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MUSIC AND EMOTION:

The Neural Correlates of Music-Induced

Positive Affect

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Title

Submitted by Anna-Karin Weivert to the University of Skövde as a final year project towards the degree of B.Sc. in the School of Bioscience. The project has been supervised by Pilleriin Sikka.

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I hereby certify that all material in this final year project which is not my own work has been identified and that no work is included for which a degree has already been conferred on me.

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Abstract

Listening to music is rated as one of the most pleasurable activities in human life and, in fact, listeners report the emotional impact of music to be one of the main motivators as to why they listen to music. This thesis focuses on the positive affective states experienced when listening to music and their underlying neural substrates. Despite the fact that research on the neural correlates of music-induced positive affect is a relatively recent undertaking our understanding has significantly improved during the last decades. The aim of the current thesis is to give an overview of the neural correlates of music-induced positive affect in healthy individuals. As such, psychophysiological, neuroimaging and electrophysiological studies are reviewed. Across studies the consistent involvement of brain regions, such as the orbitofrontal cortex, the striatum and the amygdala and left hemisphere frontal regions in response to music-induced positive affect has been found. These structures constitute an important part of the mesolimbocortical reward circuitry found to be involved in the processing of a wide range of pleasures. The thesis also discusses conceptual and methodological limitations inherent in the studies reviewed. Understanding the nature and underlying neural basis of music-induced positive affect is important because of the implications it may have for psychological and physical wellbeing.

Keywords: music, positive affect, EEG, fMRI, PET, ERP

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1. Introduction

For many people music plays a central role in daily life and with the invention of portable music devices it has never been as easily available as it is today (Skåneland, 2013). People report listening to music as a way of relaxing, to get into the right mood, to regulate their emotions or just for the pleasure of listening (Juslin & Laukka, 2004). In fact, listening to music has been reported to be one of the most pleasurable activities in human life (Dube & Le Bel, 2003). Music has been reported to induce more positive than negative affect with some of the most commonly reported emotions being calm, contentment, happiness and elation (Juslin, Liljeström,Västfjäll, Barradas, & Silva, 2008).

The ability of music to induce emotions is not completely agreed upon. The apparent lack of any clear goal implications or survival benefits of music has led some researchers to question its ability to induce emotions. Like those who emphasize the adaptive nature and survival value of emotions; that emotions are associated with specific action tendencies, for example, anger with the tendency to attack and fear with the tendency to escape (e.g., Konecni, 2008). However, based on accumulating theoretical and empirical research on the topic, most researchers today agree that music can induce a wide range of emotions, especially those of positive valence (for a review see Brattico, Bogert & Jacobsen, 2013; Juslin, 2013a).

In music and emotion research a distinction is generally made between perceived emotions and felt emotions. This distinction is based on the idea that music may both represent emotions (that are perceived by the listener) and induces emotions (that are felt by the listener) Perceived and experienced emotions may not always coincide. For example, music expressing happiness can induce happiness in the listener, but it can also induce a conflicting emotion, like frustration (Schubert, 2013). This thesis focuses on the positive emotions felt by the listener and their underlying neural substrates. The term positive affect is used because it includes not only positive emotions but also positive feelings, positive moods, preference, reward and pleasure that are all affective terms used, often interchangeably, in the literature.

Research on the neural correlates of music-induced positive affect is a relatively recent undertaking. So far mainly the pleasurable aspect of listening to music has been investigated. Using neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), it has been found that music activates the brain reward system also involved in pleasures such as food, sex and drugs (Chanda & Levitin, 2013). In other words, music seems to activate the evolutionarily old neural system that plays a crucial role in motivating the organism to engage in behaviors that increase the chance of survival (Berridge & Kringelbach, 2013a). Also, increased release of dopamine, a neurotransmitter involved in reinforcing behaviors with high adaptive value, has been reported during peak emotion when listening to music (Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). Electrophysiological studies have demonstrated greater left frontal activity in response to music-induced positive affect (Flores-Gutierrez et al., 2007; Schmidt & Trainor, 2001) which is in line with a great body of research demonstrating the role of this region in positive emotions and approach behavior in general (Davidson, 2004). Although great advances have been made in the neuroscientific study of music-induced positive affect, several inconsistencies remain. This is mostly due to methodological limitations that need to be addressed before any firm conclusions can be drawn.

The aim of this thesis is to give an overview of the neural correlates of music-induced positive affect in healthy individuals. This topic is important for our understanding of the neural correlates underlying positive affect (Kolesch, 2014) and the interaction between neural circuits involved in both fundamental and higher-order pleasures (Salimpoor & Zatorre, 2013). Additionally, music is a valuable tool for eliciting positive affect in experimental settings, in particular during functional neuroimaging when subjects are instructed to be completely still. Hence, studies investigating the neural basis of music-induced positive affect may help inform and develop research paradigms and methodologies (Kolesch & Siebel, 2005). Moreover, this topic is important due to the implications music might have for individual wellbeing as an inexpensive and easily available stimulus for eliciting positive emotions.

The thesis begins by providing clear definitions for the various positive affective terms. Next, the nature of music-induced positive affect and the underlying mechanisms that give rise to music-induced affect are discussed. Then, psychophysiological, functional neuroimaging, and electrophysiological studies investigating the neural correlates of music-induced positive affect are reviewed. And finally, the thesis ends with a discussion on the main findings and limitations of research reviewed as well as some suggestions for future directions.

2. Positive Affect

2.1 Definitions

There is a lack of consensual definitions and shared terminology in the scientific fields studying positive affect. As a result researchers use different conceptualizations for positive affect (Izard, 2010; Juslin & Västfjäll, 2008). Positive affect is often used as an umbrella term covering all positively valenced states, including positive emotion, positive mood, positive feeling, preference, reward and pleasure as well as aesthetic emotions (both implicit and explicit) (Juslin & Västfjäll, 2008). Below all these terms will be explained in more detail.

2.1.1 Positive emotion.

In an attempt to create greater clarity about the affective term emotion, Izard (2010) conducted a study in which he asked 35 prominent researchers representing various disciplines in emotion theory and research about the definition, nature, and function of emotions as well as processes that induce emotions (i.e., stimuli or events in the environment, memories, or social interactions). The results showed that there was no agreement among the researchers with regards to how emotions are defined. However, there was more consensus regarding the nature, function and induction of emotion. According to Juslin & Västfjäll (2008), researchers generally describe emotions as follows:

> Relatively brief, though intense, affective reactions to potentially important events or changes in the external or internal environment that involve several subcomponents: (a) cognitive appraisal (e.g., you appraise the situation as "*dangerous*"), (b) subjective feeling (e.g., *you feel afraid*), (c) physiological arousal (e.g., *your heart starts to beat faster*), (d) expression (e.g., *you scream*), (e) action tendency (e.g., *you run away*), and (f) regulation (e.g., *you try to calm yourself*) (p. 562).

As can be seen, emotion involves both implicit (unconscious) processes like increased physiological arousal that can be measured with psychophysiological measurements (see chapter 4.1) as well as explicit (conscious) processes like the subjective feeling of happiness (see chapter 2.1.2) (Izard, 2010).

Although there is agreement, at least to some extent, which components emotion involves, it is not clear whether emotions should be considered as discrete units or as dimensions. The categorical approach argues that emotions are discrete and based on distinct brain systems separated from each other (Izard, 2010). The concept of basic emotions is one type of categorical approach, which argues that all emotions have unique characteristics that are products of evolution for helping us deal with fundamental life-tasks (Ekman, 1992). Each emotion has its unique preceding event, physiological response and subjective experience. According to Ekman (1992), there are six basic human emotions, only one of which, happiness, is clearly positively valenced. The other four: sadness, anger, disgust and fear – are clearly negative, whereas surprise can be both, positively and negatively valenced. Ekman (1992) argues that the problem with positive emotions is that they do not have a distinctive signal value, relevant for survival.

Panksepp (2005) supports a biologically based basic emotions theory and argues that in order to understand the nature of emotions we must understand the brain systems that generate them. According to his view, all mammals share a number of discrete brain regions located sub-cortically (e.g., limbic structures) that underlie seven basic emotions: SEEKING/expectancy system, RAGE/anger, FEAR/anxiety, LUST/sexuality, CARE/nurturance, PANIC/separation and PLAY/joy. The SEEKING system of the brain processes emotions like positive excitement and euphoria and motivates seeking behavior in humans (Panksepp, 2005). This system has often been referred to as the wanting system (or incentive salience) which is the motivation to obtain a reward (see chapter 2.1.5) (e.g., Berridge & Kringelbach, 2008). The PLAY system involves positive social emotions, The LUST system generates positive emotions involved in the reward of sex and the CARE system involves positive emotions involved in nurturance and social bonding (Panksepp, 2005).

