on trait descriptive adjectives, in questionnaire measures of needs and motives, in expert ratings, and in personality disorder symptom clusters (review: McCrae & Costa Jr, 1999). These five factors are the highest level of personality hierarchy, consisting of lower level facets (e.g. neuroticism consists of anxiety, hostility, depression, self-consciousness, impulsiveness and vulnerability to stress) (Lönqvist, Verkasalo, & Leikas, 2008).

One of the traits, neuroticism, refers to the negative affect component of personality (Rentfrow & McDonald, 2010). It represents the tendency to experience psychological distress (McCrae & Costa, 2003), and people high in neuroticism tend to be anxious, moody, vulnerable, tense, and irritable (Rentfrow & McDonald, 2010). Neuroticism is associated with vulnerability to numerous mental and physical disorders as well as reduced quality of life (Goodwin & Friedman, 2006; Lahey, 2009). Neuroticism is also correlated with smaller likelihood of engaging in positive health behaviours (Williams, O'Brien, & Colder, 2004) and greater risk of mortality (Mroczek, Spiro III, & Turiano, 2009; Shipley, Weiss, Der, Taylor, & Deary, 2007).

Extraversion, on the other hand, is related to the tendency to experience positive emotions, such as joy and pleasure (McCrae & Costa, 2003). People high in extraversion are sociable, talkative, enthusiastic, active, cheerful and optimistic (Rentfrow & McDonald, 2010). Extraversion is associated with time spent in social activities, but also increased likelihood of hospitalization for accidents or illness (Nettle, 2005). Extraversion is positively correlated with affective measures such as increased work, relationship and life satisfaction (Judge, Heller, & Mount, 2002; Schimmack, Radhakrishnan, Oishi, Dzokoto, & Ahadi, 2002; Scollon & Diener, 2006).

The other three traits are less concerned with affectivity. Openness to experience refers to the degree to which a person is imaginative and sensitive to art and beauty, creative, curious, behaviourally flexible, and unconventional (McCrae & Costa, 2003; Rentfrow & McDonald, 2010). Conscientiousness contrasts scrupulous, organized, reliable, and diligent people with lax, disorganized, and lackadaisical individuals (McCrae & Costa, 2003; Rentfrow & McDonald, 2010). Agreeableness is a dimension describing interpersonal behaviour. People high on agreeableness are kind, friendly, trusting, sympathetic, and cooperative, in contrast to cynical, callous and antagonistic (McCrae & Costa, 2003; Rentfrow & McDonald, 2010).

1.4.2 Personality and emotional processing

The personality traits of neuroticism and extraversion are, as can be predicted from their tight association with negative and positive affect, the most studied in regards to emotional processing. These traits have been shown to correlate with the volume of different parts of the brain (Cremers et al., 2011; Wright et al., 2006). Therefore, it is not surprising that evidence implies that neuroticism and extraversion affect a range of emotional processes, including experience, perception, and attention (review: Hamann & Canli, 2004).

A variety of different paradigms have been used to study the brain correlates of emotional processing and personality with somewhat varying results. In studying pictures with emotional valence, extraversion has been found to correlate with an extended network of several frontal and temporal regions (Brühl, Viebke, Baumgartner, Kaffenberger, & Herwig, 2011; Canli et al., 2001). When anticipating an emotional stimulus of unknown

valence, extraversion was further related to visual-perceptual regions of the parieto-occipital regions (Brühl et al., 2011). When processing negative stimuli, extraversion has been correlated with the activity of the thalamus (Brühl et al., 2011), whereas while processing positive stimuli, activation has been found in the cortical (right cingulate gyrus, bilateral frontal areas, and right temporal areas) and subcortical areas (right amygdala, left caudate nucleus and left putamen) (Canli et al., 2001).

Neuroticism has been associated with the activity in the frontal, parieto-occipital and temporal regions (Brühl et al., 2011; Canli et al., 2001), especially when processing pictures with negative content. Subcortically neuroticism is positively correlated with the activity of the caudate nucleus during the anticipation of negative or positive pictures (Brühl et al., 2011). In a meta-analysis by Servaas et al. (2013), neuroticism was found to be associated with decreased activation in the anterior cingulate cortex, thalamus, hippocampus, striatum and several temporal, parietal and occipital brain areas during the anticipation of aversive stimuli. When processing negative visual stimuli, neuroticism was correlated with an increased activation in in the left hippocampus, left superior frontal gyrus and bilateral cingulate gyrus (Servaas et al., 2013).

Faces are assumed to be powerful emotional stimuli, and the perception of emotional faces has been linked to personality. For example, neurotic individuals are more sensitive to negative facial expressions (Chan, Goodwin, & Harmer, 2007; review: Ormel et al., 2012), whereas extraverted people seem to perceive more happiness in facial expression than do people low in extraversion (Knyazev, Bocharov, Slobodskaya, & Ryabichenko, 2008). In the neural structures, neuroticism in interaction with negative facial expressions is associated with the amygdala-prefrontal cortex connectivity (Cremers et al., 2010; Frühholz, Prinz, & Herrmann, 2010; Haas, Constable, & Canli, 2008). The activation of the amygdala to positive faces is larger in people high in extraversion (Canli, Sivers, Whitfield, Gotlib, & Gabrieli, 2002).

The previous findings are confirmed when taking the processing type into consideration. During implicit processing of emotional stimuli, there is greater activity in the amygdala in individuals high in neuroticism (Blasi et al., 2009). During explicit processing, activation has been found in neurotic individuals in the dorsolateral prefrontal cortex (Blasi et al., 2009) and bilaterally in the anterior insula (Iaria et al., 2008).

Little is known about the effect of personality on emotional processing outside the visual domain. Brück, Kreifelts, Kaza, Lotze, and Wildgruber (2011) studied the impact of personality on identification of affective prosody. There was no significant correlation between extraversion and brain activation during prosody judgment. However, neuroticism was found to correlate with neuronal responses within the right amygdala, right medial frontal cortex (including aspects of the anterior cingulate cortex), and left postcentral cortex. This is the same pattern of activation that has been found in studies of the relationship between neuroticism and emotional faces. These results suggest that in addition to visual stimuli, also the decoding of emotional speech may vary depending on differences in personality (Brück et al., 2011). However, in spite of the centrality of sounds in several pathologies (such as auditory hallucinations in schizophrenia) and their therapeutic impact, very little research has been conducted on person-related differences in emotions conveyed via the auditory modality.

1.4.3 Musical emotions and personality

The impact of personality on the processing of emotional music stimuli can be seen on many levels: in the neural responses to musical emotions, perception and induction of emotions, and even in the use of music in everyday life. People seem to like music that is compatible with their personality: agreeable individuals enjoy happy- and tender-sounding music (Vuoskoski & Eerola, 2011b), open individuals like a wide range of music, including music that is complex, reflective and rebellious (Rawlings & Ciancarelli, 1997; Rentfrow & Gosling, 2003) and extraverts like popular music that is upbeat, energetic and rhythmic (Rawlings & Ciancarelli, 1997; Rentfrow & Gosling, 2003). Personality also affects the way we use music: open and intellectually engaged individuals use music for rational or cognitive reasons, neurotic individuals use music for emotional regulation (e.g. changing or enhancing moods), and extraverted individuals use music as background or a distractor (Chamorro-Premuzic, Swami, Furnham, & Maakip, 2009; Chamorro-Premuzic & Furnham, 2007).

Besides the processes of preference and liking, personality has an impact on the emotions music induces. Openness to experience and extraversion are positively related to the intensity of emotional responses induced by music (Liljeström, Juslin, & Västfjäll, 2012; Vuoskoski & Eerola, 2011a). Neuroticism is related to experiencing more negative

emotions and fewer positive emotions when listening to music (Liljeström et al., 2012). Extraversion, by contrast, has been related to experiencing more positive than negative emotions (Liljeström et al., 2012), but also to experiencing overall more emotions when listening to music (Vuoskoski & Eerola, 2011a).

There are only a few studies on the neural and physiological correlates of personality and musical emotions. The activity of the ventral striatum when listening to pleasant in contrast to unpleasant music is correlated with a trait called self-forgetfulness, that is, a tendency to forget oneself when concentrating on a certain task and susceptibility to flow experiences (Montag, Reuter, & Axmacher, 2011). As mentioned previously, activity in the ventral striatum has also been found to correlate with listening to happy and pleasant music (Blood & Zatorre, 2001; Koelsch, Fritz, Von Cramon, Müller, & Friederici, 2006; Mitterschiffthaler et al., 2007). In a small study of 12 participants, Park et al. (2013) found positive correlations between neuroticism and activations in the bilateral basal ganglia, insula and orbitofrontal cortex in response to music expressing happiness, which could imply that the emotional processing in neurotic individuals is altered. Low level of extraversion was found to correlate with increased activation in the right amygdala in response to music expressing fear, which could be interpreted as an increased reactivity to fear in introverts (Park et al., 2013).

Koelsch et al. (2007) studied emotional personality, that is, the capability to produce tender feelings (e.g. soft, loving, joyful and warm as opposed to aggressive, impulsive, hostile and anxious) and its relationship to the processing of musical stimuli. When contrasting unpleasant emotional music stimuli with pleasant stimuli, activity changes in the amygdala and the hippocampal formation were stronger in individuals with high emotionality than in individuals with lower emotionality. These same differences were seen on the cardiac amplitude patterns of the individuals (Koelsch et al., 2007). Interestingly, these cardiac amplitude patterns also correlate with other personality traits, for example neuroticism, extraversion and agreeableness (Koelsch, Enge, & Jentschke, 2012). These results imply that the activity of both the brain and the heart are influenced by personality, and it also raises the question of the impact of personality on endocrine, autonomic and immune system activity.

1.5 Present study

The aim of the present study is to expand the knowledge of the neural basis of the processing of musical emotions. This thesis has three goals. Firstly, this thesis aims to study the neural basis of different musical emotions, that is, sadness, happiness and fear. Studies concerning musical emotions have yielded differing results. Still, based on the previous results the following hypotheses were made:

- 1) Happy music activates temporal cortical areas and the striatum
- 2) Sad music activates limbic areas and frontal cortical areas
- 3) Fearful music activates the amygdala

The second goal of this thesis is to investigate whether the implicit and explicit processing of emotional stimuli recruit different neural paths. This has been proven to be the case with visual stimuli, but it has not been studied with music. Based on the research on visual domain, the following hypotheses were made:

- 1) Implicit processing of musical stimuli recruits mainly subcortical brain areas.
- 2) Explicit processing of musical stimuli recruits mainly cortical brain areas.

The final goal of this thesis is to study whether personality affects the processing of musical stimuli. Little is known about the relationship between musical emotions and personality. Therefore, only the following hypothesis was made:

- 1) Personality affects the way musical emotions are processed in the brain.

2 Materials and Methods

2.1 Participants

This study was done as a part of the larger Tunteet (“Emotions”) -project. The whole data consists of 105 participants, of which forty-five healthy volunteers with no formal musical training participated in the fMRI-study. Inclusion criteria were 18 to 50 years of age and absence of hearing problems, neurological problems or psychopharmacological medication. Data from two participants were excluded from the data processing for abnormalities in brain structure verified by a neurologist. Additional five participants were excluded for technical difficulties encountered during the acquisition phase. After data preprocessing, six of the participants were excluded from further processing because of too much movement during scanning. The final sample consisted of 31 non-musicians (mean age: 27.4 ± 6.9 SD, range 20-64, 9 males).

