A NEUROCOGNITIVE APPROACH TO UNDERSTAND THE ROLE OF FAMILIARITY WITH MUSICAL STYLE AND INDIVIDUAL DIFFERENCES IN MUSIC-EVOKED EMOTIONS

HENG JIAMIN GLADYS

SCHOOL OF SOCIAL SCIENCES

2021

A NEUROCOGNITIVE APPROACH TO UNDERSTAND THE ROLE OF FAMILIARITY WITH MUSICAL STYLE AND INDIVIDUAL DIFFERENCES IN MUSIC-EVOKED EMOTIONS

HENG JIAMIN GLADYS

SCHOOL OF SOCIAL SCIENCES

A thesis submitted to the Nanyang Technological University in partial fulfilment of the requirements for the degree of Doctor of Philosophy

2021

Statement of Originality

I certify that all work submitted for this thesis is my original work. I declare that no other person's work has been used without due acknowledgement. Except where it is clearly stated that I have used some of this material elsewhere, this work has not been presented by me for assessment in any other institution or University. I certify that the data collected for this project are authentic and the investigations were conducted in accordance with the ethics policies and integrity standards of Nanyang Technological University and that the research data are presented honestly and without prejudice.

30 March 2021

. . . .

Date | Heng Jiamin Gladys

Supervisor Declaration Statement

I have reviewed the content of this thesis and to the best of my knowledge, it does not contain plagiarised materials. The presentation style is also consistent with what is expected of the degree awarded. To the best of my knowledge, the research and writing are those of the candidate except as acknowledged in the Author Attribution Statement. I confirm that the investigations were conducted in accordance with the ethics policies and integrity standards of Nanyang Technological University and that the research data are presented honestly and without prejudice.

30 March 2021

. . . .

Date   Prof. Annabel Chen Shen-Hsing

Authorship Attribution Statement

This thesis **does not** contain any materials from papers published in peer-reviewed journals or from papers accepted at conferences in which I am listed as an author.

30 March 2021

. . . .

Date

. . . .

Heng Jiamin Gladys

Acknowledgements

One of the most serendipitous events in my life is to have crossed paths with Prof. Annabel Chen about a decade ago. She has been a very supportive, patient, wise and nurturing mentor. Her diligence and tenacity continuously inspire me to press on. For all the support that she has given, I would like to express my utmost gratitude to her. Thank you for investing in me. I would also like to thank my co-supervisor (Assoc Prof. Quek Hiok Chai), and the thesis advisory committee (TAC): Assoc Prof. Eugene I. Dairianathan and Assoc Prof. Ho Hau Yan Andy, for their valuable feedback and guidance.

In addition, I am tremendously appreciative of the assistance rendered by fellow colleagues: Dr. Lim Jie Xin, Dr. Foong Ruyi, Dr. Dominique Makowski, Dr. Rajan Kashyap, Pham Thanh Tam, Lau Zen Juen, Alison Chew, Beatrice Tjin, Leong Li An, Nur Diyanah, Jarrad Oh, Li Sufei and colleagues from the IT department. They have very generously given me valuable time to engage in statistical, technical and philosophical discussions. Thank you for going the additional mile.

Apart from that, I would also like to thank my parents for their continuous support; friends who have journeyed with me: Dr. Eng Goi Khia, Dr. Kwok Fuyu, Dr. Sou Kalon, Dr. Mary Baker, Gan Suren, Michelle Tan, Chanya, Ling Qiu Rong, Rachel Soh, Sean Lau; and my dance partner, Rajesh, for cheering me on towards the end. I would also like to thank the NTU Research Scholarship, and funding from the Nanyang Technological University Start-Up Grant: Learning with Emotions, that made this research possible.

Lastly, thanks be to God whose faithfulness is never ceasing.

Contents

List of Tables

List of Figures

List of Appendices

Abstract

Music is widely used for leisure and relaxation purposes in everyday life, as well as in healthcare and therapeutic settings. While existing behavioral studies have mapped out basic relationships between musical features and emotions, it remains unclear why different individuals have similar or different emotional responses to music. This points towards a need to examine music-listener relationship, which could be examined by discussing underlying psychological mechanisms and considering an individual's level of familiarity with a musical style on music-evoked emotions.

Neuroimaging studies have also increasingly suggested the involvement of a widely distributed network of brain regions in music-evoked emotions, beyond the established indices of emotional processing (e.g., frontal alpha asymmetry). Moreover, the role of individual differences in music-evoked emotions, particularly absorption trait, are often either not systematically examined or considered in conjunction with neuropsychological processes. Therefore, this thesis aims to integrate perspectives from psychological sciences and neurocognitive sciences to clarify and examine individual variation in music-evoked emotions. This is addressed by two experiments.

A pilot behavioral experiment (Study 1) was first conducted to develop a suitable selection of music stimuli of a familiar (Japanese animation soundtracks) and unfamiliar musical style (Greek Laïkó music). 74 healthy young adults listened to music from both musical styles, of which Japanese animation soundtracks elicited emotions of Fear, Power and Nostalgia; and Greek Laïkó music elicited emotions of Joyful activation and Nostalgia. Subsequently, another 49 healthy young adults participated in an

electrophysiological (EEG) experiment which was designed to further clarify three research questions separately in a series of three sub-studies (Studies 2A, 2B and 2C).