The dimensional approach suggests that emotions, similarly to the spectrum of colors, have no clear boundaries. In other words, people do not experience or recognize emotions as isolated, discrete entities; instead these often overlap and are experienced in interaction with each other (Posner, Russell, & Peterson, 2005). According to

Watson and Clark (1992 as cited in Posner, Russell & Peterson, 2005), people rarely describe feeling a specific positive emotion without also reporting other positive emotions. One well-known dimensional approach of emotions is the circumplex model of affect (Yik, Russell & Steiger, 2011). According to this theory emotions are described based on their simplest elements, so called core affect, which underlies all affective states. Core affect is a part of, but not the whole of emotions, and it is defined along dimensions of arousal (varying from low to high activation) and valences (ranging from unpleasant to pleasant). Core affect makes up an emotion when combined with physiological changes, certain cognitions and behaviors directed towards and an object or event. Positive emotions like energetic, excited, elated and enthusiastic includes core affect of pleasantness and high activation. Whereas positive emotions like peaceful, placid, tranquil includes core affect of pleasantness and low activation (Yik et al., 2011) (see Figure A1 in Appendix A).

2.1.2 Positive mood.

Moods are characterized as long-lasting affective states that might last from hours to days. Contrary to emotions that are often caused in response to something that is happening in the external or internal environment there might be no apparent reason for the emergence of moods. Furthermore, emotions require a lot of energy from the organism to mobilize in response to a potentially important event and need to be quick in order to not use all the resources of the organism. In contrast, low-intensity moods have little impact on behavior and can hence be maintained for much longer periods of time without any adverse effects (Scherer, 2005). Positive moods are long-lasting states of positive affective states such as being cheerful, joyful, happy and relaxed (Diener & Diener, 1996; Scherer, 2005).

2.1.3 Positive feeling.

Feelings are a sub-component of emotions and moods representing the subjective explicit emotional experience (Juslin & Västfjäll, 2008; Scherer, 2005). Whereas an emotion is evoked in response to something that is happening in the external or internal environment, a feeling is the cognitive understanding of what it is that is happening (to make sense of mental and bodily changes). Self-reports, one of the most commonly used measurement tools in psychology (Haeffel & Howard, 2010), most often tap into this aspect of affective state.

2.1.4 Preference.

Preference is a fairly stable evaluative judgment regarding the conscious liking or disliking of a stimulus, or preferring it (or not) to other objects or stimuli. A preference is often felt with low intensity and it has low impact on behaviour except that it might generate approach or avoidance behaviour (makes the individual want to approach a stimulus/event, or withdraw from it) (Scherer, 2005).

2.1.5 Reward and pleasure.

The terms reward and pleasure have mainly been used in the neuroscientific study of positive affect (Berridge & Kringelbach, 2013b; Salimpoor & Zatorre, 2013). The reward system is believed to be the result of natural selection to improve the individual's chance of survival by motivating the organism to engage in behaviors important for survival (e.g., finding food), as well as sustaining behavior and switching behavior adaptively among different available options (Berridge & Kringelbach, 2013b). Rewards are divided into two categories: fundamental rewards like food, sex and shelter, and higher-order rewards like art, music and poetry. Whereas the fundamental rewards rely heavily on sub-cortical structures (such as the ventral tegmental area, the nucleus accumbens, the amygdala and the hippocampus) the higher-order rewards depend on highly evolved prefrontal cortical areas that underlie thinking and reasoning, abstraction, integration of mental processes with emotional responses and integration of past and present to create expectations and anticipation (Kringelbach & Berridge, 2010). This makes it possible for organisms to find more complex stimuli reinforcing (Salimpoor & Zatorre, 2013).

Pleasure is a sub-component of the reward system that includes three main components: (1) the motivation to obtain a reward – the 'wanting'/wanting system; (2) the hedonic state of pleasure when acquiring the reward – the 'liking'/liking system; and (3) reward-related – 'learning'/learning system (see Berridge & Kringelbach, 2013b for a review). All three systems include both explicit processes that are consciously experienced (referred to as wanting, liking and learning) and implicit processes that are not directly available to consciousness (referred to as 'wanting', 'liking' and 'learning'). Concerning pleasure, the liking system refers to the conscious experience of pleasure, such as the subjective feeling of happiness or joy. 'Liking' refers to more objective aspects of pleasure and is measured by affective reactions such as affective facial expressions and behaviors (Kringelbach & Berridge, 2010).

2.1.6 Aesthetic emotion.

Another affective term that needs to be addressed, especially with regards to music, is aesthetic emotion. In contrast to discrete emotions that can be quickly induced as well as perceived by a person, aesthetic emotions are often slow and require the interaction of cognitive, affective and decisional processing. Brattico et al. (2013) define an aesthetic experience of music "as one in which the individual immerses herself in the music, dedicating her attention to perceptual, cognitive, and affective interpretation based on the formal properties of the perceptual experience" (p. 2). This means that in the listener aesthetic emotions in response to music are induced only after the feature analysis of and early emotional reactions to the musical stimulus, cognitive processing of musical rules, and music-induced discrete emotions (Brattico et al., 2013). However, the neuroscientific and psychological study of music and affect has only recently started to emphasize the aesthetic experience of music, such as the judgment of music as a form of art (Brattico et al., 2013; Juslin, 2013a). Awe, being moved, nostalgia and enjoyment are a few examples of aesthetic emotions (Brattico et al., 2013).

In sum, whereas positive emotions refer to short lasting positively valenced affective reactions to events or stimuli in the external or internal environment, positive moods are more long lasting positively valenced affective states often felt with lower intensity (both of which can be implicit and explicit). Positive feelings refer to the subjective explicit aspect of positive emotions and moods. Preferences are evaluative judgments of consciously liking or disliking something and aesthetic emotions refer to more complex affective states in which cognitive, decisional and affective processes interact with each other. Reward includes three components of wanting, liking and learning (all these processes can be both explicit and implicit). Pleasure is the liking-system of reward and includes both implicit (objective 'liking') and explicit (subjective liking) positive affective states.

3. Music-Induced Positive Affect

3.1 The Nature of "Musical Emotions"

According to Juslin (2013a) investigations into the nature of musical emotions have included more or less two distinct approaches: discrete emotions and aesthetic emotions. The main difference between music-induced discrete emotions and aesthetic emotions is that whereas the former can be perceived and induced quickly after a very brief musical excerpt, the latter are slow to develop and often require listening to the piece of music as a whole. The most common approaches to measure emotions induced by music are still to use discrete and dimensional frameworks (Zentner, Grandjean, & Scherer, 2008). However, attempts in the literature have been made to investigate emotions induced by music beyond discrete and dimensional frameworks.

In 2004 Juslin and Laukka conducted a questionnaire study in order to investigate the nature of emotions induced by music in 141 Swedish music listeners. These music listeners were asked to estimate how often, approximately, they felt strong emotions in response to music. Additionally, they were asked to freely describe their emotional experiences felt in response to music. Results indicated that, on average, strong emotions were felt 55% of the times people were listening to music. In addition, positive emotions were most prevalent during music listening, such as happy, relaxed, calm and moved (Juslin & Laukka, 2004). For a complete list of reported emotional terms felt in response to music see Appendix B (Figure B1).

The Geneva Emotional Musical Scale (GEMS) is the first questionnaire to specifically investigate music-induced emotions that goes beyond discrete and dimensional approaches (Zentner et al., 2008). This questionnaire is based on the model that includes 45 affective terms categorized into 9-categories; wonder, transcendence, tenderness, nostalgia, peacefulness, power, joyful activation, tension and sadness (see Figure C1 in Appendix C). The GEMS has been validated in both naturalistic settings, during a classical music festival in Geneva, as well as in experimental settings, in response to experimenter-selected classical music (Zentner et al., 2008). The GEMS has recently also been used in neuroscientific research (Trost, Ethofer, Zentner & Vuilleumier, 2012).

3.2 The Underlying Mechanisms for Music-Induced Affect

There are many different ways in which a musical event can induce emotion in listeners. In 2008 Juslin and Västfjäll presented a framework of six psychological mechanisms hypothesized to be involved in the induction of musical emotions. These six mechanisms explain why listeners may not share the same emotional response to the same piece of music, how the same piece of music can give rise to different emotional responses in different contexts or why we prefer one song over another.