Participants in this study were recruited through various email lists of the University of Helsinki. For compensation of their time, participants were given a voucher for cultural and exercise activities for every half an hour of participation. This study was approved by the Coordinating ethical committee of Helsinki and Uusimaa Hospital District.

2.2 Personality questionnaires

To assess personality traits, all of our participants filled the Finnish versions of two personality questionnaires: Neo Five Factor Inventory (NEO-FFI) and Short Five (S5). Neo-FFI is a self-report questionnaire by Costa and McCrae (1992). NEO-FFI is a shortened version of NEO Personality Inventory. It consists of 60 items (e.g. “I am not a worrier”, “I usually prefer to do things alone”), 12 items chosen to represent each of the Big Five traits from the pool of NEO-PI items. The items are rated on a 5-point Likert scale ranging from ‘strongly disagree’ to ‘strongly agree’. The five trait scores, each representing one dimension of personality, were computed by summing the ratings of the relevant items. Reliability (Cronbach’s Alpha) of the NEO-FFI in this study was .62 for

neuroticism, .75 for extraversion, .67 for openness, .36 for agreeableness and .71 for conscientiousness (n=24).

S5 (Konstabel, Lönnqvist, Walkowitz, Konstabel, & Verkasalo, 2012) is a 60-item self-report questionnaire designed to measure the same five factors and 30 facets as the Revised NEO Personality Inventory (NEO-PI-R; Costa & McCrae, 1992). The S5 items (e.g. “I am often nervous, fearful, and anxious, and I worry that something might go wrong”, “I like people; I am friendly and open talking to strangers”) are answered on a 7-point scale ranging from -3 (the description is completely wrong) to 3 (the description is completely right). The S5 has good reliability and convergent validity with the NEO-PI-R (Lönnqvist et al., 2008). Reliability (Cronbach’s Alpha) of the S5 in this study was .70 for neuroticism, .82 for extraversion, .79 for openness, .71 for agreeableness and .69 for conscientiousness.

2.3 Stimuli

The stimuli used in this study were musical excerpts taken from Eerola et al. (2011) movie soundtrack database. Movie stimuli were chosen because music in movies is composed to represent and induce emotions in listeners. 10 excerpts were chosen to represent each of the three emotions studied: happy, sad and fearful. Excerpts were edited to last 4 seconds and loudness was normalized with Adobe Audition. The stimuli were validated behaviourally with 10 subjects to confirm that they represented the intended emotions.

2.4 Procedure

This study was conducted in the Advanced Magnetic Imaging (AMI) Centre in Aalto University. Before measurements, participants were given information about the study and gave their consent to participation. Participants were also asked to fill fMRI safety questionnaire to ensure that the fMRI procedure was safe for them.

During scanning, participants listened to the stimuli through insert ear tubes. Sound level of the stimuli was individually adjusted so that the stimuli were audible above the scanner noise but the volume stayed inside safety limits. Average sound volume of the stimuli was 80 dB. Hearing was protected and the scanner noise attenuated by placing foam cushions next to the ears. Instructions were given through a computer screen. Participants were instructed to answer by pressing one of the three push-buttons representing the three response options. These response options were shown on the computer screen in the same order as the buttons.

The study included two paradigms: the implicit and the explicit paradigm. The same stimuli were used in both of the paradigms in randomized order. In the implicit paradigm, the participants were instructed to answer whether there were one, two or many instruments playing in the stimulus (*Figure 1*). In the explicit paradigm, participants were asked to judge which one of the three emotions (happy, sad, fearful) best described the stimulus (*Figure 2*). Each stimulus was followed by a 5-second answering period. The implicit paradigm was presented first, following the explicit paradigm. Participants also completed a short training period before the two measurements.

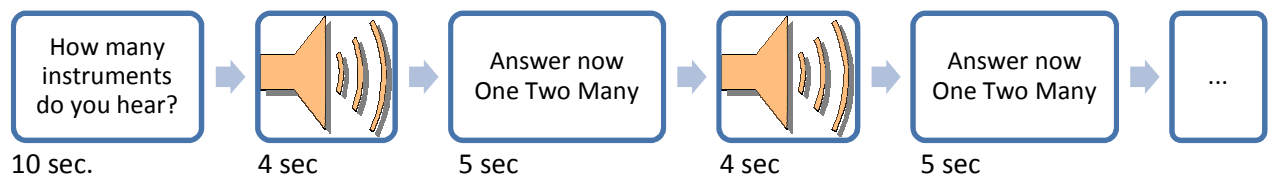


Figure 1. The Implicit paradigm.

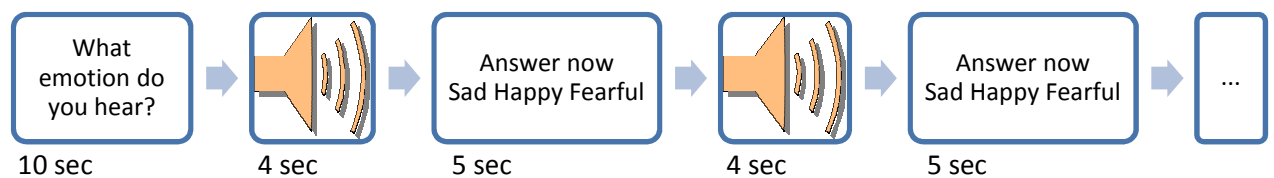


Figure 2. The Explicit paradigm.

2.5 Data recording

The fMRI experiments were performed using a 3-T MAGNETOM Skyra whole-body scanner (Siemens Healthcare, Erlangen, Germany). An interleaved gradient echo-planar imaging (EPI) sequence (TR=2 s; echo time 32 ms; flip angle 75°) sensitive to BOLD contrast was used to acquire thirty-three oblique slices allowing coverage of the whole brain (field of view 192×192 mm; 64×64 matrix; slice thickness 4 mm; spacing 0 mm). The anatomical T1 weighted MR images (176 slices, field of view 256 mm; 256×256 matrix; thickness 1 mm; spacing 0 mm) were collected in 6 minutes and after the fMRI tasks.

2.6 Data analysis

2.6.1 fMRI data analysis

The preprocessing and the statistical analysis of the whole-brain imaging data was performed using statistical parametric mapping (SPM8) on the Matlab platform. Images for each participant were realigned to adjust for movement between slices, normalized spatially onto the Montreal Neurological Institute (MNI) template (12 parameter affine model, gray matter segmentation), and spatially smoothed (Gaussian filter with an FWHM of 6 mm). Datasets were screened to see whether they meet the criteria for high quality and scan stability as demonstrated by small (<2 mm translation and <2° rotation) motion correction. The data was filtered temporally using a high-pass filter of 128 Hz to minimize scanner drift. The fMRI responses were modeled using a canonical hemodynamic response function (HRF). The six movement parameters were inserted into the model as regressors of no interest to capture artefacts related to residual movement. Subsequently, for each subject and each scan, a category-specific BOLD activation was estimated using linear contrasts.

An analysis of variance (ANOVA) was performed to compare the brain responses to different emotions (happiness, sadness and fear) and processing types (explicit and implicit). In the first-level of analysis, individual mean images corresponding to the

contrasts of happy>baseline, sad>baseline and fearful>baseline were computed. In the second level of analysis, the group effects were assessed using a full factorial analysis employing random effect model with emotion and processing type as factors. The acquired t values were normalized by transforming them into Z-scores.

A Monte Carlo simulation was conducted to protect against false positive findings. The simulation resulted in a cluster threshold of 26 voxels at $p < 0.001$. Therefore only activations with a Z-score equal to or greater than 3.5 ($p < 0.001$) and with a cluster size (k) equal to or greater than 26 voxels were considered to be significant. The anatomical structures were labeled and the Brodmann areas (BA) specified using the Talairach Client (<http://www.talairach.org/client.html>).

2.6.2 ROI analysis for correlational tests and PPI analysis

Signal change was extracted from selected cluster of activation with the Region of interest (ROI) analysis of Marsbar. ROI analyses were performed on 17 areas with significant activation surviving the FWE-correction for multiple comparisons. The coordinates for the ROIs were determined as the maximum voxel of activation in the t-map of group main effects of Emotion and Processing type. The ROIs were divided according to the six conditions used in this study (happy implicit, sad implicit, fearful implicit, happy explicit, sad explicit and fearful explicit). To determine the relationship between signal change in the ROI areas and the personality traits, the Pearson's correlation coefficients were calculated between the fMRI signal extracted from the ROIs and the personality scores.

To assess the connectivity of the right and left amygdala activation while processing the three musical emotions (happiness, sadness and fear), Psycho-Physiological Interaction (PPI) analyses were performed as implemented in SPM 8 (Friston et al., 1997). PPI identifies target regions whose activity covaries significantly with the seed region during a certain psychological task. The amygdala was chosen as a seed region based on significant activation during the current experimental conditions and prior knowledge of its central role in emotion processing. For each subject, the time course of activation was extracted for a volume of interest (VOI) centered on the amygdala coordinates from the Main Effect of Emotion. In the first-level of analysis, a general linear model was computed with three

regressors: the psychological regressor (i.e. Emotion), physiological regressor (time course of activation of the VOI), and a PPI interaction term that was calculated based on the psychological * physiological regressors.

A second level analysis was conducted using one-sample t-tests to determine areas functionally connected with the amygdala during the presentation of a specific emotional stimulus. As these analyses are exploratory, results with significance of $p < 0.001$, $k > 10$, uncorrected for multiple comparisons are reported. The goal of the PPI analysis was to explore the effect of the personality trait extraversion on the connectivity of the amygdala during the processing of musical emotions. Extraversion was chosen based on the significant correlation found in the ROI analysis between signal change in the right amygdala and individual extraversion scores. The PPI analyses were done separately to participants scoring low and high on extraversion to explore the difference in the functional connectivity between these two groups. The groups were divided using the median of the scores of extraversion as a cut point, resulting in two groups each consisting of 15 participants. For the low extraversion group, mean of the extraversion scores was 26, and for the high group, 34.73. The difference between the groups was statistically significant ($t(28) = -4.03$, $p < .001$).

3 Results

3.1 Personality measures

The results of the two personality questionnaires, NEO-FFI and S5, correlated strongly. The correlations (Pearson's r) between neuroticism scores were .79, extraversion scores .84, openness scores .82, agreeableness scores .66, and conscientiousness scores .79. Therefore, to avoid multiplication of correlational tests and hence to reduce the risk of Type I errors, only the NEO-FFI was used in the following analyses.

The mean and standard deviation of the traits of NEO-FFI in this sample are as follows: the mean of neuroticism was 17.48 ± 6.31 SD, the mean of extraversion was 30.35 ± 7.21 SD, the mean of openness was 31.61 ± 7.02 SD, the mean of agreeableness was 35.16 ± 4.95 SD and the mean of conscientiousness was 31.58 ± 5.92 SD.

3.2 Effects of emotions

As can be seen from Figure 3A, the contrast of **happy > sad** music showed significant and large activation in the bilateral auditory areas (superior temporal gyrus), amygdala/parahippocampal gyrus, cingulate cortex, right thalamus and right middle and medial frontal gyri. Likewise, the contrast **happy > fearful** revealed significant differences in the bilateral auditory areas (superior temporal gyrus), amygdala and cingulate cortex, and in addition in the precentral gyri and superior parietal lobule.

The contrast **sad > happy** revealed brain activity in the bilateral anterior cingulate cortex, precuneus, superior/inferior frontal gyrus and middle occipital gyrus (Figure 3B). Left side activation was found in the hippocampus/parahippocampal gyrus, caudate head, superior parietal lobule and middle frontal gyrus. Likewise, the contrast **sad > fearful** produced activity in the superior/inferior parietal lobule, medial frontal gyrus and precuneus.