Firstly, Study 2A clarified the electrophysiological correlates of music-evoked emotions by adopting a whole-brain approach to examine EEG activity and brain asymmetries of emotional valence and arousal elicited by music selected from Study 1. Results showed neither support for the hypothesized association between emotional valence and frontal alpha asymmetry/frontal midline theta, nor association between emotional arousal and absolute frontal alpha/right parietal activity. Instead, both music conditions showed left-biased fronto-occipital and right-biased parieto-temporal asymmetries.

Next, Study 2B investigated the effects of familiarity with musical style on music-evoked emotions, and found that music of the familiar musical style (Japanese animation soundtracks) was felt as significantly more pleasant as compared to the unfamiliar musical style (Greek Laïkó music). However, music of the unfamiliar musical style (Greek Laïkó music) elicited greater theta power in all brain regions (including the midline region), alpha power in the frontal region, and beta power in fronto-temporo-occipital regions as compared to the familiar musical style. This was postulated to reflect the need for greater attentional resources when listening to music of an unfamiliar style. In addition, classification analyses yielded an accuracy rate of 89.39% - 94.49% in distinguishing between both types of musical style.

Lastly, Study 2C investigated the role of absorption trait in music-evoked emotions and its association with EEG activity. Results showed that the moderating effect of absorption was only observed in the arousal ratings of music of an unfamiliar musical style, such that individuals with low absorption trait felt that music of unfamiliar musical style was significantly more passive as compared to individuals with high absorption trait. However, no significant associations between EEG activity and absorption trait were found.

Overall, the current thesis highlights the importance in considering the relationship between music and listener (e.g., familiarity with musical style), as well as the characteristics of the listener (e.g., absorption trait), when examining music-evoked emotions. Taken together, results from this thesis provided further insight into how and why music evokes emotion in different individuals. In so doing, it is hoped that improvements could be made to general well-being and current non-pharmacological personalized treatment approaches in healthcare settings.

CHAPTER I: INTRODUCTION

Music is present in almost every culture and society. The discovery of musical instruments (flutes made of vulture bones, found near Southern Germany) dating 30,000 to 40,000 years ago (Conard et al., 2009) suggest that music listening and music making has been integral in human civilization. Indeed, music has been reported to serve many functions, including various societal and social functions (Koelsch, 2013), communication (Trehub, 2003) and emotional regulation (Moore, 2013). Of these, the ability of music to express and evoke emotions has most intrigued the scientific community (Juslin & Zentner, 2001). This is also evident with the publications of various influential books such as: *Emotion and Meaning in Music* by Leonard B. Meyer (1956), *The Emotional Power of Music* by Cochrane, Fantini and Scherer (2013) and *Handbook of Music and Emotion* by Juslin and Sloboda (2011), and conferences dedicated to the research of music and emotions (e.g., *Brain, Cognition, Emotions and Music*, 2020).

In everyday life, people engage in musical activities mainly because of its emotional effects (Juslin & Laukka, 2004; Sloboda & O'Neill, 2001). Tapping on the emotional power of music, a variety of applications ranging from the advertising and marketing industries (Abolhasani et al., 2017; Stevens, 2011) to healthcare settings and therapeutic settings (Baird & Samson, 2015; Fachner et al., 2013; Fachner & Stegemann, 2013; Gold et al., 2004) have employed music to influence human behavior.

Inherent in this phenomenon is the philosophical perspective that music elicits genuine emotional experiences in listeners (the emotivist position; Lundqvist et al., 2009), in contrast to the cognitivist position, which states that listeners simply perceive emotions expressed by the music. In other words, the cognitivist posits that music merely expresses emotions without inducing them, while the emotivist position argues that music induces emotions in listeners (Kivy, 1990). The distinction between emotivist and cognitivist positions alludes to distinguishing between perceived and felt emotions (Gabrielsson, 2001), whereby felt emotions are thought to reflect introspective perceptions of psychophysiological changes (Khalfa et al., 2002; Thayer & Faith, 2001) and perceived emotions reflect intellectual processing of an intended or expressed emotional character. Building on the emotivist position, this thesis is thus mainly concerned with felt emotion, as compared to perceived emotion.

Another differentiation present in the study of music and emotion is the distinction between 'absolutists' and 'referentialists'. Absolutists postulate that the meaning in music is exclusive within the context and perception of relationships set forth in the musical composition itself. In contrast, referentialists argue that music further communicates meanings which relate to the extramusical world of mental concepts and emotional states (Meyer, 1956).

Adopting these philosophical perspectives, many different studies have set out to answer this overarching question of how music evokes emotions. Studies from the music analytic approach are mainly interested in how structural features of music, such as pitch, mode, tempo, are related to evoked emotions (Gabrielsson & Juslin, 2003; Gabrielsson & Lindström, 2010; Juslin, 2001; Juslin & Laukka, 2003; Juslin & Lindström, 2010). While information generated from this approach has been valuable, it is far from complete in helping to understand how music evokes emotion. As pointed out by Juslin (2013):

> Scholars have aimed to obtain direct links between surface features of the music and aroused emotions, but such correlations do not constitute an explanation: they just move the burden of explanation from one level (Why does the 2nd movement of Beethoven's 'Eroica' symphony arouse sadness?) to another level (Why does slow tempo arouse sadness?) Only a description of the process that mediates between surface features and aroused emotions (the mechanism) constitutes a proper explanation. The neglect of mechanisms has prevented researchers from explaining individual differences, like, for example, why the same piece of music may arouse different emotions in different listeners. (p. 239).