According to Juslin and Västfjäll (2008), the nature of music-induced positive affect depends on the underlying mechanism that gives rise to them. Below these six mechanisms are described.

Brainstem reflexes refers to the quick detection of sounds indicating changes in the environment, like a sudden loud noise (Kolesch, 2011). The reflexes are hardwired, quick and implicit and involved in the early levels of musical processing. This mechanism is believed to function even prior to birth (Juslin & Västfjäll, 2008). Research suggests that loud music produces increased heart rate and motor responses in fetuses, whereas soft music produces moderate heart rate and reduced movement (see Lecanuet, 1996 for a review). Brain stem reflexes respond to timbre differences as well as consonant and dissonant chords (Kolesch, 2011). From an evolutionary perspective the ability to detect dissonance has been suggested to have an adaptive value. Many animals including humans make harsh, irregular and loud sounds when being in stressful or dangerous situations (Blumstein, Bryant & Kaye, 2012). Dissonance arises in music that contains pitch-matching errors and irregular melodies. People often report increased arousal and displeasure in response to dissonant music (Blumstein et al., 2012). However, it is also closely linked to cultural difference and it seems like liking for dissonant music increases as an effect of exposure (McLachlan, Marco, Light, & Wilson, 2013). Consonant music, on the other hand, is stable, contains harmony (i.e., chords are played simultaneously) and is strongly associated with familiarity for tunes and perceived as pleasant (Brattico et al., 2013; McLachlan et al., 2013). Our impetus to move to the rhythm seems to be mediated by the brainstem. Preferred rhythm has been found to be an important component of the pleasurable aspect of music (Kolesch, 2011).

Evaluative conditioning (EC) is an implicit, unintentional and effortless process, involving subcortical regions such as the amygdala and the cerebellum (Saccheti, Scelfo, & Strata, 2005). It is similar to affective learning or fear conditioning; it involves the pairing of a neutral conditioned stimulus (CS) with unconditioned stimulus (US). EC is hypothesized to induce emotions in listeners when music has been paired repeatedly with positive or negative stimuli (Juslin & Västfjäll, 2008). This process can be established without the listener being aware of it (Öhman & Mineka, 2001 as cited in Juslin & Västfjäll, 2008). Music listening in everyday life often occurs without this being the primary activity (Juslin & Laukka, 2004) and it can therefore be hypothesized that in such contexts EC can occur without conscious awareness (Juslin & Västfjäll, 2008).

Emotional contagion (EmC) is another mechanism believed to induce emotions in listeners by mirroring the emotional expression in music internally (Juslin & Västfjäll, 2008). The process of EmC is thought to occur through the mediation of the so-called mirror neurons, the hypothesized mechanism underlying our ability understand the actions and intentions of other people (Kolesch, Fritz, Von Cramon, Muller, & Friederici, 2006). The emotional message expressed in music with fast tempo and major mode is, on average, perceived by the listener as happy and preferred over music with slow tempo and minor mode that tend to be experienced as sad (Schellenberg, Peretz, & Vieillard, 2008). It has been argued that we become pleasantly aroused especially by the voice-like aspect of music, such as hearing a violin, which sounds very similar to the human voice (Juslin & Laukka, 2004).

Visual imagery is suggested to induce emotions through the close interaction between having an inner representation of, for example, a beautiful landscape while listening to music (Juslin & Västfjäll, 2008). The exact process of this visual imagery process remains to be determined but listeners seem to conceptualize the musical structure in metaphorical images (Bonde, 2006 as cited in Juslin & Västfjäll, 2008). Juslin and Västfjäll (2008) argue that the listener responds to these inner representations in the same way as they respond to stimuli in reality. For example, seeing a beautiful landscape induces positive emotions, such as wonder. Music is believed to be a very effective stimulus for visual imagery, especially music with a slow tempo, music that is very predictable, melodic and harmonic (McKinney, Antoni, Kumar, Tims & McCabe, 1995 as cited in Juslin & Västfjäll, 2008).

Episodic memory refers to the process during which listening to music evokes a memory which brings back the emotions connected to that memory (Juslin & Västfjäll, 2008). It is suggested that episodic memories are one of the most frequent and highest valued source of emotions in listeners (Sloboda, O'Neill & Ivaldi, 2001). Memories evoked by music tend to involve social relationships, but can be related to all kinds of events, such as movies, vacations and concerts (Baumgartner, 1992 as cited in Juslin & Västfjäll, 2008). Music-evoked autobiographical memories have been found to often give rise to nostalgia and other types of positive emotions (e.g., Barrett et al., 2010; Janata, Tomic & Rakowski, 2007).

Musical expectancy refers to the expectancies that involve syntactical relationships between different parts of musical structure (Patel, 2003 as cited in Juslin & Västfjäll, 2008). Music has its own grammar with discrete elements organized into a specific order according to well-formed rules. An emotional reaction through musical expectancy occurs when music violates, delays or confirms the listener's expectations about the continuation of music (Juslin & Västfjäll, 2008). As a consequence of everyday listening to music even individuals without musical training have a highly sophisticated implicit knowledge about musical syntax in the music they are often exposed to (Kolesch, 2011). When an individuals explicit expectations about the musical structure are being confirmed it can be felt with a sense of pleasantness (Van den Bosch, Salimpoor, & Zatorre, 2013).

In sum, music-induced positive affect can be induced as a result of several different underlying mechanisms such as brainstem reflexes, EC, EmC, visual imagery, episodic memory and musical expectancy. However these aspects have been largely neglected in psychophysiological, neuroimaging and electrophysiological studies that will be described below.

4. Neural Correlates of Music-Induced Positive Affect

4.1 Psychophysiological Studies

The autonomic nervous system (ANS) has long been known to be a major component of an emotional response mediating emotional arousal (Kreibig, 2010). It consists of the parasympathetic nervous system that is involved in the relaxation response and the sympathetic nervous system (SNS) involved in physiological arousal. The SNS plays an important role in the synchronization of bodily functions, to maintain homeostasis and to prepare the body to fight or flight by increasing heart rate (HR), galvanic skin response (GSR) (activation of sweat glands in hands and feet), respiration rate (RESP), blood flow, and muscle tension as well as decreasing skin temperature (especially in hands and feet) (Kreibig, 2010).

The involvement of ANS in emotions induced by music has also been studied, especially in response to musical chills. Musical chills, also known as "goosebumps", "frissons" or "shivers-down the spine" are well-established characteristics of intense pleasure in response to music (Krumhansl, 1997; Salimpoor & Zatorre, 2013). Not all people have the ability to experience musical chills, but those who do, tend to experience them consistently during peak moments of pleasure to music (Blood & Zatorre, 2001).

Several studies have investigated the link between ANS arousal and intense emotional experience (i.e., chills) during music listening. The studies differ in what kind of musical stimuli; ratings of emotions and/or of chills as well as physiological measurements have been used. The most common approach for selecting musical stimuli has been to ask participants bring their own highly liked music that reliably evokes chills in the listener. This, however, has not been the case in all studies. For example, Grewe, Nagel, Kopiez and Altenmüller (2007) used experimenter-selected classical music. In some studies, the emotional response has been measured in real-time during music listening by asking the participants to rate their pleasure on a scale ranging from high to low by pressing buttons (Salimpoor, Benovoy, Longo, Cooperstock, & Zatorre, 2009) or by rating the valence and arousal of emotional experience on a computer screen (Grewe et al., 2007). In other studies, the emotional experience has been measured by asking participants to fill in questionnaires after listening to each excerpt in which they have to rate, for example, perceived arousal, perceived valence (Rickard, 2004), intensity of chills tension and anxiety during chills (Craig, 2005) and knowledge, appreciation and pleasantness of each piece as well as bodily sensations (Craig, 2005; Grewe et al., 2007). ANS arousal has been measured by the GSR (also known as skin conductance level or electrodermal response) (Blood & Zatorre, 2001; Craig, 2005; Grewe et al., 2007; Rickard, 2004; Salimpoor et al., 2009), HR and blood volume pulse (BVP) (relative blood flow for each heartbeat), skin temperature (SkT), RESP (Salimpoor et al., 2009), piloerection (goose bump formation of the hairs on the skin) (Craig, 2005), salivary cortisol (Rickard, 2004) and facial muscle tension (using electromyogram, EMG) (Grewe et al., 2007). In some studies participants have been selected based on their ability to experience musical chills (Blood & Zatorre, 2001; Craig, 2005; Salimpoor et al., 2011) or simply by their enjoyment of music listening (Rickard, 2004).