As shown in Figure 3C, the contrast **fearful > happy** showed significant activation in the bilateral caudate, middle frontal gyrus, precentral gyrus and precuneus. Right hemisphere

activation was found in the anterior cingulate/cingulate cortex and cuneus. Left side activation was found in the insula, parahippocampal gyrus, superior/inferior parietal lobule and middle occipital gyrus. The contrast **fearful > sad** produced activity in the bilateral superior temporal gyrus and middle frontal gyrus, left claustrum, supramarginal gyrus, post- and precentral gyrus, and right insula and inferior parietal lobule. Locations and magnitudes of the activations can be found in Appendix 2.

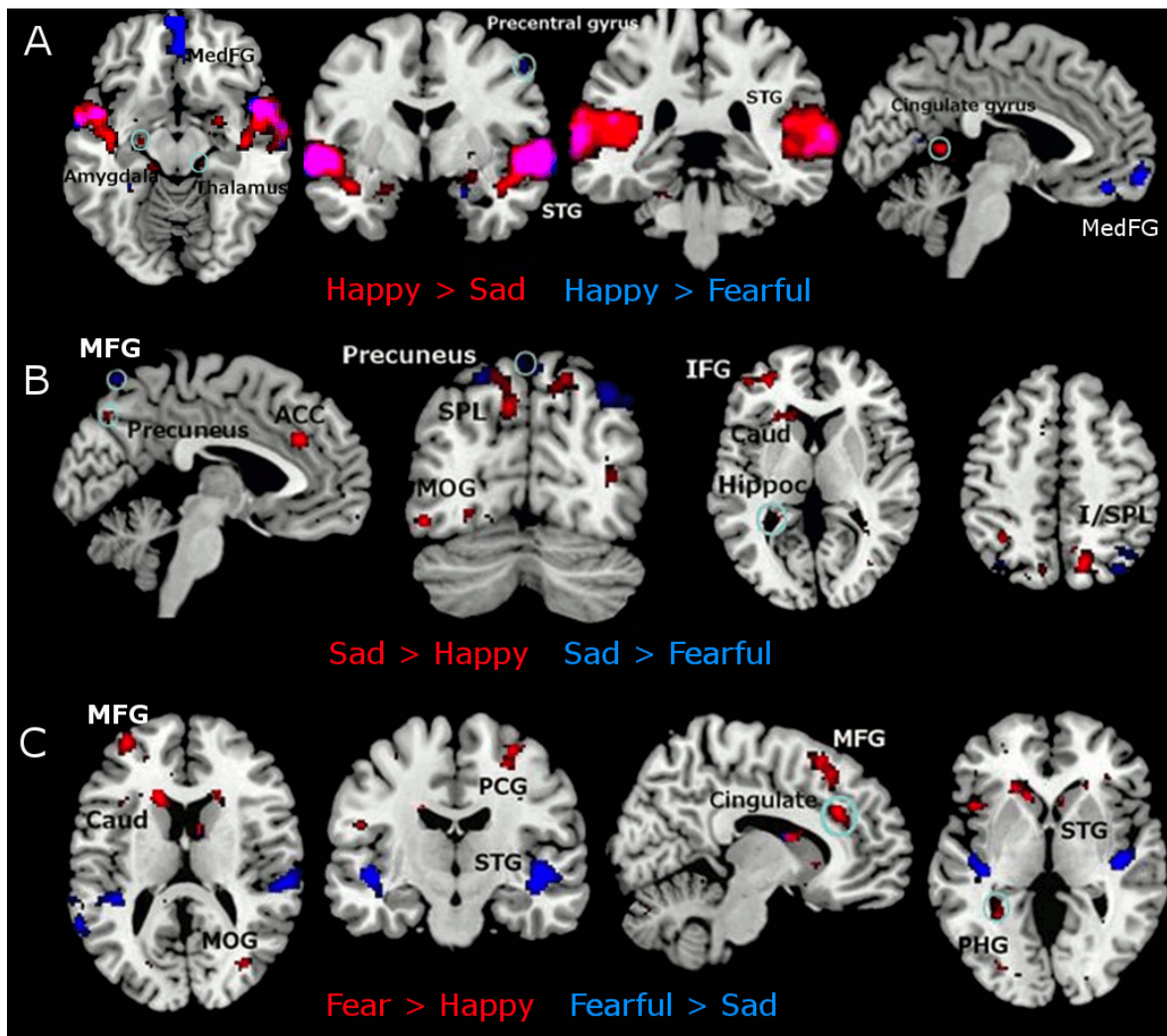


Figure 3. Brain activation during listening to happy (A), sad (B) and fearful (C) music. Abbreviations: Caud = caudate nucleus, Hippoc = hippocampus, IFG = inferior frontal gyrus, I/SPL = inferior/superior parietal lobule, MedFG = medial frontal gyrus, MFG = middle frontal gyrus, MOG = middle occipital gyrus. PCG = precentral gyrus, PHG = parahippocampal gyrus, STG = superior temporal gyrus. Activations were considered significant at $p < 0.001$, $Z > 3.5$ and $k > 26$.

3.3 Effects of processing type: implicit and explicit

As illustrated in the Figure 4, the contrast **implicit > explicit** showed activation in cortical areas, such as the bilateral middle/inferior frontal and temporal gyri, superior/inferior parietal lobule and cingulate cortex, and also in the right fusiform gyrus, postcentral gyrus and insula. Subcortically activation was found bilaterally in the caudate and parahippocampal gyrus as well as in the right medial dorsal nucleus of thalamus. In addition, activation was found in the cerebellum (bilaterally in culmen and uvula, in right pyramis and in left cerebellar tonsil).

As shown in Figure 4, the contrast **explicit > implicit** processing type revealed significant activation in cortical areas, such as the bilateral medial/inferior occipital and frontal gyri, bilateral insula, right superior temporal gyrus, left cingulate cortex and left precentral gyrus. Subcortically activation was found in the right claustrum. Locations and magnitudes of the activations can be found in Appendix 3.

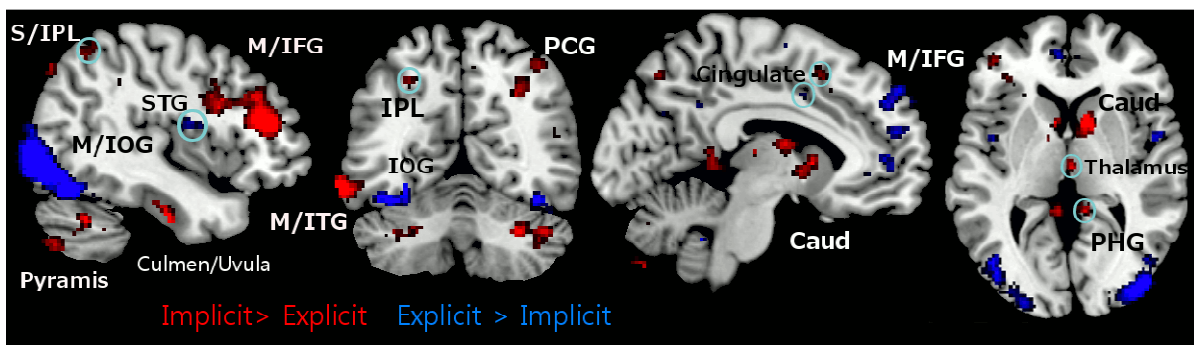


Figure 4. Brain activation during implicit and explicit processing of musical emotions. Abbreviations: Caud = caudate nucleus, M/IFG = middle/inferior frontal gyrus, M/IOG = middle/inferior occipital gyrus, M/ITG = middle/inferior temporal gyrus, PCG = precentral gyrus, PHG = parahippocampal gyrus, S/IPL = superior/inferior parietal lobule, STG = superior temporal gyrus. Activations were considered significant at $p < 0.001$, $Z > 3.5$ and $k > 26$.

3.4 Effects of personality

Neuroticism scores showed significantly positive correlation with the BOLD-signal in the left superior temporal gyrus in explicit processing of sadness and fear, left caudate body and left culmen of cerebellum while implicitly processing happiness, and left frontal cortex

while explicitly processing fear (Table 1 and Figure 5A). **Extraversion** correlated negatively with fMRI activity in the subcortical areas of caudate and amygdala while explicitly processing happy music (Table 1 and Figure 5B). **Openness** was positively correlated with activation in the right inferior occipital gyrus while implicitly processing happy and sad music and left fusiform gyrus while implicitly processing happy music (Table 1 and Figure 5C).

In the *PPI-analysis*, the group of high extraversion showed more connectivity between the right amygdala and widespread brain areas while processing fearful music, whereas the group of low extraversion showed more connectivity of the right amygdala with frontal and parietal areas while processing sad music (Figure 6).

Table 1. Pearson's r correlation coefficients between personality scores and signal change in ROI-areas. Signal change is extracted from Main Effect of Processing or Main Effect of Emotion. Brain areas are reported in MNI-coordinates.

ROI-area	Condition	x	y	z	r	p
NEUROTICISM						
Left STG	Sad explicit	-46	-16	-4	.52	.004
Left STG	Fearful explicit	-46	-16	-4	.55	.002
Left Caudate Body	Happy implicit	-14	22	14	.49	.007
Left MFG	Fearful explicit	-6	18	48	.63	<.001
Left Culmen	Happy implicit	-24	-64	-32	.49	.007
EXTRAVERSION						
Right Amygdala	Happy explicit	18	-6	-18	-.48	.008
Right Caudate	Happy explicit	10	10	2	-.57	.001
OPENNESS						
Right IOG	Happy implicit	42	-76	-10	.49	.005
Right IOG	Sad implicit	42	-76	-10	.47	.008
Left FusG	Happy implicit	-38	-50	-22	.48	.006

STG = superior temporal gyrus, MFG = medial frontal gyrus, IOG = inferior occipital gyrus, FusG = Fusiform gyrus