In addition, a growing body of research have also pointed out that the characteristics of the individual affect music-evoked emotions. For instance, an individual's personality (Vuoskoski & Eerola, 2011), music experiences and preferences (Bigand et al., 2005; Rentfrow & Gosling, 2003), absorption trait (Sandstrom & Russo, 2013) and degree of alexithymia (Taruffi et al., 2017) are associated with different emotional intensity. This again reinforces the notion that simply mapping the relationship between structural features of music and emotion is likely to be insufficient in explaining how music evokes emotions, and that there is a need to look at individual differences as well. While current literature has examined these factors, there is a lack of studies that integrates them with one another or in conjunction with neuropsychological or neurocognitive approaches.

Following this argument, Juslin suggests the need to consider the underlying biological, psychological and cognitive mechanisms of music and emotion (Juslin, 2013; Juslin & Västfjäll, 2008). In this framework, he postulated several biological, psychological and cognitive mechanisms which could elicit emotions during music listening or making. Different mechanisms differ in the extent to which they could be influenced by cultural impact or learning. Psychological mechanisms that are influenced by cultural impact or learning can be examined by investigating listener's familiarity with the music or musical style. This is because the phenomenon of differences in emotional responses to a same piece of music is likely to be a result of differences in learned schemata of musical styles which depend on an individual's environment or culture. Existing studies have broadly studied this in terms of cultural familiarity or recognition, but relatively few studies examined the effects of familiarity with musical styles. An investigation of the effects of familiarity with musical style on music-evoked emotions could thus help to elucidate the influence of cultural impact or learning on music-evoked emotions and help to better understand the relationship between listener and music.

Besides these theoretical issues, a natural methodological question that arises when studying music-evoked emotions will land itself with the selection of music stimuli. In a review that surveyed 251 studies from year 1988 to 2009 in the field of music and emotion (Eerola & Vuoskoski, 2013), it was reported that a large majority of studies used Euro-American art music. This result echoes similar findings from previous studies (Tirovolas & Levitin, 2011; Västfjäll, 2002) and meta-analyses (Juslin & Laukka, 2003). Given that meaning and emotions derived from music is not entirely universal, but dependent on the location and context of the individuals, results based on current research of music and emotion might lack generalizability to other musical styles and cultures. As such, there is a need to look beyond the use of Euro-American art music so as to increase generalizability of findings from music and emotion studies. To address this gap, this thesis proposes using other musical styles that are more relevant to the current age group of the sample being recruited in the studies.

Adopting this methodological approach, this thesis synthesizes perspectives and findings from music analytic studies, neuroscience, psychology and individual differences, to help map out a more systematic and comprehensive picture of the underlying mechanisms of how music evokes emotions. With that, the aim of this thesis is two folds: First, to develop and select music stimuli from a familiar and unfamiliar musical style in an Asian context, using musical materials that are not of Western classical music. Second, an empirical study employing electrophysiological measures designed to address the following research questions:

1. What are the effects of familiarity with musical style on music-evoked emotions?
2. How does absorption trait affect music-evoked emotions?

Overall, this thesis is organized in the following manner: Chapter 2 brings together literature from musicologists, psychologists, neuroscientists and engineering to provide a basic understanding on why and how music evokes emotions. This includes exploring questions such as how an abstract sequence of sounds expresses emotions, how music elicits emotions, and what are the underlying neural correlates of music-evoked emotions. Next, Chapter 3 presents a pilot behavioral experiment on music stimuli development and selection to be used as music from familiar and unfamiliar musical styles in an Asian context. Following, an EEG experiment was designed of which differential components of this experiment is outlined in Chapters 4, 5 and 6 to clarify the electrophysiological correlates of music-evoked emotions, investigate the effects of familiarity with musical style on music-evoked emotions and the role of absorption trait on music-evoked emotions respectively. Lastly, the thesis concludes with an overall discussion to integrate all findings (Chapter 7).

Results from this thesis could contribute to current datasets of validated music stimuli, provide a better understanding of the neural correlates of music-evoked emotions after taking into account the effects of familiarity with musical style and individual differences. In so doing, it is hoped that this could help guide music therapists in their choice of song selection so as to increase therapy sensitivity and specificity, and provide further insight in the broad application of music for its emotional powers.

CHAPTER II: LITERATURE REVIEW

This chapter will provide an overview of music and emotion research from multi-disciplinary perspectives. First, definitions of music and emotion that the thesis is using will be stated. Next, research on music and emotion from music analytic, neurobiological and psychological approaches will be outlined. After surveying literature from these perspectives, the chapter will conclude with the research motivation and aims of the thesis.

2.1. Music and Emotion

Definition of Music

The study of music cognition is amongst one of the oldest topics in psychology, dating back to the time of Aristotelian philosopher, Aristoxenus (Levitin & Tirovolas, 2009), who argued that musical intervals should be examined by their effects on listeners rather than by classifying their mathematical ratios (Griffiths, 2004). Unlike the studies of language or mathematical ability, where the definition of the domain of interest is seldom questioned, the question of *what is music* is one that emerges more frequently in this field of inquiry in contrast to others (Levitin & Tirovolas, 2009).