Results of the studies have been inconsistent. Increased ANS arousal in response to chills has been demonstrated by increased GSR (Craig, 2004; Salimpoor et al., 2011) and piloerection (Craig, 2005) and decreased SkT (Salimpoor et al., 2011). A correlation between the experience of musical chills and increased HR, RESP have been observed in two studies (Blood & Zatorre; 2001; Salimpoor et al. 2011) but in another no significant increase was observed for any of the measures (Rickard, 2004). A similar pattern has been observed for EMG that increased in one study (Blood & Zatorre, 2001) but not in two others (Grewe et al., 2007; Rickard, 2004). No effects were reported for cortisol measurements (Rickard, 2004).

In sum, these results show that chills can be accompanied with increased ANS arousal, at least with respect to some physiological measurements, but that it does not seem to be necessary. The inconsistent results might be due to variability between subjects with regards to their ability to experience chills as well as other methodological differences between the various studies described above.

4.2 Neuroimaging Studies

It was only about ten years ago when neuroscientists began investigating the neural substrates of emotions induced by music (Kolesch, 2011). Although during the last decade our knowledge about the neural basis of music-induced positive affect has rapidly advanced, the number of studies investigating the topic is still rather limited (Chanda & Levitin, 2013) and there are several limitations to research conducted so far (addressed in the Discussion). Despite this, a set of changes in neuronal activity in response to music-induced positive affect has been consistently reported, especially in brain regions known to be involved in the processing of pleasure and reward (Kolesch, 2014).

fMRI and PET are the most widely used functional neuroimaging techniques in research of music-induced positive affect (Koelsch et al., 2010). fMRI estimates the involvement of neural regions by examining changes in blood oxygenation level (BOLD) while participants are performing tasks compared to control conditions (Salimpoor et al., 2011). PET has lower resolution than fMRI but has the advantage that it can trace the biological pathways of specific neurotransmitters and their distribution in the brain (e.g., dopamine) in response to experimental stimulus (Kolesch et al., 2010).

The core brain regions involved in the processing of pleasure include both cortical and sub-cortical structures (Kringelbach & Berridge, 2010). The causation of pleasure and reward seems to be restricted to the activation of sub-cortical structures, while the representation of pleasure is less anatomically restricted and involves both cortical and sub-cortical structures (Berridge & Kringelbach, 2013b). Sub-cortical structures involved in pleasure include regions of the striatum (the nucleus accumbens and the ventral pallidum) and the brainstem. Cortical structures include the orbitofrontal (OFC), the medial prefrontal (mPFC), insular and cingulate cortices. These cortical structures have been reported in a large amount of research to be involved in the anticipation, appraisal, and memory of pleasurable stimuli. Whereas the sub-cortical structures have been suggested to underlie implicit pleasure or 'liking', the cortical structures are thought to play a role in explicit or subjective experience of pleasure or liking (Kringelbach & Berridge, 2010).

Some of the brain regions most frequently activated in response to music-induced positive affect are the OFC, the striatum and the amygdala. The OFC is situated in the ventromedial prefrontal cortex (vmPFC). This region has been found to be involved in the processing of a wide variety of rewards and is strongly connected to other limbic regions including the amygdala, the ventral striatum and the hippocampus (Kringelbach & Berridge, 2010).

The striatum (situated in the basal ganglia) includes the caudate, the putamen and the nucleus accumbens (NAcc) (Sescousse, Caldu, Segura, & Dreher, 2013). The NAcc, situated in the ventral parts of the striatum, is a major site for dopaminergic output from the ventral tegmental area (VTA) and has been found to be involved in various pleasures. Dopamine is established to be an important neurotransmitter for the rewards associated with drug usage (Sescousse et al., 2013).

The amygdala has mainly been associated with the experience of negative affect, such as fear. However, according to Sescousse et al.'s (2013) recently published meta-analysis, the amygdala is involved in the processing of both reward and aversive behavior. The amygdala consists of three major sets of nuclei: the so-called laterobasal, centromedial and superficial (SF) group. These three different groups of nuclei seem to have their own unique functional, structural and connectional properties (Bzdok, Laird, Zilles, Fox, & Eickhoff, 2013). The SF has been reported to be involved in emotional processing and social interaction (Bzdok et al., 2013).

As the OFC, the striatum and the amygdala have been across studies most consistently reported to be involved in music-induced positive affect this chapter focuses first and foremost on these structures. Below, an overview of key fMRI and PET studies reporting changes in these brain areas will be reviewed.

4.2.1 Orbitofrontal cortex.

The first study to use functional brain imaging to investigate affective response to music was conducted by Blood, Zatorre, Bermudez and Evans (1999). PET was used to investigate brain activity in ten non-musicians (five females) in response to six 30-second unfamiliar and artificial melodies varying in degree of consonance and dissonance. Immediately after each musical excerpt participants indicated their subjective affective experience. This was done according to the dimensions of irritation – unirritation, tension – relaxation, displeasure – pleasure, annoying – unannoying, dissonance – consonance, angry – calm, bored – interested and happy – sad on a scale ranging from -5 (not at all) to +5 (very much). Behavioral results demonstrated higher ratings of consonance, relaxation, pleasure, unannoying, calm, interested and happy for consonant music. Dissonant music showed the opposite pattern and correlated with adjectives associated with negative affective terms. PET results showed increased activity in the OFC (bilaterally), medial sub-callosal cingulate regions and the frontal pole (bilaterally) in response to consonant stimuli. Dissonant stimuli correlated with increased activation in the right parahippocampal gyrus and the precuneus. When contrasting the most consonant stimuli with the most dissonant ones, increased activity in the right parahippocampal gyrus and decreased activity in the right OFC as well as in the medial sub-callosal cingulate regions was found in response to increased dissonance. According to the authors (Blood et al., 1999), this study suggests that subjectively rated pleasant (i.e., consonant) music can modulate activity in brain areas known to be involved in the processing of reward and pleasure. In addition, activity underlying both pleasant and unpleasant emotional responses was fairly similar suggesting a heavy overlap in regions involved in the processing of both positive and negative music-induced affect.

Menon and Levitin (2005) used fMRI to investigate music-induced positive affect in 13 non-musicians (7 females). Musical stimuli were excerpts of classical and scrambled versions of classical music each lasting for 23 seconds. A separate pilot study was conducted in which six additional subjects rated musical stimuli according to pleasantness ranging from 1 (not at all pleasant) to 7 (very pleasant). A mean score of 6.13 was reported in response to classical music and 2.35 for scrambled music. The same musical excerpts were played to participants during fMRI scanning. Results indicated increased activation in the left and the right inferior frontal cortex, the left OFC, the anterior cingulate cortex as well as the cerebellar vermis and the brainstem in response to classical music. Additionally, effective connectivity analyses showed significant VTA-mediated interaction between the NAcc, the hypothalamus, the insula and the OFC while listening to classical music (Menon & Levitin, 2005)

In another fMRI study conducted by Trost et al. (2012) affective experience in 15 non-musicians (9 females) was investigated in response to a wide variety of contemporary instrumental music. Immediately after each excerpt participants rated how strongly they had felt the emotions of joy, sadness, tension, wonder, peacefulness, power, tenderness, nostalgia and transcendence on a scale ranging from 0 (not at all) to 10 (very strongly felt) using the Geneva Emotion Music Scale (Zentner et al., 2008). Also, arousal, valence and familiarity were rated on a scale ranging from 0 to 10. Increased activity in the medial OFC was only observed in response to positive affect rated with low intensity (such as wonder and tenderness) while high intensity positive affect (power and joy) correlated with increased activity in the insula. According to Zentner et al (2008), this finding suggests a distinction in neural activity among positive emotions with high versus low intensity.

In sum, neuroimaging studies have reported increased activity in the OFC in response to music varying in degree of dissonance and consonance (Blood et al., 1999), to classical music (Menon & Levitin, 2005) and to a wide variety of musical genres (Trost et al., 2012). Close interactions between the OFC and other limbic structures have also been demonstrated in response to music-induced positive affect (Menon & Levitin, 2005).