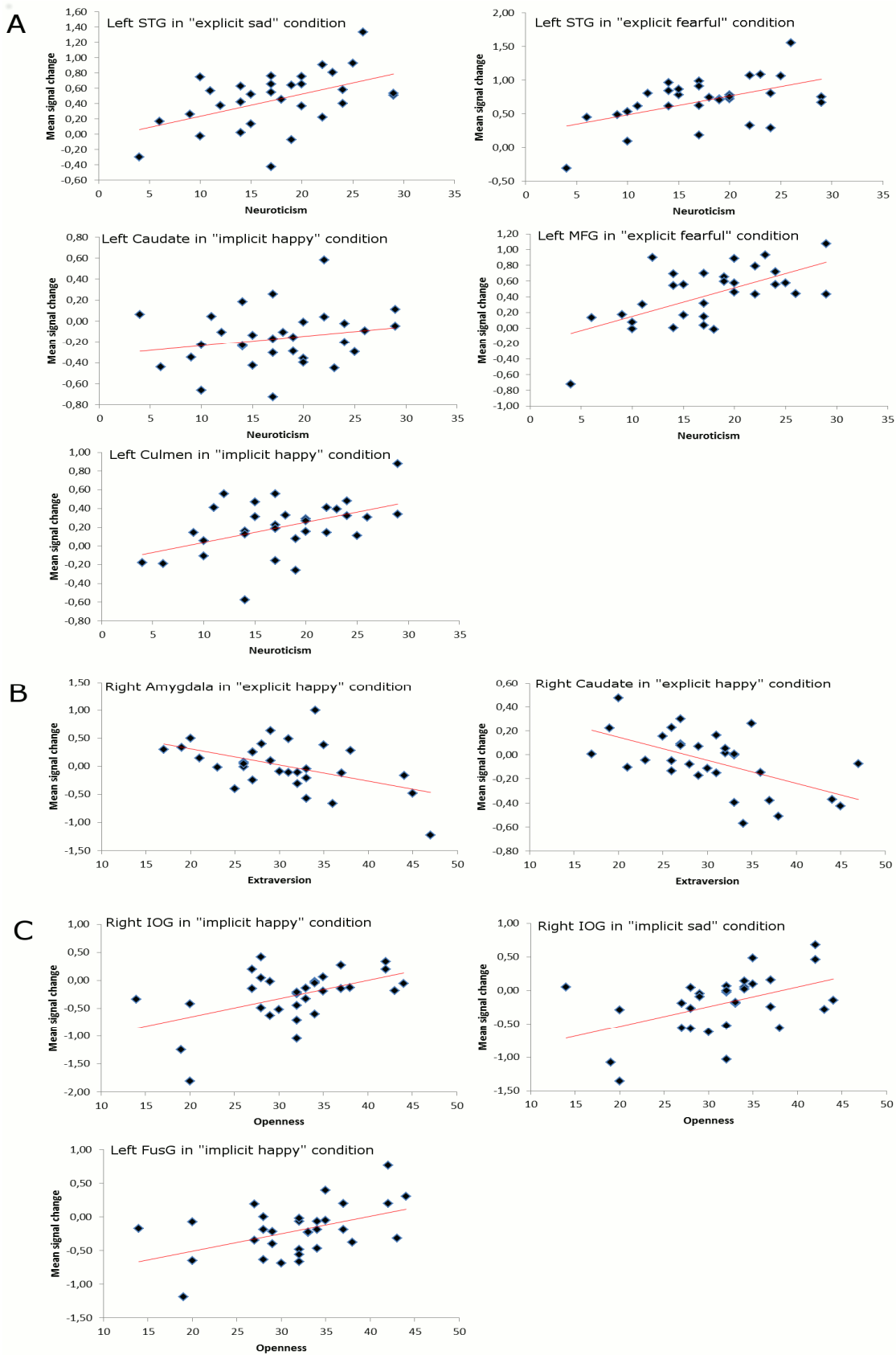


Figure 5. Correlations between signal change in ROI-areas and neuroticism (A), extraversion (B) and openness (C). FusG = Fusiform gyrus, IOG = inferior occipital gyrus, MFG = medial frontal gyrus, STG = superior temporal gyrus

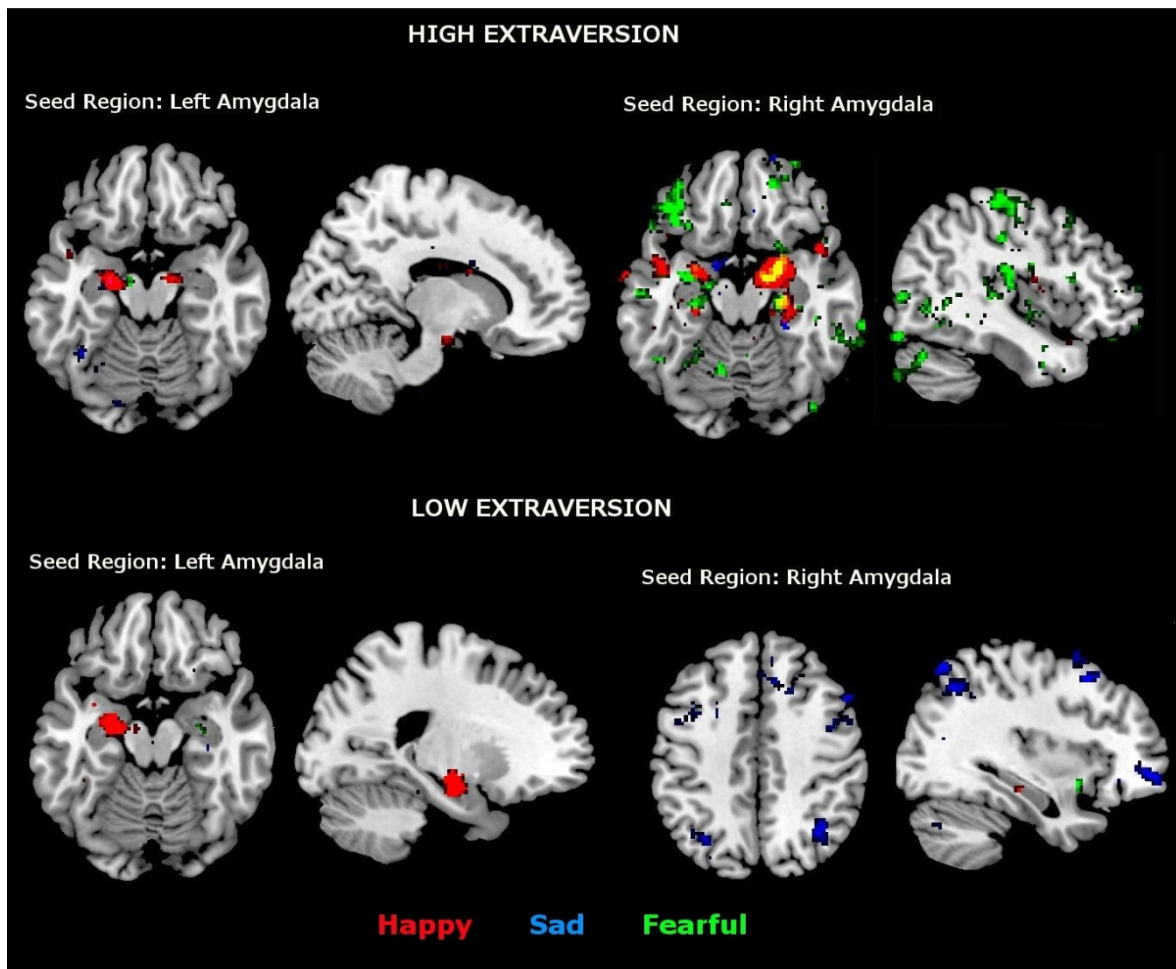


Figure 6. The results of the Psychophysiological Interaction Analysis (PPI) for the seed regions of right and left amygdala while contrasting listening to happy, sad and fearful music to baseline in groups of low and high extraversion. Activations were considered significant at $p < 0.001$ and $k > 10$.

4 Discussion

The present study contributes to the knowledge of the effect of personality on the processing of musical emotions, while also shedding light on the brain bases of the processing of different musical emotions and the implicit and explicit processing of musical emotions. Music is a powerful channel for conveying emotions (Peretz, 2006). Still, the knowledge of processing types of music and the effect of individual characteristics on music processing has been limited. The present study lends support to the notion that the processing of happy music activates auditory areas and the processing of sad music limbic and frontal areas. We also discovered that the two processing types studied differ with regards to the brain activations elicited. As was expected, implicit processing of musical emotions seems to recruit both cortical and subcortical brain areas, whereas explicit processing recruits only cortical areas. Moreover, we found the processing of musical emotions to depend on personality traits. Neuroticism correlated positively with the activation in temporal and frontal areas while processing explicitly negative musical emotions, and subcortical areas when processing implicitly happy music. Extraversion was found to correlate negatively with the activity of subcortical areas while processing explicitly happy music. Lastly, Openness was positively correlated with activity in the occipital areas while implicitly processing happy and sad music.

4.1 The neural correlates of musical emotions

In accordance to our hypothesis and the study of Mitterschiffthaler et al. (2007), listening to happy music was correlated with activation in the superior temporal gyrus. Besides its important role in sound, speech and language processing (Howard et al., 2000), this area has also been linked to the processing of happiness (Vytal & Hamann, 2010), happy faces (Fusar-Poli et al., 2009), and melody (Liégeois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998). Activation was also found in the right medial frontal gyrus, an area that has been related to processing of happy faces (Talati & Hirsch, 2005) as well as to high-level executive functions and decision-related processes (Fusar-Poli et al., 2009).

In addition, activation when listening to happy music was found in the subcortical areas of bilateral amygdala, posterior cingulate cortex and right thalamus. This is in accordance

with the study of Koelsch et al. (2013) in which increased activity was found in the bilateral amygdala when processing joyful compared to fearful music. In addition, the amygdala and posterior cingulate, which are part of the limbic system, have been found to activate while processing emotional music (Mitterschiffthaler et al., 2007) and emotions from faces (Fusar-Poli et al., 2009), and decreased activity in the amygdala as well as increased activity in the right thalamus has been linked to experiencing chills while listening to pleasant music (Blood & Zatorre, 2001). Activity in the thalamus has also been previously correlated with regulating arousal (Paus, 2000) and experiencing unpleasant emotions (Moll et al., 2002).

The amygdala is most commonly associated with the processing of fear and anxiety (Adolphs, 2002; Phan, Wager, Taylor, & Liberzon, 2002), and therefore it is interesting that amygdala activation was found in our study when contrasting happy over fearful music. This difference might be explained by differences in methods. Amygdala has been shown to activate in response to all emotional stimuli and to have a general role in the detection of biologically, socially and affectively relevant information, with stronger activation for faces than other visual stimuli (Adolphs, 2002; Feinstein, Adolphs, Damasio, & Tranel, 2011; Pape & Pare, 2010; Sergerie, Chochol, & Armony, 2008). In addition, amygdala activity might differ in response to the processing type of the stimulus, preferring implicit processing (Adolphs, 2002; Williams, McGlone, Abbott, & Mattingley, 2005). This implies that the reduction of amygdala's response while processing explicit information may be mediated by the inhibition of the amygdala by the frontal cortex (Adolphs, 2002). In our study, we used musical stimuli and both explicit and implicit modes of processing, which might have yielded these differing results.

In our study, processing of sad music was found to activate subcortical areas, such as the bilateral anterior cingulate cortex, left hippocampus and caudate head, and parts of the frontal cortex (superior, medial and inferior frontal gyri). This gave support to our hypothesis that sad music activates limbic and frontal cortical areas. Previous studies have found similar results concerning the anterior cingulate cortex (Green et al., 2008; Phan et al., 2002; Vytal & Hamann, 2010), left hippocampus (Green et al., 2008), caudate head (Brattico et al., 2011), and frontal gyri (Green et al., 2008; Mitterschiffthaler et al., 2007; Vytal & Hamann, 2010). In contrast to previous research, activation was also found in parietal areas of the cortex (superior parietal lobule and precuneus). The superior parietal

lobule has been previously associated with processing of emotional faces (Fusar-Poli et al., 2009), but also in decision making (Krain, Wilson, Arbuckle, Castellanos, & Milham, 2006) and visual attention (Culham & Kanwisher, 2001). Precuneus, an area that is closely connected to the superior parietal lobule, responds to a wide spectrum of tasks and functions, including visuo-spatial imagery, episodic memory retrieval and self-processing operations, namely first-person perspective taking and an experience of agency (Cavanna & Trimble, 2006). The activation of the precuneus in the processing of sad music could be due to the ability of sad music to stir memories. On the other hand, the precuneus has been found to activate in response to music with low activity and low fullness (Alluri et al., 2012), features that could possibly be more prominent in the sad music used in the present study. However, to ultimately understand the role of the precuneus in music-emotion processing, investigations combining musical emotion and feature analysis, and using longer stimuli would be needed.