In the most generic terms, a well-encompassed definition of music should include the following components: music's historical and anthropological roots in sound and movement, the heterogeneity of meaning in music, its grounding in social interactions coupled with personalized significance (Cross, 2001). Taken together, a resulting definition is as follows:

> Music can be defined as those temporally patterned human activities, individual and social, that involve the production and perception of

> sound and have no evident and immediate efficacy or fixed consensual reference. (p. 47)

While this definition encapsulates the essence of music well, a more concise definition of music would be useful in the study of music. With that goal, Patel (2008) defined music as:

> Sound organized in time, intended for, or perceived as, aesthetic experience. (p. 12)

Despite having operationalized music in more concrete terms, critics have pointed out that this definition might still be too broad, as organized sounds could also include human speech, sounds of animals and machines (Kania, 2014). In this regard, *The Concise Oxford Dictionary* (1992) defined music as:

> The art of combining vocal or instrumental sounds (or both) to produce beauty of form, harmony, and expression of emotion. (p. 781)

A synthesis of the aforementioned definitions points towards the notion of referring to music as musical sounds (excluding other forms of organized sounds), with a function for emotional or aesthetic purposes. As such, the current thesis will employ this working definition of music.

Looking further into the elements of music, researchers studying music cognition have characterized music by eight perceptual attributes: pitch, rhythm, timbre, tempo, meter, contour, loudness and spatial location (Levitin, 2006; Levitin & Tirovolas, 2009; Parsons, 2001; Wieser, 2003):

I	Pitch	the actual frequency of a tone and its relative position in the musical scale
II	Rhythm	the duration of a series of notes and the manner by which they are grouped together into units
III	Timbre	the distinction between one instrument and another, for instance, piano versus violin
IV	Tempo	the overall speed of the musical piece
V	Meter	the way in which tones are grouped with one another across time, e.g. waltz (in groups of three) or march (in groups of two or four)
VI	Contour	the overall shape of a melody
VII	Loudness	relating to the physical amplitude of a tone
VIII	Spatial location	where the sound is coming from

and noted that meaningful combinations of these basic elements then give rise to higher-order musical concepts such as mode and harmony, and ultimately to emotion and other aesthetic attributes.

Approaches to Develop Music Stimuli

In the field of music and emotion, two main methodological approaches employed are: the *experimental* and *naturalistic* approaches (Sluckin et al., 1983). The experimental approach uses music stimuli such as electronically generated sound waves, intervals or tone sequences played in controlled laboratory environments, and assesses emotional responses by means of standardized rating scales or questionnaires. Consequently, this results in high internal validity but lacks ecological validity. In contrast, the naturalistic approach uses commercially available music that is played under environments that are designed to mimic real-life environments (for a review, see Abeles &

Chung, 1996). Therefore, this approach yields high ecological validity is constrained in terms of internal validity.

Eerola and Vuoskoski (2013) reviewed 251 studies and found that selection of music stimuli is pre-dominantly researcher-driven: music stimuli were selected intuitively by the authors in 33% of the studies. Other forms of selection include: music stimuli chosen on the basis of a previous study (9%), a pilot study (8%), and by a panel or group of experts (6%).

In terms of musical genre most commonly employed, there is a consensus that classical music is the dominant genre in existing literature (Eerola & Vuoskoski, 2013; Juslin & Laukka, 2003; Västfjäll, 2002). Studies that employed more than one musical genre commonly select three separate styles (e.g., classical, pop and film music) (Eerola & Vuoskoski, 2013), so as to elicit different types of emotional responses (Ali & Peynircioğlu, 2006; Nater et al., 2006) or increase generalizability of results (Hunter et al., 2008). Despite the increased number of studies using mixed genres, further work is required in this area, as emotional responses may differ across genres due to their intrinsic musical differences.

With the inherent trade-offs of the experimental and naturalistic approaches in mind, this thesis will adopt the methodological approach of using naturalistic music in a controlled laboratory setting so as to maximize resulting inferences. In addition, the approach of using a pilot study as part of music stimuli development will be employed. Lastly, other music genres besides classical music will be considered.

Definition of Emotion

The question of *what is an emotion* has been debated since William James (1884), but has yet to receive a definitive answer till date. This is evident by Kleinginna and Kleinginna (1981), who identified 92 definitions in textbooks, articles and dictionaries, each definition based on different criteria. Despite the lack of consensus regarding the definition of an emotion, researchers generally agree on the following characteristics of emotions, that emotions are:

> relatively brief, intense and affective reactions to potentially important events (subjective challenges or opportunities) in the external or internal environment, usually of a social nature, which involve a number of subcomponents that are more or less 'synchronized' (Davidson et al., 2003, p. 13).

Sub-components of emotion include cognitive appraisal, subjective feeling, physiological arousal, emotional expression, action tendency and emotion regulation (Ekman, 1992b; Johnson-laird & Oatley, 1992; Scherer, 2000). 'Synchronization' refers to the coordinated organization of responses in different sub-components so as to prepare the individual for adaptive behavior and regularities (Juslin & Scherer, 2005; Levenson, 2003). In the scenario above, this would refer to demonstrating both physiological arousal and emotional expression simultaneously.