4.2.2 Striatum.

Blood & Zatorre (2001) used PET to investigate brain regions involved in the processing of musical chills in ten musicians (5 females). They were asked to bring with them their own favorite classical music that consistently produced intense pleasure, including chills. During every 60-second PET scan subjects listened to self-selected music, control music (other participants' music) and two baseline stimuli –

amplitude-matched noise and silence. While being in the scanner and listening to music participants indicated the experience of chills by pressing a button. Immediately after each excerpt participants indicated affective dimensions of intensity and valence. Chills were reported during 77% of the scans while listening to self-selected music. Average scores of emotional intensity were 7,4, for chill intensity 4,5 and for pleasantness 7,4 on a scale ranging from 1 to 10 (10 being most intense/pleasant). Emotional intensity can be correlated with both the feeling of pleasure and displeasure. For example both feeling distressed and upset as well as feeling enthusiastic and elated is correlated with high activation (Yik et al., 2011). However, in this study a strong correlation was found between emotional intensity and pleasantness. Concurrent psychophysiological measurements revealed increased HR, EMG and RESP when the self-selected music condition was compared to the control music condition. PET measurements demonstrated a correlation between increased subjectively reported chill intensity and increased activation in the left ventral striatum, left dorsomedial midbrain, and the right thalamus. This study suggests that the ventral striatum plays a critical role in subjectively experienced intense emotional pleasure (Blood & Zatorre, 2001).

In a more recent study by Salimpoor et al. (2011), the neural correlates of musical chills were investigated in ten subjects with varied musical experience (five females) with fMRI and PET. Similarly to Blood and Zatorre (2001), subject-selected music served as musical stimuli (although in this study it did not have to include any specific genre). Control stimuli were emotional neutral music. Emotions were measured directly after each excerpt by having the subjects indicate the number of experienced chills, dimensions of chill intensity and overall pleasure. Psychophysiological measurements (HR, RESP, GSR, BVP and body temperature) were also obtained during PET scanning.

During PET scanning [11C]raclopride (a radioactively labeled ligand) was released to compete with endogenous dopamine for D2 receptor binding in the striatum. PET scans indicated a correlation between increased subjectively reported pleasure and decreased [11C]raclopride binding in the striatum, especially in the right caudate and the right NAcc. Decrease in [11C]raclopride indicates that more dopamine is being released. To gain information about the temporal dynamics of dopamine release fMRI scans for the same ten participants listening to the same musical stimuli were obtained. When subjects experienced musical chills they pressed a button in the scanner.

Dopamine release was studied in two different time periods; during anticipation (which was calculated 15s before the subject was pressing the button) and during chills (Salimpoor et al., 2011).

When the fMRI scans were conjoined with the PET masks, a temporally mediated BOLD response was identified in the right side of the dorsal (caudate) and the ventral (NAcc) striatum that correlated with the anticipation and peak experience, respectively. Subjectively reported number of chills was positively correlated with decreased [11C]raclopride binding in the right caudate which was linked to BOLD response immediately preceding chills (that is anticipation period). On the other hand, subjectively reported mean intensity of chills and pleasure were more significantly correlated with decreased [11C]raclopride binding changes in the right NAcc which was linked to BOLD response during chills (see Figure 1 below*)*. Similarly to Blood and Zatorre (2001), increased activity in the striatum was observed during musical chills. More specifically, this study reported increased activation in the NAcc during the peak experience of chills while increased activation in the caudate correlated positively with the anticipation of chills. Most importantly this study demonstrated the involvement of dopamine in intense emotional experience in response to music (Salimpoor et al., 2011).

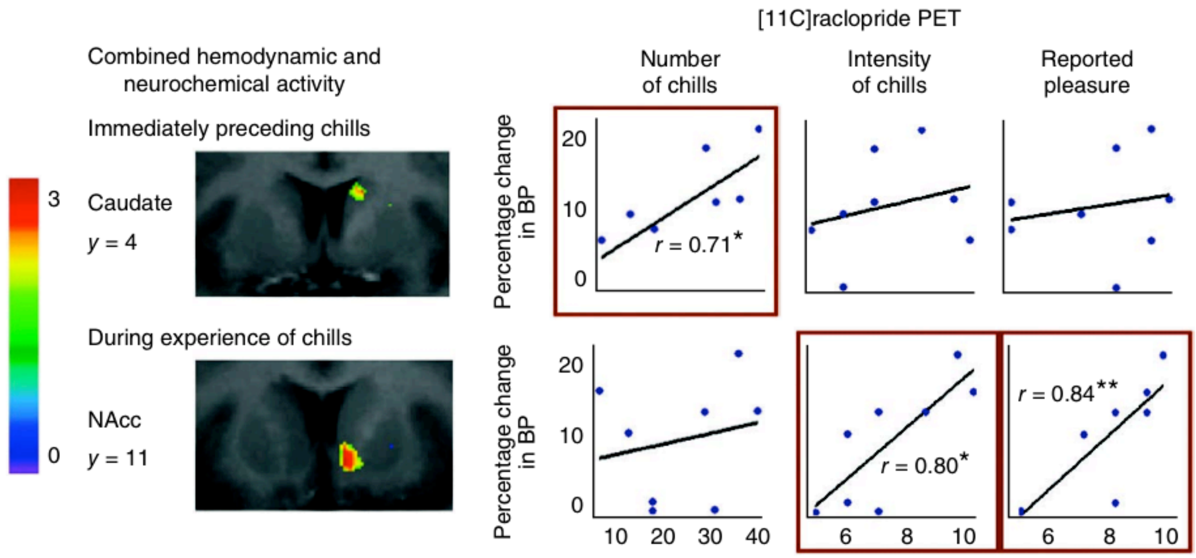

Figure 1. Top left, showing [11C]raclopride binding changes in caudate which is plotted against behavioral ratings in the top right figure. Bottom right, showing 11C]raclopride binding changes in NAcc which is plotted against behavioral ratings in

the right bottom figure. Adapted from "Antatomically Distinct Dopamine Release During Anticipation and Experience of Peak Emotion to Music," V. N. Salimpoor, M. Benvoy, K. Larcher, A. Dagher, and R. J. Zatorre, 2011, *Science, 340,* p. 259.

In another study, Salimpoor et al. (2013) investigated the neural processes of music-induce reward value in 19 subjects (10 females) with a wide variety of musical experience. Reward value for music was assessed by asking participants to indicate how much money they were willing to pay for the music listened to during scanning (four different bids were included; $0, $0.99, $1.29, $2). Musical stimuli included a wide variety of 30-second excerpts of new music (including indie, rock and electronic genre). Emotions were rated immediately after each excerpt according to the dimensions of pleasure (from -3 "hated it" to +3 "loved it"), arousal (from 1 "calm" to 4 "extremely excited") and familiarity (0 "never heard it before", 1 "may have heard it once or twice" and 2 "know very well"). Music that was rated as familiar was not included in the study. The highest bids correlated with the highest ratings of pleasure and arousal. Increased functional connectivity between the NAcc, the ventromedial prefrontal cortex (VMPF) and the OFC correlated with increased reward value for the music (contrasted to lowest reward value) (Salimpoor et al., 2013).

In sum, neuroimaging studies have reported increased activity in the striatum in response to musical chills (Blood & Zatorre, 2001; Salimpoor et al., 2011) and unfamiliar pleasurable music with high reward value (Salimpoor et al., 2013). Dopamine involvement during the experience of musical chills has been suggested (Salimpoor et al., 2011).

4.2.3 Amygdala.

In an fMRI study by Koelsch et al. (2006) ten non-musicians (five females) listened to 45–60 seconds of joyful instrumental dance tunes from the last four centuries and electronically manipulated counterparts of the original tunes made permanently dissonant. Emotions were measured by indicating the level of valence ranging from -2 (very unpleasant) to +2 (very pleasant). Results showed that the average rating for joyful stimuli was +1.1 and for dissonant stimuli -0.6. fMRI results indicated that dissonant stimuli correlated with increased, whereas consonant stimuli with decreased, activity in the left hippocampus, the left parahippocampal gyrus, the left amygdala and the right temporal lobe. On the other hand, consonant music correlated with increased activity, whereas dissonant with decreased activity, in the Heschl's gyrus, the anterior superior insula and the left inferior frontal gyrus. This study suggests decreased activity in the amygdala during music-induced pleasure and increased activity during displeasure (Kolesch et al., 2006).