In regards to fear, our hypothesis was not supported by the results of this study. In previous studies, processing of fear has mainly activated the amygdala (Gosselin et al., 2005; Park et al., 2013), though contradicting results have also been found (Koelsch et al., 2013). In our study, we did not find activation in the amygdala in relation to fearful music, though activation was present in the parahippocampal gyrus, an area closely related to the amygdala. Cortical activation was found in the bilateral middle frontal gyri, insula, precentral gyrus and inferior parietal lobule. These findings get partial support from previous research. The middle frontal gyri and insula, two areas tightly connected to the amygdala, have been found to activate in response to fearful faces (Fusar-Poli et al., 2009) as well as in overall processing of musical emotions (Mitterschiffthaler et al., 2007). Though activity of the insula, and specifically the anterior insula, is most often correlated with processing of disgust (Cisler, Olatunji, & Lohr, 2009), activation has also been observed in regards to general processing of fear (Vytal & Hamann, 2010). Indeed, because of its abundant connections with the sensory areas, inferior prefrontal cortex and amygdala, it has been suggested that the role of the insula would be to respond to potentially distressing cognitive stimuli (review: Husted, Shapira, & Goodman, 2006) and to integrate information from bodily sensations, individual traits and external context to produce a general feeling (Singer, Critchley, & Preuschoff, 2009). In this respect, the insula might be responsible in our study of the more distressing bodily sensations caused by fearful musical excerpts than by happy and sad ones.

The precentral gyrus and other motor areas have not been associated with the processing of fear in previous studies, although the supplementary motor cortex, together with the caudate gyrus, is associated with fear conditioning (Etkin, Egner, & Kalisch, 2011). In addition, the supplementary motor area and premotor cortex, together with the caudate nucleus and putamen, are activated while viewing bodily expressions of fear (De Gelder, Snyder, Greve, Gerard, & Hadjikhani, 2004). This implies that there is a strong link between fear and action even with aesthetic stimuli without a direct survival function like musical excerpts.

4.2 The neural correlates of implicit and explicit processing of musical emotions

The second aim of this study was to examine the neural correlates of implicit and explicit processing of emotions from musical stimuli. To our knowledge, this has not been studied before, so our hypothesis was based on the neural paths found in regards to visual stimuli and studies of prosody. Our hypotheses were partly confirmed. Explicit processing of emotional musical stimuli did recruit mainly cortical areas, while implicit processing recruited both cortical and subcortical areas. However, the brain areas activated in these processing types differed partly from previous findings.

In accordance to previous studies concerning facial stimuli (Critchley et al., 2000; Fusar-Poli et al., 2009), we found activation during implicit processing of musical emotions in the right insula, bilateral anterior cingulate cortex, and bilateral inferior frontal gyrus. Contrary to studies of visual domain, we did not find activation in amygdala. This might reflect amygdala's sensitivity to the implicit processing of facial stimuli (Adolphs, 2002), which could explain why amygdala did not activate exclusively in response to either of the processing types used in the present study. We also found activation in the superior parietal lobule and parts of the temporal lobe, that is, the same areas that, with the addition of inferior frontal gyrus and insula, were activated with the implicit processing of prosody (Bach et al., 2008; Frühholz et al., 2012). Other limbic structures, such as the anterior nucleus of the thalamus and parahippocampal gyrus, were also found active. Our results give support to the idea that implicit processing is dependent on a large network of frontal, limbic and insular areas. Since the superior parietal lobule has been found to respond to

implicit processing of music and prosody but not faces, this area might be exclusively related to auditory stimuli.

In regards to the results of the implicit paradigm, we cannot rule out the possibility that activity in the frontal and parietal areas reflect the more cognitively demanding nature of the task of implicit paradigm of counting the number of instruments compared to explicit paradigm of emotion recognition. Prefrontal cortex and intraparietal sulcus, which is located between the inferior and parietal lobule, are key structures in numerical cognitive tasks (review: Nieder, 2005). In addition, these areas are activated in response to increasing cognitive, especially attentional, demands (Culham, Cavanagh, & Kanwisher, 2001; Desai, Conant, Waldron, & Binder, 2006). Therefore, the cortical activity found in our study may also reflect the numeric nature of the paradigm or the possibly increased cognitive load in the implicit paradigm compared to the explicit paradigm.

Some additional areas were recruited during implicit processing in our study. The bilateral caudate nucleus, as mentioned before, is related to conditioning (Etkin et al., 2011), that is, implicit learning, as well as other reward-based learning (Haruno et al., 2004; Seger & Cincotta, 2005). Moreover, the caudate nucleus is activated in response to motivational behaviour, especially to changing motivational contexts (Delgado, Stenger, & Fiez, 2004). The activation of the caudate nucleus might thus express implicit learning or motivational effort made, since the task of recognizing the number of instruments is cognitively more difficult than the explicit task of recognizing emotions. Precuneus is related to for example episodic-memory retrieval and visuo-spatial imagery (Cavanna & Trimble, 2006). It is possible that processing the number of instruments in the excerpts allured the participants into imaging the instruments.

Interestingly, the implicit processing of musical emotions activated many parts of the bilateral cerebellum. The role of the cerebellum in cognitive processes is still somewhat unclear. The cerebellum has been associated with implicit learning and memory, especially the effort of retrieving memories (Desmond & Fiez, 1998). Most of the activation found in our study was in the vermis, the part of the cerebellum called “the limbic cerebellum” (Schmahmann, 2004). Damage to the vermis has been related to affective symptoms, such as blunting of emotions and disinhibited behaviour, and the size of the vermis correlates with ADHD and psychotic disorders (Schmahmann, 2004). Thus, vermis of cerebellum

seems a potential candidate for implicit processing of musical emotions, though more research is needed.

Explicit processing of musical emotions was found to activate mainly cortical areas, such as bilateral superior and medial frontal gyri, bilateral insula, and right superior temporal gyrus. Our findings concur with the research of Critchley et al. (2000) and Scheuerecker et al. (2007) on visual stimuli, and Frühholz et al. (2012) on prosody. In these studies greater superior temporal gyrus activation was observed for explicit than for implicit processing of emotional stimuli. Thus it seems likely that the superior temporal area is associated with the explicit processing of musical emotions as well as of faces and prosody. Moreover, frontal area activation has been observed previously in studies using faces (Fusar-Poli et al., 2009; Scheuerecker et al., 2007; Williams et al., 2006) and prosody (Bach et al., 2008; Frühholz et al., 2012) as a stimulus. The medial frontal cortex participates together with anterior cingulate cortex in the conscious experience of emotion, inhibition of excessive emotion, or monitoring one's own emotional state to make relevant decisions (review: Husted et al., 2006). Altogether, this implies that there is a cortical control while processing emotions explicitly.

Activation in the bilateral inferior occipital gyri, which is part of the visual area of the brain, was also observed in our study. This activation might be caused by the difference in visual stimuli in our paradigm. In the implicit paradigm, participants are shown on the screen the alternatives “one”, “two” or “many”, which are intuitively easier to remember and to act on than the emotions “sad”, “happy” or “fearful”. Therefore participants may have verified the order of the emotions after each musical excerpt and thus processed the visual stimuli more in the explicit paradigm than in the implicit paradigm. In the studies using visual emotional stimuli (Critchley et al., 2000; Fusar-Poli et al., 2009; Habel et al., 2007), activation was found in limbic areas (amygdala and hippocampus). We did not find such activation in our study. This is possibly due to differences in modalities. In accordance to our study, previous studies using auditory prosody stimuli (Bach et al., 2008; Frühholz et al., 2012) did not report finding limbic activation in response to explicit emotional processing.

4.3 The effect of personality on processing of musical emotions

As expected, there were many correlations between personality and brain areas responsible for processing of musical emotions, suggesting that personality has an important role in the neural processing of emotions conveyed in music. Neuroticism correlated with the activity of the left medial frontal gyrus when explicitly processing fearful music. This is in line with previous studies that have found activation in this area to correlate with neuroticism while processing negative stimuli (Canli et al., 2001; Servaas et al., 2013), sad facial expressions (Haas et al., 2008) and emotional prosody (Brück et al., 2011). In addition, the left superior temporal gyrus was found to activate while processing negative (both sad and fearful) musical emotions. This finding is also consistent with previous studies, where neuroticism has been associated with overall activity in this area (Deckersbach et al., 2006) as well as increased activity while processing sad expressions (Jimura, Konishi, & Miyashita, 2009) and suppressed activity while anticipating painful stimuli (Kumari et al., 2007).

Both the medial prefrontal cortex and the superior temporal gyrus have been found to participate in judging one's own and other individuals' emotional states (Ochsner et al., 2004). Since neuroticism is associated with a negative evaluation of oneself (Robinson & Meier, 2005), higher levels of negative affect (Robinson & Meier, 2005; Suls & Martin, 2005) and increased processing of negative information (Chan et al., 2007), our findings could reflect the negative bias of emotional information processing in neurotic individuals. This is supported by the behavioral evidence collected by Liljeström et al. (2012) where neuroticism was associated with experiencing more negative emotions when listening to music.

Subcortically, activation in regards to neuroticism was found in the left caudate body while processing implicitly happy music. Previous studies have found similar results: Park et al. (2013) observed caudate activation in response to happy music, and Brühl (2011) found similar activation during the anticipation of negative and positive stimuli. In our study, activation in response to implicit processing of happiness in neurotic individuals was found also in the culmen, part of the cerebellar vermis. Cerebellar volume has been found to covariate with neurotic personality (DeYoung et al., 2010; Schutter, Koolschijn, Peper, & Crone, 2012), and an association has been observed between the level of cerebellar activity

and neuroticism scores (Chan et al., 2007; Coen et al., 2011; Smith et al., 2002). This implies that neuroticism is associated with altered emotional processing. Individuals high on neuroticism experience greater arousal in response to emotional pictures (Norris, Larsen, & Cacioppo, 2007), and since happy music in our study could have been experienced as more arousing than sad musical stimuli (as evidenced by the arousal ratings of the stimuli used in the present study by Eerola & Vuoskoski, 2011), the activation of caudate and culmen could also reflect the arousing effect of the music. This hypothesis is supported by the study by Colibazzi et al. (2010), where increased activity of caudate and culmen were associated with highly arousing emotions.

In our study, extraversion was correlated with a decreased activity in the right amygdala and right caudate while processing explicitly happy musical emotion. This is in accordance with the previously found association between extraversion and positive emotions (Knyazev et al., 2008). Also, the negative correlation between extraversion and amygdala activation has been observed in response to fearful music (Park et al., 2013), humorous stimuli (Mobbs, Hagan, Azim, Menon, & Reiss, 2005), and positive conditioning (Hooker, Verosky, Miyakawa, Knight, & D'Esposito, 2008). In addition, low extraversion has been previously associated with the activity of the caudate nucleus (Fischer, Wik, & Fredrikson, 1997). There have also been opposite results: Canli et al. (2001) found increased activity in right amygdala in response to positive versus negative pictures. These contradicting results could be explained by the differing stimuli used in these studies: perhaps music and humor can induce stronger feelings than static 2D photos of unfamiliar faces.

The amygdala and caudate nucleus are interconnected and part of the reward circuit of the brain (Haber & Knutson, 2010), and amygdala activation is especially essential for the processing of emotional aspects of reward (Murray, 2007). In regards to music, this is seen in the activation changes in the caudate and amygdala in response to experiencing chills (Blood & Zatorre, 2001) and while processing pleasant and unpleasant music (Koelsch et al., 2006). On the other hand, listening to pleasurable music is found to activate the sympathetic nervous system, thus being pleasantly arousing (Salimpoor, Benovoy, Longo, Cooperstock, & Zatorre, 2009). Our finding of decreased activity in reward areas of the brain while listening to happy music in extroverts is in accordance to the personality theory of Eysenck (1967/2006). This theory suggests that introversion, that is, low scores on extraversion, is associated with lower response threshold and thus, especially under low

stimulation or easy tasks, introverts are more aroused than extraverts (review: Corr, 2004). This effect has been found also in previous research (e.g. Furnham & Strbac, 2002; Kumari, Ffytche, Williams, & Gray, 2004).