Models of Emotion

With a working definition of emotion, models of emotions that have been commonly employed in the study of music and emotion will be introduced in the next section. These are the discrete, dimensional and music-specific emotion models (Schubert, 1999; Zentner et al., 2008).

Basic Emotion Model

The basic emotion model postulates that all emotions can be derived from a limited number of innate and universal basic emotions such as fear, anger, disgust, sadness and happiness (Ekman, 1992a; Tomkins, 1962). A seminal work by Ekman (1971) provided support for the universality of emotional facial expressions. In this study, photographs of actors making facial expressions of emotions such as surprise, happiness, sadness, disgust, anger and fear, were presented to people from various cultures, who were asked to choose an appropriate facial expression to match a specific emotion word. Results showed that people from both Western and non-Western cultures performed similarly well, thus lending support to the notion of universality in these emotional expressions.

To a basic emotion theorist, an independent neural system was thought to subserve every basic emotion. As the basic emotion model considers emotional states to be universal, it therefore proposes that a same pattern of neural activation would be observed when a person from any culture experiences a given emotion. Extending the notion of having an independent neural system subserve every emotion to music-evoked emotions, several studies have shown different brain activation patterns when comparing different types of emotions (e.g. Hu et al., 2017; Zhao et al., 2018).

Dimensional Model

In contrast, the two-dimensional circumplex model (Posner et al., 2005; Russell, 1980) proposes that all emotions can be distributed along a two-dimensional continuum: valence (pleasant/pleasure – unpleasant/displeasure) and arousal (active/activation – passive/deactivation) (Fig. 2-1). The dimensions of valence are arousal are thought to be two independent neurophysiological systems. In this two-dimensional circular space, the vertical axis represents arousal, the horizontal axis represents valence and the center of the circle denotes a neutral state. The validity and reliability of the two-dimensional emotion-space in measuring emotions evoked by music has been demonstrated as well (Schubert, 1999).

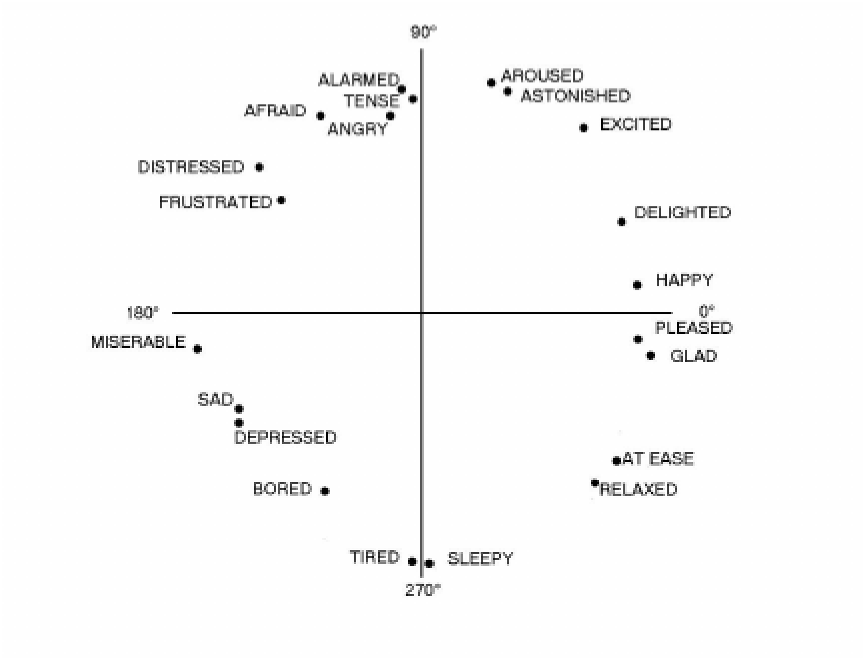


Figure 2-1. Circumplex model of emotion. *Adapted from Russell (1980).*

Music-specific Model

While the basic and dimensional models have been commonly used in music and emotion research, there is another line of debate as to whether these models fully capture the types of emotions that can be evoked by music (i.e., emotions beyond the dichotomies of pleasant to unpleasant, or happiness to sadness). To address this issue, Zentner et al. (2008) conducted a series of field and laboratory studies, in which participants rated their felt emotional responses to music with an extensive list of emotional adjectives, comprising more than 500 terms. Results show that the emotion labels were best represented by a model with nine emotion factors, namely: Sadness (depressed, sorrowful), Amazement (feeling of wonder and happiness), Solemn (feeling of transcendence, inspiration), Tenderness (sensuality, affect, feeling of love), Nostalgia (dreamy, melancholic, sentimental feelings), Calmness (relaxation, serenity, meditativeness), Power (strong, heroic, triumphant, energetic), Joyful activation (feels like dancing, bouncy feeling, animated, amused), Tension (nervous, impatient, irritated) . This model is subsequently termed as the Geneva Emotion Model Scale (GEMS).

With the framework of GEMS, Trost et al. (2012) further investigated the neural correlates of a wider spectrum of affective responses reported during music listening. It was found that positive emotions correlated with activation of different brain regions when high-arousing as compared to low-arousing. Irrespective of valence, emotions of a high arousal level were correlated with sensory and motor areas, whereas low-arousal emotions selectively a different set of brain regions. Thus, results suggest that a differentiated recruitment of brain networks in different types of musical emotions, which comprise networks involved in reward, self-reflective, sensorimotor and memory processes.