In Kolesch et al.'s (2013) fMRI study music-induced fear and joy were investigated in 18 musicians (9 females). Musical stimuli included 30-second excerpts of joyful music from a wide variety of genres that had been indicated in previous studies to be experienced as joyful (e.g., Fritz et al., 2009). Fearful music included soundtracks from videogames and movies. Emotions were reported by having subjects indicate the level of emotional arousal, emotional pleasantness, joy and fear on a scale ranging from 1 (not at all) to 6 (very much). Behavioral results demonstrated the highest mean ratings of pleasantness (4.84) and joyfulness (4.83) while listening to joyful music, similar ratings of arousal for both fearful and joyful music (3.97 and 4.05, respectively) and the highest ratings of fear for fearful music (4.02). fMRI results showed increased activity in the superficial amygdala (SF) bilaterally and in the auditory cortex (AC) during joy, contrasted to fear. The opposite subtraction (fear > joyful) indicated increased activation in the primary somatosensory cortex (S1). Temporal dynamics of activation in the SF, the AC and the S1 was conducted by dividing fMRI data from each excerpt into two 15-second halves. Average activation across subjects in the SF indicated a signal increase for all conditions but the highest for joy stimuli with increased bilateral activation being most obvious 10 seconds after stimuli onset. For fear stimuli, an increased signal was observed only in the right SF. Significant increases in the AC were observed bilaterally and the left SF for joy stimuli. In the right S1, all conditions evoked an initial signal decrease, followed by a stronger signal increase for fear stimuli. Contrary to Kolesch et al. (2006) this study showed increased activation in the left SF during music-induced joy.

In sum, neuroimaging studies have reported contradictory results regarding the amygdala's involvement in music-induced positive affect. Kolesch et al. (2006) reported decreased activity in the amygdala in response to joyful music, contrary to increased activation in left SF in response to joyful music by Kolesch et al. (2013). In addition Kolesch et al. (2013) reported decreased activity in the right SF suggesting a functional dissociation of left versus right SF.

4.3 Electrophysiological Studies

Electroencephalography (EEG) measures the moment-by-moment changes of electrophysiological activity over a number of cortical EEG sources. When the EEG is time-locked to specific events (i.e., the presentation of a stimulus or execution of a response), the resulting positive and negative voltage changes over time are referred to as event-related potentials (ERPs) (Kreibig, 2010). EEG and ERPs can provide additional information about the functional interactions among and between brain areas and follow the moment-to-moment changes in brain activity during longer period of music listening (Flores-Gutierrez et al., 2007). While PET and fMRI have better spatial resolution EEG has better temporal resolution and can quickly provide information regarding changes in neural processes.

EEG and ERPs have been important tools in the study of emotion. One important finding that has been extensively studied outside of the music domain is the EEG hemispheric asymmetry in relation to emotional stimuli. More specifically, a greater left (compared to right) (pre) frontal activation, reflected as a decrease in alpha (8–13Hz) power, in response to positive emotions has been consistently reported (for an overview see Davidson, 2004). These findings suggest a hemispheric specialization, especially over the frontal regions, for emotional valence (Davidson, 2004). It has to be noted, however, that controversial findings exist, either not reporting left hemispheric lateralization in response to positive stimuli (e.g., Gur et al., 2002) or relating the differential (pre) frontal activation to approach (versus avoidance) motivation rather than valence of stimuli (see Harmon-Jones, Gable, & Peterson, 2010 for a review).

Other findings that have received attention in the literature, and are relevant with respect to music-induced positive affect, are ERP studies reporting the involvement of the late positive potential (LLP) in response to emotional, as compared to neutral stimuli (Brattico et al., 2013). The LPP is a positive-going and sustained increase in stimulus-locked ERP that has been identified in occipital, parietal and inferotemporal regions of the brain approximately 400 ms after stimulus onset and sustained during a few hundred milliseconds up to a second (Hajcak, MacNamara, & Olvet, 2010). According to Hajcak et al. (2010), increased LLP amplitude is believed to indicate increased emotional salience and increased intensity (such as highly arousing pleasant or unpleasant stimuli).

Both the EEG hemispheric asymmetry and the LLP have been investigated in the study of music-induced positive affect which will be briefly reviewed below.

4.3.1 Left hemisphere asymmetry.

In 2001 Schmidt & Trainor conducted an EEG study to investigate emotional response to joyful, happy, sad and fearful orchestral excerpts, that had been subjectively rated in a separate pilot study to induce feelings of pleasure, displeasure, low and high arousal. 59 participants (30 females) were included in the study that had EEG electrodes placed on four different locations on their scalps: the left and right mid-frontal lobe and the left and right parietal lobe. During EEG measurement, participants were told to “feel the mood” that the music evoked (Schmidt & Trainor, 2001, p.493). Results indicated that positively valenced musical excerpts (joyful and happy music) elicited significantly lower EEG alpha power (8–13 Hz), compared with negatively valenced musical excerpts (sad and fearful) in left frontal regions. This suggests that music-induced positive affect is related to relatively more activity in the left, as compared to the right, frontal cortical regions (Schmidt & Trainor, 2001)

Additional support for the left hemispheric specialization during music-induced pleasure was reported in a combined EEG and fMRI study including 19 non-musicians (8 females) (Flores-Gutiérrez et al., 2007). 16 subjects participated in fMRI scanning and three in EEG measurements. Musical stimuli included three 30-second excerpts of unfamiliar western classical music composed by Bach, Mahler and Prodromidés (famous classical music composers). A significant number of subjects reported that they liked and would hear Bach and Mahler’s excerpts again (as indicated in two yes and no questions) and that Prodromidés induced significantly more negative emotions (as indicated by a list of 19 emotions terms used to rate the musical excerpts). EEG and fMRI results identified a left cortical system involved in positive affect induced by Bach and Mahler (compared to Prodromidés) in posterior temporal-parietal, occipital and middle prefrontal regions all in the left hemisphere (Flores-Gutiérrez et al., 2007).

In sum, the reported left (pre) frontal hemispheric activation when listening to music inducing positive affect in these two studies supports the left hemisphere asymmetry for positive emotions that has been reported outside of the music domain. However, increased activity reported by Flores-Gutiérrez (2007) was not limited to only frontal regions but was also observed over temporal-parietal and occipital regions.

4.3.2 Late positive potential.

In an ERP study by Brattico, Jacobsen, De Baene, Glerean, & Tervaniemi (2010) affective response was measured to rhythmic musical excerpts in12 non-musicians (10 females). The last chord varied between excerpt, by either completely fit the rules of western music theory (congruous), mildly fit (incongruous) or did not fit at all (ambiguous). Participants were assigned with two button assignment tasks; (1) indicated if they liked/disliked the music (2) if they perceived the last cords of the excerpt to be correct/incorrect according to its musical structure. Behavioural results demonstrated that the congruous excerpts were most highly liked and had the highest ratings of correctness. Furthermore, reaction times for the like/dislike task took significantly longer time (mean 453 ms) than the correct/incorrect task (mean 407 ms). ERP results showed a LPP at posterior regions after the onset of the last chord, on average, at 469 ms for the liking judgement and at 516 ms for the correctness task. Negative answers for both tasks elicited larger LPP amplitude. This study suggests that a large LPP is found for dislike versus liked chord sequences as well as for chord sequences rated as incorrect compared to correct (Brattico et al, 2010).

Another ERP study investigated the effect of music preference in a genre classification task and liking task (Istók, Brattico, Jacobsen, Ritter & Tervaniemi, 2012). Participants included 12 Latin American music fans (LAm-fans) and 13 hard rock music fans (HMm-fans). Musical stimuli included 90 excerpts of hard rock music and 90 excerpts of Latin-American music. During EEG measurements a liking judgment task (indicate whether music is liked or not) and one very simple genre classification task (indicate if the music was being electronic dance music or not) was done by pressing buttons. LAm-fans rated that they liked 80% of the LA-music and disliked 89% of the HM-music. Contrary, HMm-fans liked 80% of the HM music and disliked 87% of the LA music. ERP results indicated a LPP in all conditions at posterior electrodes between 230 and 270 ms after stimulus onset and lasted up to 1000ms. However, the non-preferred genre elicited a stronger LPP response compared to the preferred genre during the classification task (no significant difference was observed during the liking task). This study suggest that affective responses may affect early processes of music categorization even when the task is not to give liking judgments (Istók et al., 2013)

In sum, these two studies suggest an involvement of the LPP in posterior regions during both liking and correctness classification task. This suggests that the presentation of music automatically and implicitly elicits affective reactions even though the task is not to decide whether the piece of music is liked or not. In addition a greater positive LPP was observed for negative ratings for genre task (Istók et al., 2013) and for both genre task and liking task (Brattico et al., 2010).

5. Discussion

The present thesis focused on the neural correlates of music-induced positive affect. As has been shown consistently across brain imaging and electrophysiological studies, music can evoke changes in core brain structures underlying positive affect. This suggests that brain regions implicated in emotions induced by music heavily overlap with those involved in the processing of emotions in response to other stimuli.