Furthermore, in the exploratory analysis of connectivity between the amygdala and other brain areas in low and high extraversion groups, the low extraversion individuals showed enhanced connectivity of right amygdala while processing sad music, whereas the high extraversion individuals showed enhanced connectivity while processing fearful music. The increased activity of introverted individuals while processing sad music is consistent with the behavioral study by Ladinig and Schellenberg (2012). In their study, introversion correlated with tendency to like music that induces sadness. This could be understood as a preference of the introverted individuals to non-social and reflective music compared to popular or easy listening music. The relationship between extraversion and increased connectivity while processing fear in music is novel in the literature. It could reflect the preference of extraverts to high-arousing stimuli, even when it is aversively arousing. Individuals high on extraversion have been found to prefer energetic and rhythmic musical stimuli (Chamorro-Premuzic, Fagan, & Furnham, 2010; Kallinen & Ravaja, 2004; Rentfrow & Gosling, 2003; Rentfrow & Gosling, 2006), that is, arousing musical stimuli. In addition, the subscale of extraversion called excitement seeking is closely related to the trait sensation seeking (Aluja, García, & García, 2003), which has been related to liking for more arousing music styles such as heavy metal, hard rock and rap (McNamara & Ballard, 1999; Rawlings & Furnham, 2000).

Interestingly, in our study neuroticism correlated exclusively with the activation in the left hemisphere whereas extraversion correlated with reduced activity in the right hemisphere. This is contrary to the traditional 'valence lateralization hypothesis' of the brain, in which the left hemisphere is associated with positive emotions, approach tendencies and mania, whereas the right hemisphere is associated with negative feelings, withdrawal tendencies and depression (Demaree, Everhart, Youngstrom, & Harrison, 2005). However, there are also studies that have found results similar to ours. Neuroticism has been associated with a thinner cortex mantle in the left orbitofrontal cortex (Wright et al., 2006), alterations in posterior left hemisphere functioning while processing visual stimuli (Compton & Weissman, 2002) and left side activity while processing emotional pictures (Canli et al., 2001; Gale, Edwards, Morris, Moore, & Forrester, 2001). In addition, subjects high on

negative affect, a trait closely related to neuroticism, have greater left temporal cortical activation while resting (Hagemann et al., 1999). Extraversion is correlated with thinner cortical gray matter ribbon in right prefrontal cortex and fusiform gyrus (Wright et al., 2006), right prefrontal cortex and cingulate cortex activity during cognitively challenging tasks (Kumari et al., 2004), and right hemisphere activity while processing non-verbal human emotional sounds (Smith et al., 1995). Thus, our results concur with the meta-analysis by Wager, Phan, Liberzon, and Taylor (2003) in that lateralization of emotional activity seems to be more complex than the ‘valence lateralization hypothesis’ has previously suggested.

Openness to experience was found to correlate in our study with the activity of the inferior occipital gyrus and the fusiform gyrus. These areas are most often associated with the processing of faces (Gauthier et al., 2000; Rossion, Schiltz, & Crommelinck, 2003), but there are studies that have found both the fusiform gyrus and the inferior occipital gyrus to activate in response to emotional processing. For example, fearful faces compared to neutral faces (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002) as well as happy and fearful dynamic expressions compared to happy and fearful static faces have been found to activate both the fusiform gyrus and the inferior occipital gyrus (Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004). In addition, visual emotional stimuli together with musical stimuli compared to visual stimuli alone have been found to yield increased activation in the fusiform area (Baumgartner, Lutz, Schmidt, & Jäncke, 2006).

Openness to experience has been correlated previously with the ability to recognize emotions from facial expressions and sentences (Matsumoto et al., 2000; Terracciano, Merritt, Zonderman, & Evans, 2003). Also, openness is negatively correlated with alexithymia, that is, a disorder characterised by difficulties in identifying feelings and expressing feelings to others (Luminet, Bagby, Wagner, Taylor, & Parker, 1999). In regards to music, openness is related to the intensity of musical emotions (Liljeström et al., 2012; Vuoskoski & Eerola, 2011a), and experiencing chills is described as one of the best markers of openness (McCrae, 2007). Since open individuals seem more prone to experiencing emotions, it is possible that these emotion sensitive areas would be more active while processing musical emotions. Still, to our knowledge, there is only one other study that has reported correlations between openness and emotion processing. In the study of Hooker et al. (2008), openness was related to left inferior temporal gyrus activation

while observationally learning through associating fearful or happy expressions to objects. Therefore, the activation between openness and the processing of musical emotion warrants more investigation.

4.4 General discussion

The present study is the first to demonstrate the impact of personality on the implicit and explicit processing of musical emotions. This is the first step to understanding the individual differences in the processing of musical emotions. Our study contributes to the increasing body of evidence showing that neuroticism is associated with negative bias in the emotional information processing, extraversion is associated with low arousal and that open individuals are more prone to experiencing emotions as evidenced by their brain activity.

Understanding the brain base of the processing of musical emotions and the individual differences contributing to this processing is crucial for the use of music in an efficient way in the clinical context and for receiving predictable and measurable treatment results. Emotions influence the behavior on many levels, for example by affecting perception, attention, memory, and social functioning (Dolan, 2002; Keltner & Kring, 1998). Music is a powerful tool to elicit emotions, which may hence influence behavior (review: Thaut & Wheeler, 2010). Therefore, it is not surprising that music is used successfully in the treatment of autism (Whipple, 2004), depression (Erkkilä et al., 2011; Maratos, Gold, Wang, & Crawford, 2008) and dementia (Koger, Chapin, & Brotons, 1999) as well as in enhancing recovery after stress (Chafin, Roy, Gerin, & Christenfeld, 2004; Khalifa, Bella, Roy, Peretz, & Lupien, 2003), cerebral stroke (Särkämö et al., 2008) and surgery (Nilsson, Unosson, & Rawal, 2005).

New innovations in health care make it possible to use the knowledge of emotional processing directly to enhance the interventions. In the process of fMRI-based neurofeedback, the knowledge of brain bases of emotion processing is used to train the individual to control their own brain activations in specific brain areas processing positive emotions (Johnston et al., 2011). This self-control of emotions could potentially be used in

clinical settings, for example, in the interventions of affective disorders (Johnston et al., 2011).

In addition, new perspectives on health care open up possibilities to use the knowledge of brain processing of musical emotions to support recovery. The emerging model of integrative medicine has redefined the service of the health care system to include responding to the emotional needs as well as to the physical symptoms of the patient (Hanser, 2010). Since music can be used to reduce pain, relieve symptoms and decrease arousal (review: Hanser, 2010), music could be incorporated into the health care culture as an inexpensive way to enhance the quality of life of patients. The present study aids these clinical efforts in providing information about the neurological bases of emotion processing and thus provides means for building these interventions on an evidence-based ground.

Outside the clinical context, music can be used to advance the well-being of individuals in the everyday life. Our results show that the emotions in music are processed spontaneously by subcortical emotion-related structures even when we are not concentrating on the music. Even mild positive mood can affect cognitive processing, for example by improving creative problem solving, facilitating recall and changing strategies used in decision-making (review: Ashby, Isen, & Turken, 1999), though this might happen at the cost of increased distractibility (Dreisbach & Goschke, 2004; Gold, Frank, Bogert, & Brattico, 2013). Since listening to happy music can increase our positive mood (Husain, Thompson, & Schellenberg, 2002), it could be possible to affect mood with background music. So far studies concerning the effects of background music on performance in schools and work places have yielded contradicting results (Kämpfe, Sedlmeier, & Renkewitz, 2011). Still, there is evidence that listening to music may enhance the learning of children with special educational needs (Hallam & Price, 1998; review: Črnčec, Wilson, & Prior, 2006), especially by reducing arousal and inducing positive mood (Tesoriero & Rickard, 2012; review: Črnčec et al., 2006). Our results suggest that this process is influenced by personality, which is an important factor to take into consideration while implementing interventions using background music.

There are some limitations to our study. First, executing a study using musical stimuli inside the fMRI scanner is demanding for the reasons listed previously. The noise made by

the scanner could attenuate the emotional power of music and thus, influence the results of our study. Still, the results found were equivalent to the results of previous studies, which implies that the participants were able to process the musical stimuli. Second, the influence of musical background was not taken into account in this thesis. Though only participants without formal musical training were recruited, even non-musician might have differing musical backgrounds and the amount of music consumption may differ significantly. Still, this research project is ongoing and the information regarding musical background is being collected. Third, the participants of this study were recruited mainly through university mailing lists, which may have resulted in a sample of highly educated participants. Thus we cannot rule out that the possible analytical education of participants could have affected the results. Fourth, the paradigms were not counterbalanced, which means that all participants performed implicit paradigm first. This was done to avoid the transfer effects between conditions. However, new data with the reverse order is now being collected to rule out the possible effect of block order on the results. Fifth, the PPI results were derived using multiple t-tests from an exploratory analysis with relatively few subjects. Therefore, future research will be required to confirm the results. Last, we did not analyze the answers to the questions regarding recognition of emotions or number of instruments. This could have helped in understanding the individual variation of responses and ensure the correct explicit recognition of emotions.

Still, this research is the first to explore the relationship between personality and the implicit and explicit processing of musical emotions. This study expands knowledge of the processing of musical emotions by examining fear in addition to happy and sad emotions, which were the only emotions explored in previous studies. Also, our results highlight the importance of considering the personality of subjects when studying the processing of music and implementing interventions using musical stimuli.

4.5 Conclusion

In summary, the current study is the first to shed light on the implicit and explicit processing of basic musical emotions and the effect of personality on this processing. Our results suggest that the processing of happy music activates auditory areas, the processing of sad music activates limbic and frontal areas and the processing of fearful music activates the parahippocampal gyrus, middle frontal areas, insula and motor areas. When processing musical emotions implicitly, both cortical and subcortical brain areas are recruited. On the contrary, explicit processing recruits mainly cortical areas.

Our results show that the processing of musical emotions depends on personality traits. Neuroticism was associated with increased activity in the left prefrontal and superior temporal cortex while processing negative musical stimuli. Subcortically, activation in regards to neuroticism was found in the left caudate body and cerebellar vermis while processing happy music. Extraversion was associated with decreased activity in the right amygdala and caudate while processing happy musical stimuli. Openness to experience correlated with the activity of the inferior occipital gyrus and the fusiform gyrus while processing happy and sad musical stimuli. These results offer perspectives and evidence base for the applied use of music in health care and educational settings. In addition, this research underlines the importance of taking into account the effect of personality when conducting studies on musical emotion processing.