Comparison of Emotion Models

Several studies have attempted to investigate which emotion model best captures music-evoked emotions. Some studies demonstrated that the GEMS model might be most appropriate in representing musical emotions (Zentner et al., 2008), while other studies reported that the dimensional model outperformed the GEMS model (Vuoskoski & Eerola, 2011) and also achieved highest overall consistency in emotion ratings. This inconsistency is suggested to reflect a dependency on the type of music that is used in the study. While there might not be a consensus in whether GEMS or dimensional model is the most efficient model, both studies agree that the basic emotion model achieved the least efficacy.

2.2. Music Analytic Approach

Many studies have sought to investigate the effects of different aspects or dimensions of music on emotional response as well as the consistency of these associations. Common musical features studied include tempo, mode, loudness and pitch. Some studies investigated how manipulating one aspect of the music, such as pitch (Jaquet et al., 2012), rhythm (Thompson & Robitaille, 1992; Watson, 1942; Wedin, 1972), or timbre (Eerola et al., 2012) affects emotional response. Other studies varied several features of music either independently or congruently (e.g. Bresin & Friberg, 2011). In a seminal series of studies, Hevner (1935, 1936, 1937) systematically varied music along a number of dimensions (e.g., mode, tempo, pitch) and had participants select emotional adjectives that best fit the music they were presented with. Results showed that tempo and mode were the strongest determinants of emotional response. In another review of emotional expression in music, Gabrielsson and Juslin (2003) also reported that tempo is one of the most frequently used parameters in emotionally expressive performances. As such, this section will further elaborate research findings on tempo and mode.

Tempo

Tempo has been shown to be one of the most effective musical features for communication of a specific emotion (Gabrielsson & Lindström, 2010; Juslin & Laukka, 2004). Fast tempo is usually associated with active emotions such as happiness, anger and fear (Bresin & Friberg, 2011). It is also associated with increased autonomic arousal, as reflected by measures of respiration, skin conductance, and heart rate (Husain et al., 2002). On the other hand, slow tempo is commonly associated with more passive emotions (Bresin & Friberg, 2011; Gabrielsson & Lindström, 2010; Juslin, 2001).

Mode

Since the baroque and classical periods, two main modes are frequently employed in music: the major mode and minor mode. Major mode is generally associated with positive emotions, such as happiness, joy, gracefulness, serenity, and solemnness (Hevner, 1936; Rigg, 1939). On the other hand, minor mode is commonly associated with negative emotions, such as sadness (Crowder, 1984; Fritz et al., 2009; Peretz et al., 1998), tension, disgust and anger (Hevner, 1936; Nielzén & Cesarec, 1982; Scherer & Oshinsky, 1977).

Summary and Limitations

In essence, differences between fast and slow tempo are mainly associated with arousal, while differences between major and minor mode are mainly related to valence. While the effect of tempo and mode on emotion has been well-established, it should be noted that manipulating only a single musical feature is seldom sufficient in communicating or eliciting a specific emotion. For instance, fast tempo is used in both anger and happiness. This shows that a given musical feature can be used in a similar manner for emotional expression. In addition, the type of emotional expression felt or perceived is dependent on the presence and level of other musical features. For example, irrespective of the mode, the emotion of happiness could be better elicited with loud and high-pitched chords as compared to soft and low-pitched chords (Gabrielsson & Lindström, 2010).

Besides, the music analytic approach only maps direct links between musical features and a listener's emotional response. Consequently, it does not yet fully explain the underlying mechanisms of *why* emotions are elicited in the listener. To bridge this theoretical gap, researchers from the psychological and neurobiological disciplines have proposed several cognitive and neural mechanisms to explain the underlying mechanisms of music-evoked emotions. Understanding these mechanisms is important as it provides insight on the cognitive and neural organization of music-evoked emotions, which informs better uses of music in everyday life and therapeutic treatments.

2.3. Neurobiological approach

There are two main neuroimaging techniques that have been employed in research on cognition: functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). fMRI provides good spatial resolution, which allows for an accurate picture of what brain regions are involved in a task. On the other hand, EEG provides good temporal resolution, which enables insight into the time course of cognitive processes involved in a task. Therefore, the EEG technique is more suitable for investigation of music-related processes as it is able to capture the temporal dynamics of music, which varies over time. As such, this section will first provide a brief overview of neural networks involved in music-evoked emotions before outlining literature of EEG studies.

Neural Networks Involved in Music Listening and Music-Evoked Emotions: Functional Neuroimaging Studies

In principle, music-evoked emotions could involve three classes of brain regions: (1) regions related to perception of music (e.g., primary auditory cortex); (2) regions involved in the conscious experience of emotions (e.g., the rostral anterior cingulate and the medial prefrontal cortex (Lane, 2000); and (3) regions involved in information processing that might differ depending on the mechanism inducing the emotion.

Music Listening

Studies have found that auditory processing (both music and sound) activate a widely distributed cortical neural network which involves superior temporal lobe, dorsolateral frontal cortex, and parietal region (Peretz, 1990; Platel et al., 1997; Sergent et al., 1992).