Increased activity has been reported in the OFC in response to music-induced positive affect (Blood et al., 1999; Trost et al., 2012), which has been suggested to be an important neural substrate underlying the conscious experience of liking (Kringelbach, 2005). Increased activity in the striatum, especially in NAcc, has been found to correlate with increased intensity of reported pleasure and musical chills in response to music (Blood & Zatorre, 2001; Salimpoor et al., 2011). The NAcc is believed to have a key role in the causation of 'pleasure' (Berridge & Kringelbach, 2013a). Both the OFC and the striatum are thought to play an important role in the mesolimbocortical reward circuitry underlying all kinds of pleasures. Increased functional and effective connectivity between the OFC and the NAcc has been reported in response to music-induced positive affect (Menon & Levitin, 2005; Salimpoor et al., 2013) which demonstrates that these interactions may be important in mediating the rewarding aspects of music. The involvement of dopamine during music-induced positive affect (Salimpoor et al., 2011) offers further support for this, as the mesolimbocortical reward circuitry is the main dopaminergic pathway (Berridge & Kringelbach, 2010).

Another structure that has been shown to be involved in the processing of positive affect in response to music is the amygdala (Kolesch et al., 2013). This brain region has mainly been associated with the processing of negative affect, but more recently also been shown to be involved in the coding of emotional salience and socially relevant information (Bzdok et al., 2013). Controversial results have been reported regarding the amygdala's involvement in the processing of music-induced positive affect. Kolesch et al. (2006) reported decreased activity and Kolesch et al. (2013) increased activity in the left SF when listening to joyful music. This indicates a more complex functional role of the amygdala in emotional processing.

EEG studies have suggested a left hemispheric (pre) frontal dominance in response to music-induced positive affect (Flores-Gutierrez et al., 2007; Schmidt & Trainor, 2001) which is in line with a wealth of evidence in emotion research in general (Davidson, 2004). However, increased activity reported by Flores-Gutiérrez (2007) was not limited to only frontal regions but also observed over temporal-parietal and occipital regions. In ERP studies a LPP in posterior regions has been observed both during liking and correctness/classification task suggesting that the presentation of music automatically and implicitly elicits affective reactions even when the task is not to decide whether the piece of music is liked or not. In addition, a greater positive LPP has been observed for negative ratings for genre task (Istók et al., 2013) and for both genre task and liking task (Brattico et al., 2010). This has been hypothesized by Brattico et al. (2010) to reflect the so-called 'negativity bias' which refers to the phenomenon that negatively valenced stimuli attract attention more readily than positive or neutral information (Rozan and Royzman, 2001 as cited in Istók et al., 2013).

However, there are several limitations of the research reported. Mainly these have to do with the diversity of methods employed across studies, such as the lack of standardized means for selecting musical stimuli, and large variability in how positive affect has been induced and measured as well as in what kind of participants have been included. These limitations will now be discussed.

First, there are no standardized means for selecting musical stimuli and as a consequence a wide variety of musical stimuli have been used across studies (Chanda & Levitin, 2013). As described above, some researchers have asked the participants to bring their own favorite music (Blood & Zatorre, 2001; Salimpoor et al., 1999), others have only included music unfamiliar to the participants (Flores-Gutierrez et al., 2007). Some studies have investigated emotional response to naturalistic music (Istók et al., 2013; Kolesch et al., 2006; Kolesch et al., 2013; Menon & Levitin, 2005; Schmidt &

Trainor, 2001; Salimpoor et al., 2013), others to digitalized sounds (Blood et al., 1999), or simple rhythms (Brattico et al., 2010).

Second, positive affect has been induced in a wide variety of ways. Some studies have used musical syntax (the relationship of regularities and structure in music) as a means to induce positive affective states (Brattico et al., 2010), others dissonance and consonance in music (Blood et al., 1999), and still others the repeated exposure of music (Salimpoor et al., 2009). It is important to note that familiarity has been found to increase the liking of music. Schellenberg et al. (2008) suggest an inverted u-shaped function for liking ratings after repeated exposure of music with initial increases in liking after two exposures followed by decreases after 8 to 32 exposures. They also suggested that our appreciation and love for music is learned and not based on inherent ability, in other words the more we listen to a specific genre of music, the better we understand its structure and the more we like it (Schellenberg et al., 2008). This also explains why unfamiliar music is often perceived as less pleasant (e.g., music from another culture) (McLachlan et al., 2013).

Third, the studies differ in how positive affect has been measured. The majority of studies have used self-report scales (Blood et al., 1999; Blood & Zatorre, 2001; Kolesch et al., 2006; Salimpoor et al., 2011; Trost et al., 2012). One of the main limitation of using self-reports is that humans can be very inaccurate when they report their own mental states (Nisbett & Wilson 1977 as cited in Haeffel & Howard, 2010). Some studies have also assessed objective components of emotions by measuring physiological reactions (Blood & Zatorre, 2001; Salimpoor et al., 2011). With regards to the latter, we nevertheless have to rely on subjective reports in order to know what the subjects were actually experiencing (Krumshansl., 1997). Moreover, there seems to be richness in affective states that music is capable of inducing in the listener (Juslin & Laukka, 2004; Zentner et al., 2008), however, this stands in sharp contrast with the current neuroscientific studies investigating music-induced positive affect. Most studies using self-report scales have measured different degrees of emotional valence and arousal (Blood et al., 1999; Blood & Zatorre, 2001; Kolesch et al., 2006) or basic emotion categories (Kolesch et al., 2013). The Geneva Music Scale seems to capture the broader dimensions of music-induced positive affect and have recently been used in neuroscientific research by Trost et al. (2012). According to this study the nine emotion categories of wonder, transcendence, tenderness, nostalgia, peacefulness, power, joyful activation and sadness were also successfully induced in response to a wide variety of music (Trost et al., 2012).

Fourth, the amount and length of previous musical training among participants varies across studies. Some studies have only included musicians (Blood & Zatorre, 2001), others only non-musicians (Menon & Levitin, 2005) and some have included both musicians and non-musicians (Salimpoor et al., 2011). A recently published EEG study by Mikutta, Maissen, Altorfer, Strik and Koeing (2014) showed that professional musicians have a more intense emotional response to music as indicated by a correlation between subjective ratings of increased emotional arousal and increased posterior alpha, central delta and beta rhythm. This highlights the influence of musical experience on emotional processes during music listening. Moreover, it has been hypothesized that musical expertise can lead to increased expectations regarding syntactic relationships in the music (Pearce & Wiggins, 2006) and positive affect has been reported when these explicit expectations are confirmed (Van den Bosch et al., 2013). Another variable that has been found to affect the emotional response to music is personality. In a recently conducted study by Liljeström, Juslin and Västfjäll (2013) listeners with high scores on the trait openness to experience were more prone to experience intense emotions in response to music than listeners scoring low on that particular trait (Liljeström et al., 2013).

In addition, contemporary research regarding music and emotion has mainly concerned Western individuals ranging in age from 20–30 years. Consequently little is known regarding the relation between music and emotions in non-Western cultures, as well as in other ages. More cross-cultural studies and with different age groups are needed. Music has been suggested to play a particularly important role during adolescence especially for maintaining and regulating mood (Saarikallio & Jakko, 2007). Research outside of the music domain has reported that old age is associated with the experience of fewer negative emotions and more complex emotional experience (such as the co-occurrence of positive and negative emotions) (Carstensen et al., 2011).

In order to increase our understanding of music-induced positive affect future research should pay more attention to all these aspects. Standardized tools for selecting musical stimuli, for inducing as well as measuring emotions and for the selection of participants is suggested to increase reliability of studies.

Throughout this thesis music has been reported to induce positive affect in listeners, regardless of previous musical experience. Listening to music is an inexpensive, and thanks to recent advances in technology, a convenient way to experience positive emotions. The role of positive emotions has recently received increased attention in the scientific literature and has been reported to have several cognitive, social and health benefits (Fredrickson, 2013). This suggests that music might have a beneficial effect on our wellbeing. In fact, music has already been used in the treatment of depression (Kolesch, 2014) and stroke (e.g. Särkämö & Soto, 2012). The promise of music-based interventions lies in that they are noninvasive, have minimal or no side effects, are relatively inexpensive and convenient (Chanda & Levitin, 2013).