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Appendices

Appendix 1: The main effects of emotions and processing

Anatomical labels of the main effects of emotion and processing, MNI-coordinates, and Z-score of global maxima within clusters of significant activations ($p < 0.001$; $Z > 3.5$; $k > 26$ with k standing for number of voxels: distance between clusters $> 8\text{mm}$). H = Hemisphere, BA = Brodmann area, L = left, R = right

Brain Region	H	BA	Z	k	x	y	z
MAIN EFFECT OF EMOTION							
Superior Temporal Gyrus	R	22/41	Inf	4312	52	-8	-2
Superior Temporal Gyrus	L	22/41	Inf	4136	-46	-16	-4
Anterior Cingulate	R	32	5.38	118	10	30	28
Amygdala	L	*	5.23	136	-18	-8	-18
Caudate Body/Head	L	*	4.91	276	-14	22	14
Medial Frontal Gyrus	L	11	4.76	361	0	66	-10
Medial Frontal Gyrus	L	8	4.67	127	-6	18	48
Amygdala	R	*	4.67	49	18	-6	-18
Superior/Middle Frontal Gyrus	L	*/10	4.47	141	-30	48	6
Insula	L	13	4.47	56	-46	14	2
Anterior Cingulate	L	32	4.45	86	-6	32	28
Caudate Body	R	*	4.43	46	8	2	16
Middle Frontal Gyrus	R	6	4.23	72	56	4	44
Precuneus/ Superior Parietal Lobule	R	7	4.10	95	14	-66	50
Medial/Superior Frontal Gyrus	R	8/6	4.06	92	8	28	52
Hippocampus	L		4.01	25	-30	-42	0
Precentral Gyrus	R	6	4.00	34	30	-14	62
Caudate Body	L		3.97	31	-12	-6	24
Superior Occipital Gyrus	R	19	3.95	40	34	-74	12
Postcentral Gyrus	L	3	3.91	40	-42	-26	60
Middle Frontal Gyrus	R	6	3.82	36	30	-2	52
Superior Parietal Lobule/ Precuneus	L	7	3.63	40	-18	-74	56
MAIN EFFECT OF PROCESSING							
Inferior/Middle Occipital Gyrus/ Declive	R	19	6.75	1517	42	-76	-10
Middle/Inferior Frontal Gyrus	R	46/9	6.29	943	46	38	20
Fusiform/Inferior Occipital Gyrus	L	37/19	6.07	1376	-38	-50	-22
Inferior/Middle Frontal Gyrus	L	9/6	5.73	290	-44	10	30
Caudate Head/Body	R	*	5.49	252	10	10	2
Inferior/Middle Temporal Gyrus	L	37/20/21	5.21	201	-64	-60	-10
Culmen/Uvula	L	*	5.10	106	-24	-64	-32
Inferior Temporal Gyrus	R	20	5.10	91	60	-38	-18
Fusiform Gyrus	R	20	5.06	62	42	-14	-32
Precuneus	L	7/19	4.91	122	-24	-82	44
Inferior Parietal Lobule/	R	40/2	4.90	213	48	-42	56

Postcentral Gyrus							
Culmen/Tuber/Cerebellar Tonsil	R	*	4.89	127	30	-64	-32
Superior Frontal Gyrus	L	6	4.88	142	-26	4	58
Uvula	R	*	4.86	133	12	-84	-50
Middle Frontal Gyrus	L	46	4.63	69	-44	48	8
Middle/Superior Frontal Gyrus/ Inferior Parietal Lobule	R	6/40	4.59	217	32	14	62
Inferior Parietal Lobule	L	40	4.54	59	-48	-44	50
Caudate Head/Anterior Nucleus (Thalamus)	L	*/*	4.52	146	-8	10	4
Precuneus/Superior/Inferior Parietal Lobule	R	19/7/40	4.39	388	32	-70	40
Superior/Medial Frontal Gyrus	L	9	4.36	457	-14	48	28
Cingulate Gyrus	L/R	32	4.35	124	-2	20	44
Posterior Cingulate	L	29	4.35	49	-4	-44	8
Middle/Inferior Frontal Gyrus	L	46	4.29	109	-48	34	28
Superior/Middle Temporal Gyrus	R	39	4.25	78	52	-64	20
Pyramis	R	*	4.23	53	44	-76	-46
Insula	R	13	4.18	33	48	-26	24
Superior Temporal Gyrus/ Insula/Clastrum	R	22/13	4.17	73	52	2	6
Medial Dorsal Nucleus (Thalamus)	R	*	4.15	46	6	-14	10
Anterior Cingulate/Medial Frontal Gyrus	L/R	32/10	4.05	79	-4	46	8
Inferior Semi-Lunar Lobule	L	*	4.05	26	-22	-76	-50
Cerebellar Tonsil	L	*	3.97	31	-20	-46	-48
Superior Parietal Lobule/Precuneus	L	7	3.95	42	-26	-64	46
Cuneus	R	19	3.90	45	16	-94	30
Middle Temporal Gyrus	R	21	3.81	27	72	-48	-2
Middle Frontal Gyrus	R	6	3.80	35	48	12	54
Precentral Gyrus	L	4	3.60	26	-26	-26	64

Appendix 2: The contrasts between emotions

Anatomical labels of contrasts between emotions based on center of mass, MNI-coordinates, and Z-score of global maxima within clusters of significant activations ($p < 0.001$; $Z > 3.5$; $k > 26$ with k standing for number of voxels: distance between clusters $> 8\text{mm}$). H = Hemisphere, BA = Brodmann area, L = left, R = right

Brain Region	H	BA	Z	k	x	y	z
HAPPY VS. SAD							
Superior Temporal Gyrus	R	22/41	Inf	4962	52	-8	-2
Superior Temporal Gyrus	L	22/41	Inf	4850	-46	-16	-4
Parahippocampal Gyrus/Amygdala	L	34/28	5.61	216	-18	-10	-22
Middle Frontal Gyrus	R	6	4.58	118	56	6	42
Amygdala	R	*	4.31	79	26	0	-12
Posterior Cingulate/Culmen/Posterior Cingulate	L/R/R	29*/29	4.23	94	-4	-48	6
Thalamus	R	*	4.19	28	14	-28	-6
Medial Frontal Gyrus	R	10	4.03	43	10	70	10
Parahippocampal Gyrus	L	35	3.99	37	-16	-28	-14
Parahippocampal Gyrus	L	36	3.99	27	-40	-22	-26
Medial Frontal Gyrus	R	10	3.72	36	2	62	28
HAPPY VS. FEARFUL							
Superior Temporal Gyrus	R	22	Inf	2732	58	2	-6
Superior/Middle Temporal Gyrus	L	22/21	7.44	2109	-54	-6	-2
Medial Frontal Gyrus	L	11	5.25	660	0	66	-10
Amygdala	R	*	4.85	62	18	-6	-18
Amygdala	L	*	4.55	78	-18	-6	-18
Posterior Cingulate	L/R	30/29	4.25	141	0	-54	18
Precentral Gyrus	R	6	4.10	53	54	0	48
Precentral Gyrus	L	6	3.91	32	-52	-6	50
Superior Parietal Lobule	L	7	3.65	36	-34	-72	52
SAD VS. HAPPY							
Anterior Cingulate	R	32	5.06	97	8	32	28
Precuneus	R	7	4.59	254	14	-66	50
Superior/Inferior Frontal Gyrus	L	10	4.51	149	-28	52	2
Anterior Cingulate	L	32	4.42	84	-4	32	28
Hippocampus/Parahippocampal Gyrus	L	*/30	4.34	57	-32	-44	0
Precuneus/Superior Parietal Lobule	L	7	4.23	154	-8	-74	44
Lingual Gyrus	L	19	4.19	37	-28	-68	-8
Middle Occipital Gyrus	L	19	4.08	31	-48	-72	-10
Posterior Cingulate/Middle Occipital Gyrus	R	30/19	3.88	56	32	-78	10
Caudate Head/Clastrum	L	*	3.69	74	-14	26	6

Superior Parietal Lobule	L	7	3.69	35	-32	-52	50
Middle Frontal Gyrus	L	46	3.68	61	-42	36	18
Superior Frontal Gyrus	L	11	3.64	37	-20	44	-16
Sub-Gyral	R	40	3.62	39	36	-48	36

SAD VS. FEARFUL

Angular Gyrus/ Superior/ Inferior Parietal Lobule	R	39/7/40	4.5	260	42	-66	36
Superior Parietal Lobule/ Precuneus	L	7	4.13	108	-20	-74	54
Medial Frontal Gyrus	R	11	4.07	48	2	38	-14
Precuneus	L	7	4.07	80	-2	-70	62
Superior Parietal Lobule	L	7	3.69	40	-36	-68	48
Medial Frontal Gyrus	L	10	3.48	26	0	58	-10

FEARFUL VS. HAPPY

Caudate Body/Head	L	*	5.35	535	-14	22	14
Anterior Cingulate/ Medial Frontal Gyrus/ Cingulate Gyrus	R /L/R	32/8/32	5.33	959	10	30	28
Insula/Inferior Frontal Gyrus	L	13/47	4.98	100	-46	14	2
Middle/Medial Frontal Gyrus	L	10/9	4.90	277	-34	54	10
Paracentral Lobule/ Superior/ Inferior Parietal Lobule	L	5/7/40	4.60	82	-22	-48	54
Caudate Body	L	*	4.48	81	-12	-6	24
Precentral Gyrus	R	6	4.45	95	30	-14	62
Caudate Body	R	*	4.45	167	8	2	16
Middle Occipital Gyrus/ Posterior Cingulate	R	37/30	4.37	131	34	-72	18
Middle Frontal Gyrus	R	6	4.37	180	30	-2	52
Caudate Head	R	*	4.33	110	14	18	-8
(Cerebellum (Lobule X))	R	*	4.28	27	16	-40	-40
Caudate Tail	R	*	4.24	122	34	-46	10
Superior Frontal Gyrus	L	11	4.19	31	-20	46	-14
Lingual Gyrus/ Middle Occipital Gyrus	L	17/18	4.04	106	-20	-84	2
Precuneus	L	31/7	4.02	55	-20	-78	20
Precuneus	R	7	4.02	26	20	-62	38
Parahippocampal Gyrus	L	30	3.94	36	-30	-50	0
Cuneus	R	17	3.77	31	22	-90	4
Postcentral/Precentral Gyrus	L	3	3.77	74	-42	-28	60
Cuneus	R	18	3.73	32	12	-84	26
Caudate Body/Head	L	*	5.35	535	-14	22	14

FEARFUL VS. SAD

Superior Temporal Gyrus/ Clastrum	L	22/21	7.06	1224	-46	-16	-6
Insula/ Superior Temporal Gyrus	R	22/13/21	6	594	46	-10	-8
Superior Temporal Gyrus/	R	41/42/40	5.94	667	52	-28	8

Inferior Parietal Lobule							
Postcentral Gyrus	L	3	4.28	77	-44	-24	60
Precentral Gyrus	L	44	4.15	28	-50	12	10
Middle Frontal Gyrus	R	6	4.07	26	40	2	48
Inferior/Middle Frontal Gyrus	L	47	4.02	90	-52	36	-8
Clastrum/Putamen	L	*/*	4	33	-30	4	8
Inferior Parietal Lobule/ Supramarginal Gyrus	L	40	3.88	39	-52	-44	32

Appendix 3: The contrasts between processing types

Anatomical labels of contrasts between processing types based on center of mass, MNI-coordinates, and Z-score of global maxima within clusters of significant activations ($p < 0.001$; $Z > 3.5$; $k > 26$ with k standing for number of voxels: distance between clusters $> 8\text{mm}$). H = Hemisphere, BA = Brodmann area, L = left, R = right