Music-evoked Emotions

Beyond the auditory processing network, neuroimaging studies have also shown that music elicits intense emotional responses that activate brain regions thought to be involved in reward/motivation, emotion and arousal, including a network of sub-cortical brain regions such as ventral striatum, midbrain, thalamus, orbitofrontal cortex, anterior cingulate cortex (ACC) and the insula (Blood & Zatorre, 2001; Brattico et al., 2011; Brown et al., 2004;

Koelsch, 2014; Koelsch et al., 2006; Mueller et al., 2011). Lesion studies corroborate the findings that cerebral cortex (particularly the frontal region) is pivotal in many aspects of human emotional behavior and experience (Kolb & Taylor, 1981). A recent meta-analysis showed that the experience of music-evoked emotions is associated with changes in activity of the core emotion networks, consisting of limbic and paralimbic structures such as: the amygdala, nucleus accumbens, cingulate cortex (consisting of the anterior cingulate) and orbitofrontal cortex (Fig. 2-2a). These regions are associated with experiencing emotions, pleasure and reward, and also regulate the activity of the autonomic nervous system (Koelsch, 2014). In another meta-analysis that aimed to establish the functional relation between brain regions when listening to music, they also showed a involvement of the auditory network, fronto-insular network and other sub-cortical structures (Frühholz et al., 2016) (Fig. 2-2b).

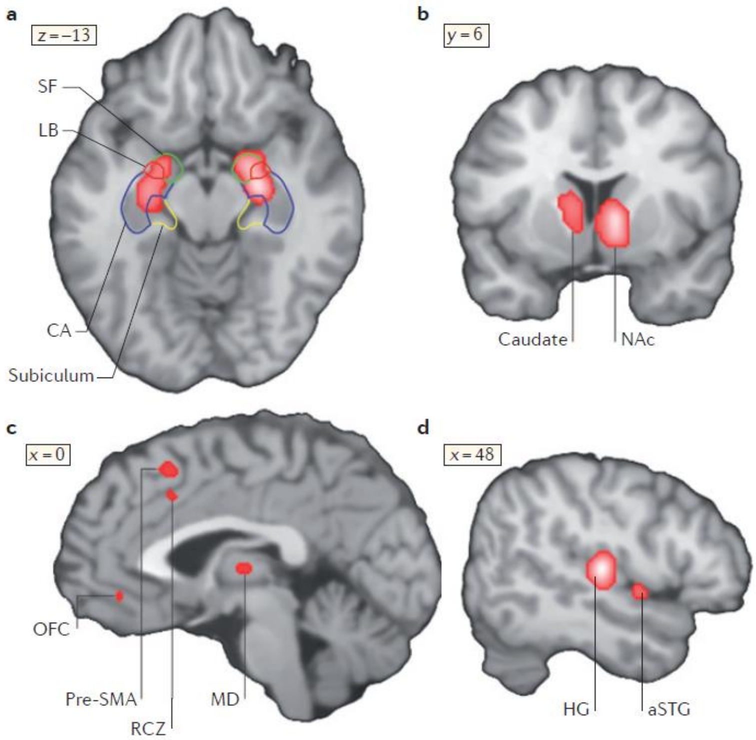


Figure 2-2a. Neural correlates of music-evoked emotions *(adapted from Koelsch, 2014).* Abbreviations: aSTG = anterior superior temporal gyrus, HG = Heschl's gyrus, LB = laterobasal amygdala, MD = mediodorsal thalamus, NAc = nucleus accumbens, OFC = orbitofrontal cortex, Pre-SMA = pre-supplementary motor area, RCZ = rostral cingulate zone, SF = superficial amygdala.

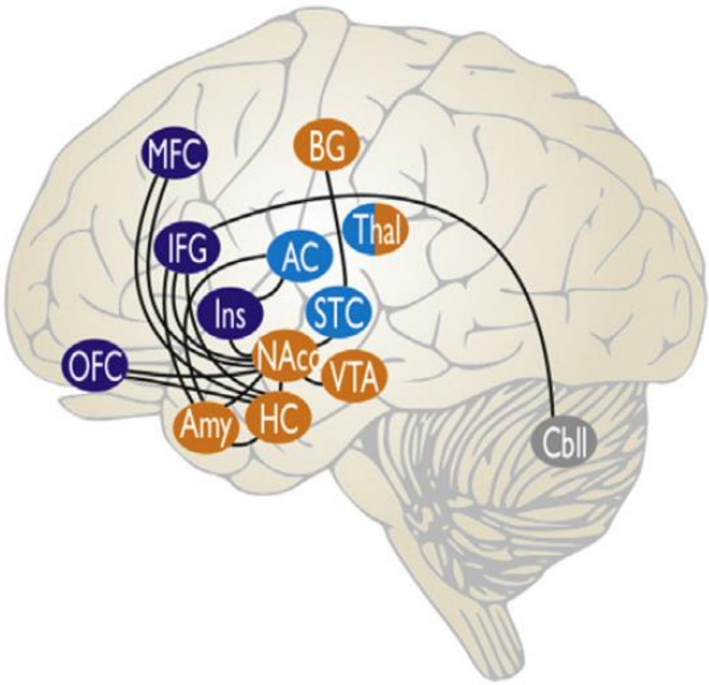


Figure 2-2b. Brain regions involved in the processing of music. *(adapted from Frühholz et al., 2016).*

Black lines: functional connections between brain regions if they were reported to underlie the decoding of emotional meaning from sounds. Arrows indicate unidirectional connections. Light blue regions: ascending auditory system. Dark blue regions: fronto-insular regions. Orange regions: other subcortical structures.