6. Conclusion

The aim of this thesis was to provide an overview of the neural correlates of music-induced positive affect. As described above, across studies consistent involvement of brain regions, such as the orbitofrontal cortex, the striatum and the amygdala and left hemisphere frontal regions in response to music-induced positive affect have been found. These structures constitute an important part of the mesolimbocortical reward circuitry found to be involved in the processing of a wide range of pleasures. Understanding the nature of and the underlying neural basis of music-induced positive affect is important because of the implications it may have on psychological and physical wellbeing.

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Appendix A

12-Point Affect Circumplex (12-PAC)

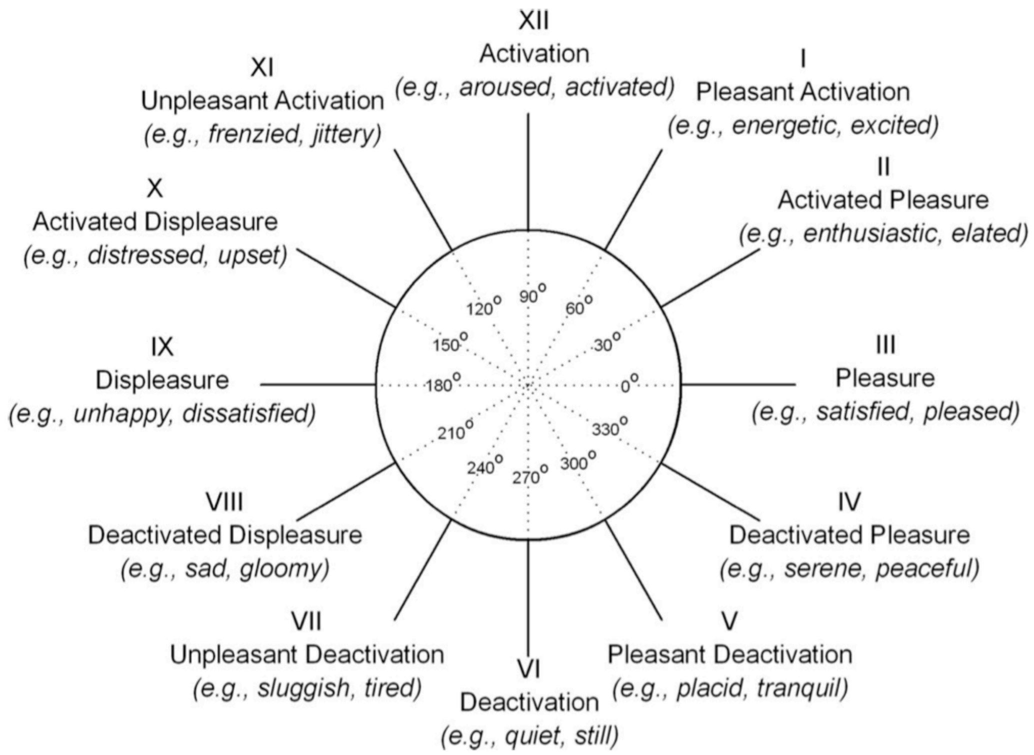

Figure A1. A 12-Point Affect Circumplex (12-PAC). A hypothesized model of 12 segments of Core Affect. Reprinted from "A 12-Point Circumplex Structure of Core Affect," by M. Yik. J. A. Rusell, and K. R. Steiger, 2011, *Emotion, 11*, p. 706.

Appendix B

Frequency of Music-Induced Emotions

1. Happy*
2. Relaxed*
3. Calm*
4. Moved
5. Nostalgic
6. Pleasurable*
7. Loving*
8. Sad*
9. Longing*
10. Tender
11. Amused
12. Hopeful
13. Enchanted
14. Expectant*
15. Solemn*
16. Interested
17. Admiring
18. Angry*
19. Ecstatic*
20. Lonely
21. Content*
22. Desiring
23. Empathic
24. Proud
25. Spiritual
26. Curious
27. Relieved
28. Bored
29. Indifferent
30. Frustrated*
31. Tense*
32. Disappointed*
33. Surprised*
34. Honored*
35. Regretful
36. Contemptuous
37. Confused*
38. Anxious*
39. Afraid*
40. Jealous
41. Disgusted
42. Guilty
43. Shameful*
44. Humiliated

Figure B1. *emotions mentioned in free descriptions. Reprinted from “Expression, Perception, and Induction of Musical Emotions,” by P. N. Juslin, and P. Laukka, 2004, *Journal of New Music Research, 33*, p. 23.

Appendix C

Geneva Emotional Music Scale (GEMS)

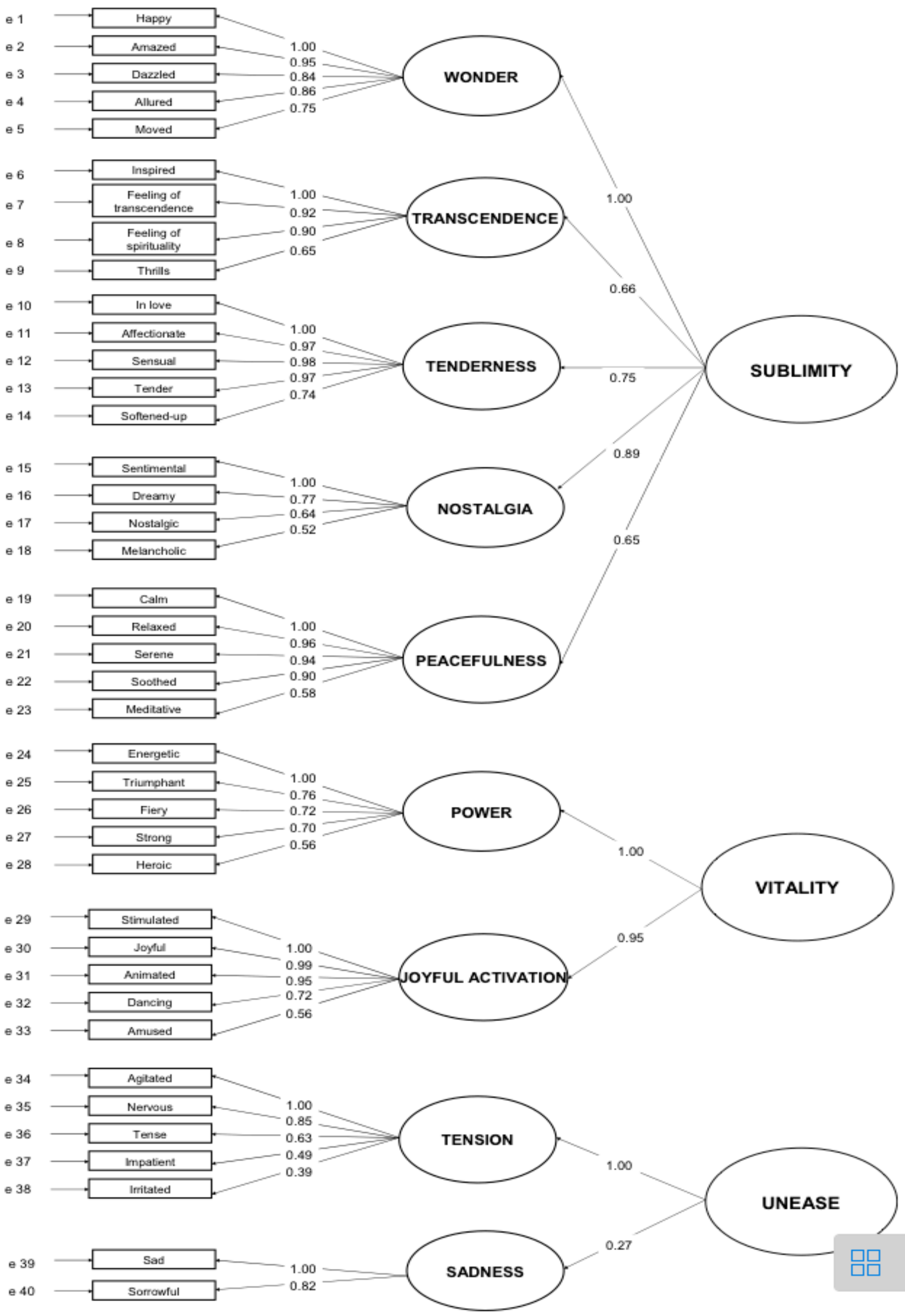

Figure C1. Geneva Music Scale, in the middle main categories. Reprinted from "Emotions Evoked by the Sound of Music: Characterization, Classification, and Measurment" by M. Zentner, D. Grandjean, and K. R. Scherer, 2008,. Emotion, 8, p. 507.