Brain Region	H	BA	Z	k	x	y	z
IMPLICIT VS. EXPLICIT							
Middle/Inferior Frontal Gyrus	R	46/9	6.39	1129	46	38	20
Inferior/Middle Frontal Gyrus	L	9/6	5.85	365	-44	10	30
Caudate Head/Body	R	*	5.61	296	10	10	2
Inferior/Middle Temporal Gyrus	L	37/20/21	5.34	238	-64	-60	-10
Culmen/Uvula	L	*	5.23	136	-24	-64	-32
Inferior Temporal Gyrus	R	20	5.23	124	60	-38	-18
Fusiform Gyrus	R	20	5.19	73	42	-14	-32
Precuneus	L	7/19	5.04	178	-24	-77	44
Inferior Parietal Lobule/ Postcentral Gyrus	R	40/2	5.03	281	48	-42	56
Culmen/Tuber/Pyramis	R	*	5.02	176	30	-64	-32
Superior/Middle Frontal Gyrus	L	6	5.02	207	-26	4	58
Uvula/Interior Semi-Lunar Lobule	R	*	5.00	242	12	-84	-50
Middle Frontal Gyrus	L	46	4.77	93	-44	48	8
Middle/Superior Frontal Gyrus	R	6	4.74	277	32	14	62
Inferior Parietal Lobule	L	40	4.68	89	-48	-44	50
Caudate Head/Anterior Nucleus (Thalamus)	L	*/*	4.66	189	-8	10	4
Precuneus/Superior/Inferior Parietal Lobule	R	19/7/40	4.54	566	32	-70	40
Cingulate Gyrus	L/R	32	4.50	167	-2	20	44
Posterior Cingulate	L	29	4.50	69	-4	-44	8
Middle/Inferior Frontal Gyrus	L	46	4.44	165	-48	34	28
Superior/Middle Temporal Gyrus	R	39	4.40	106	52	-64	20
Pyramis	R	*	4.38	69	44	-76	-46
Medial Dorsal Nucleus (Thalamus)	R	*	4.31	65	6	-14	10
Inferior Parietal Lobule	L	40	4.27	27	-42	-40	40
Parahippocampal Gyrus	R	30	4.26	27	10	-42	4
Cerebellar Tonsil	L	*	4.22	68	-26	-42	-36
Superior Parietal Lobule/ Precuneus	L	7	4.11	112	-26	-64	46
Parahippocampal Gyrus	L	35/28	4.10	28	-20	-22	-18
Sub-Gyral/Insula	R	47/13	4.02	29	28	24	-6
Middle Temporal Gyrus	R	21	3.98	45	72	-48	-2
Middle Frontal Gyrus	R	6	3.97	50	48	12	54
EXPLICIT VS. IMPLICIT							
Inferior/Middle Occipital Gyrus/ Declive	R	19	6.85	1848	42	-76	-10
Fusiform/Inferior Occipital Gyrus	L	37	6.18	1737	-38	-50	-22
Superior/Medial Frontal Gyrus	L	9	4.51	646	-14	48	28
Inferior Frontal Gyrus	R	47	4.5	29	36	20	-16

Insula	R	13	4.33	42	48	-26	24
Superior Temporal Gyrus/Insula/ Claustrum	R	22/13/*	4.33	120	52	2	6
Anterior Cingulate/Medial Frontal Gyrus	L/R	32*/10	4.21	122	-4	46	8
Cingulate Gyrus	L	24	4.1	38	-6	6	36
Cuneus	R	19	4.07	74	16	-94	30
Superior Frontal Gyrus	R	9	3.95	31	16	48	38
Insula	L	13	3.92	26	-36	-26	18
Precentral Gyrus	L	4	3.83	97	-22	-24	56
Middle Occipital Gyrus	R	19	3.69	31	30	-82	22

Appendix 4: The results of the PPI-analyses

Anatomical labels of emotions contrasted with baselines of participants with low and high extraversion based on center of mass, MNI-coordinates, and Z-score of global maxima within clusters of significant activations ($p < 0.001$; $k > 10$ with k standing for number of voxels: distance between clusters $> 8\text{mm}$). BA = Brodmann area, L= left, R=right

SEED REGION: LEFT AMYGDALA													
LOW EXTRAVERSION							HIGH EXTRAVERSION						
Brain Region	BA	Z	k	x	y	z	Brain Region	BA	Z	k	x	y	z
HAPPY							HAPPY						
L Lateral Globus Pallidus		6.51	327	-22	-14	-10	R Caudate Body		3.81	41	10	0	22
L Precentral Gyrus	6	4.03	11	-64	-14	44	L Caudate Tail		3.72	28	-14	-26	24
L Insula	13	3.32	28	-40	-10	14							
L Middle Frontal Gyrus	47	3.29	43	-52	40	-2							
SAD							SAD						
R Caudate Body		4.33	30	2	2	18	L Insula	13	4.27	15	-46	-26	24
L Caudate Body		4.04	13	-10	-8	26	L Fusiform Gyrus	37	4.04	17	-38	-56	-14
L Thalamus		3.34	14	-10	-22	22							
FEARFUL							FEARFUL						
L Precentral Gyrus	6	4.02	12	-68	-12	32	NO RESULTS						

SEED REGION: RIGHT AMYGDALA													
LOW EXTRAVERSION							HIGH EXTRAVERSION						
Brain Region	BA	Z	k	x	y	z	Brain Region	BA	Z	k	x	y	z
HAPPY							HAPPY						
L Red Nucleus		4.06	68	-4	-22	-16	R Inferior Frontal Gyrus	45	4.14	29	58	30	4
L Putamen		3.63	11	-28	-12	-10	L Caudate Tail		4.03	21	-26	-36	8
							R Insula	13	3.99	27	34	-40	18
							L Hypothalamus		3.80	40	-4	-2	-12
							L Caudate Head		3.58	11	-14	28	6
SAD							SAD						
R Middle Frontal Gyrus	8	4.46	153	34	16	50	R Cingulate Gyrus	24	4.68	27	6	0	34
R Middle Frontal Gyrus	10	4.14	84	32	50	-6	L Subcallosal Gyrus	34	3.82	17	-12	0	-14
R Superior Parietal Lobule	7	4.05	170	32	-68	58	L Insula		3.74	17	-32	20	0
R Inferior	40	3.87	170	36	-56	44	L Extra-Nuclear	13	3.73	15	-32	18	-12

Parietal Lobule														
L Superior Temporal Gyrus	38	4.00	22	-50	-2	-14	R Parahippoc. Gyrus	36	3.68	13	26	-34	-16	
L Middle Frontal Gyrus	6	3.94	27	-32	-2	50								
R Middle Frontal Gyrus	46	3.87	58	52	28	22								
R Caudate Body		3.86	24	16	14	14								
L Middle Frontal Gyrus	46	3.28	14	-38	34	22								
L Middle Frontal Gyrus	8	3.25	30	-24	16	50								
R Middle Frontal Gyrus	8	3.76	18	52	16	44								
R Uvula	6	3.76	11	16	-76	-44								
R Medial Frontal Gyrus	8	3.56	17	12	24	50								
R Medial Frontal Gyrus	8	3.29	27	2	30	42								
R Fusiform Gyrus	37	3.73	30	42	-56	-24								
L Superior Parietal Lobule	7	3.67	16	-14	-64	62								
L Superior Parietal Lobule	7	3.55	38	-30	-66	46								
R Tuber		3.52	11	52	-50	-30								
L Declive		3.49	22	-12	-76	-30								
R Superior Temporal Gyrus	22	3.47	14	70	-46	20								

FEARFUL

NO RESULTS

FEARFUL

R Parahippoc. gyrus/Amygdala	34	5.17	362	16	-6	-20
R Middle Occipital/ Temporal Gyrus	37	5.00	107	38	-68	-4
L Medial Frontal Gyrus /R Anterior Cingulate	10	4.83	233	-10	58	18
R Precentral Gyrus/ Middle Frontal Gyrus	6	4.83	737	26	-18	50
L Parahippoc. gyrus/Amygdala		4.83	238	-32	-6	-16
L Inferior Temporal Gyrus	20	3.84	234	-50	-54	-14
L Inferior Frontal Gyrus	44	4.76	155	-44	18	12
R Middle Temporal	21	4.70	181	64	-6	-4

Gyrus						
L Middle/Inferior						
Frontal Gyrus	11	4.65	494	-38	34	-18
R Caudate Tail		4.64	47	20	-44	14
R Cingulate Gyrus	31	3.76	47	16	-42	22
R Inferior Frontal						
Gyrus	45	4.62	28	46	20	16
R Insula	13	4.59	175	44	-20	20
L Middle Frontal						
Gyrus	10	3.30	68	-34	52	12
L Claustrum		4.48	51	-38	0	-2
R Precentral Gyrus	4	4.47	105	40	-22	38
R Pyramis/ Declive		4.47	533	12	-84	-34
R Caudate Body		3.44	23	16	4	16
L Thalamus		4.34	309	-8	-24	10
L Middle Temporal						
Gyrus	39	3.71	63	-28	-60	24
L Insula	13	3.62	89	-36	10	8
R Superior Frontal						
Gyrus	10	4.32	61	6	62	32
R Medial Frontal						
Gyrus/Cingulate						
gyrus	6	4.31	104	14	-4	62
R Middle Temporal						
Gyrus	39	4.30	40	52	-76	16
L Middle Temporal						
Gyrus	21	3.93	70	-64	-48	-2
L Inferior Temporal						
Gyrus	20	4.26	27	-44	-2	-48
L Middle Occipital						
Gyrus	19	4.26	42	-34	-78	12
L Middle Frontal						
Gyrus	6	4.25	46	-36	4	54
L Culmen		4.25	33	-12	-60	-14
L Putamen		3.67	49	-26	-10	16
L Precentral Gyrus	4	4.24	534	-34	-16	56
R Parahippoc. gyrus	19	4.23	21	26	-52	-4
L Pyramis/ Declive		4.23	212	-8	-74	-34
R Superior Frontal						
Gyrus	11	4.20	87	32	58	-10
R Superior						
Temporal Gyrus	41	4.17	97	38	-30	10
L Caudate Tail		4.15	37	-34	-26	-4
R Thalamus		4.14	78	4	-10	4
R Middle Frontal						
Gyrus	46	4.14	65	50	46	8
L Inferior Semi-						
Lunar Lobule		4.09	229	-16	-80	-48
L Anterior Cingulate	24	4.09	20	-10	22	30
R Inferior Frontal						
Gyrus	47	4.07	19	38	32	-4
R Medial Frontal						
Gyrus	10	4.04	17	12	40	-12
R Inferior Occipital						
Gyrus	18	4.01	25	42	-82	-18
R Middle Frontal						
	11	4.01	60	20	46	-18

Gyrus						
L Caudate Body		4.01	21	-20	-16	28
L Superior Frontal						
Gyrus	10	4.00	42	-30	56	0
R Claustrum		3.99	12	28	18	-6
R Cerebellar						
Lingual		3.95	80	6	-46	-12
L Inferior Parietal						
Lobule	40	3.68	46	-36	-38	32
R Putamen		3.93	61	28	-22	4
L Caudate Body		3.87	17	-20	20	18
L Superior Frontal						
Gyrus	8	3.83	63	-6	26	58
L Superior Parietal						
Lobule	7	3.77	54	-32	-50	62
L Precuneus	7	3.73	32	-16	-52	60
R Superior						
Temporal Gyrus	38	3.72	29	50	14	-20
R Inferior/ Middle						
Temporal Gyrus	20	3.71	25	48	-4	-38
R Medial Frontal						
Gyrus	8	3.67	21	4	30	46
L Fusiform Gyrus	20	3.67	30	-44	-22	-24
R Superior Frontal						
Gyrus	10	3.64	22	12	62	-8
R Middle Frontal						
Gyrus	8	3.60	24	46	16	48
R Culmen		3.54	11	34	-40	-34