Abbreviations: AC = auditory cortex, Amy = amygdala, BG = basal ganglia, Cbll = cerebellum, IFG = inferior frontal gyrus, HC = hippocampus, NAcc = nucleus accumbens, Ins – Insula, MFC = medial frontal cortex, OFC = orbitofrontal cortex, STC = superior temporal cortex, Thal = thalamus, VTA = ventral tegmental area.

Neural Networks Involved in Music Listening: Electrophysiological Studies

Parallel efforts from electrophysiological studies have converged with findings from fMRI studies in terms of which regions of the brain are activated during music listening and the experience of emotion. Altenmuller et al. (2002) investigated the electrophysiological correlates of emotional valence responses of jazz, rock-pop, classical music and environmental sounds. In general, a widespread bilateral fronto-temporal activation was reported during music listening, although there was a highly significant lateralization effect such that positive emotions were accompanied by increased left temporal activity, and negative emotions by a more bilateral with preponderance of the right fronto-temporal cortex. This pattern of brain activity is mainly due to decreased activation over right fronto-temporal areas when participants were listening to music they liked.

Baumgartner et al. (2006) examined the emotions of happiness, sadness and fear elicited by visual and music stimuli. They presented the stimuli either alone or combined (congruent) and showed that brain activity was higher in the combined visual-musical condition, followed by visual condition and lastly music condition. The observed brain activity was in a distributed emotion and arousal network which comprised the frontal, temporal, parietal and occipital neural structures.

Before discussing further findings from these studies, it is useful to have a basic understanding of the background of EEG power spectrum.

Background of EEG

The human EEG power spectrum is conventionally categorized into at least five frequency bands: delta, theta, alpha, beta, and gamma (Niedermeyer, 1999). Each frequency band has been related to a variety of neural and cognitive processes (Sammler et al., 2007). In addition, precise time and phase-locked changes in EEG activity have been shown to reflect time-limited responses to stimuli and other cognitive processes (Handy, 2005). Of these frequency bands, the neural underpinning of theta, alpha and beta have been most extensively studied.

Theta (4 – 8 Hz). Widespread scalp distribution of theta activity is mainly observed during states of drowsiness and low-level alertness, resulting in inefficient information processing (Schacter, 1977).

Alpha (8 – 13 Hz). Traditionally, it is thought that there are three different types of alpha rhythm. Firstly, alpha that originates from parieto-occipital cortex, also known as posterior alpha rhythm, is dependent on attentional factors and the individual’s vigilance. Secondly, alpha that is dominant in the central region, also known as Rolandic mu rhythm, originates from somatosensory cortex, is related to motor movements and preparation. Thirdly, alpha that is generated from auditory cortices, also known as tau alpha rhythm, is modulated by auditory stimulation.

Existing literature on alpha power desynchronization (for a review, see Klimesch, 1999) and several recent studies employing the combined EEG-fMRI technique indicate that alpha power is inversely related to brain activity (Laufs, Kleinschmidt, et al., 2003; Laufs, Krakow, et al., 2003; Oakes et al., 2004). Alpha is broadly associated with perceptual and memory processing, and is more strongly linked to cognition and behavior as compared to power in other frequency bands (Davidson & Hugdahl, 1996).

Beta (13 – 30 Hz). In general, beta rhythm is related to increased alertness and cognitive processes (Schomer et al., 2017). Studies that investigated the relationship between beta power and music-evoked emotions have generally reported increased beta power following an increase in emotional arousal, that is mainly independent of valence.

Electrophysiological Models and Indices of Emotional Processing

Regarding brain models of emotional processing, studies have suggested several models and indices: (1) right hemisphere hypothesis, (2) hemispheric valence hypothesis (Davidson, 1984, 1988, 1992a): greater relative left frontal activity for positive emotions and greater relative right frontal activity for negative emotions, (3) association of emotional valence and frontal midline theta, (4) Heller's (1993) model: in addition to hemispheric valence hypothesis, the involvement of right parietal region for arousal, (5) Heilman's (1997) model: in addition to hemispheric valence hypothesis, the involvement of the right parieto-temporal region for arousal, and (6) association of emotional arousal: absolute frontal alpha EEG activity.

As a general note, these are the common neural patterns and indices derived from studies investigating emotion processing in general. While similar findings have been demonstrated in music-evoked emotions with considerable success, other studies have reported the involvement of additional brain regions associated with emotions elicited by music. Further details are discussed in Chapter 4.

Right Hemisphere Hypothesis

One of the earliest theories of brain asymmetry is that the left hemisphere is involved with cognitive processes while the right hemisphere is associated with emotional processing. The association between right hemisphere and emotion received support from brain damage (Mills, 1912) and brain lesion studies (Babinski, 1914), and other studies that documented a right-hemisphere advantage in general emotional information processing (Alves et al., 2008; Borod et al., 1998).

Hemispheric Valence Hypothesis

One of the first hypotheses or brain models concerning the evaluation of emotional valence is put forth by Davidson (1984, 1988, 1992a). Davidson investigated emotions with facial stimuli and found that greater left frontal brain activity (i.e., decreased alpha power in left frontal region) is associated with positive emotions, while greater right frontal brain activity is associated with negative emotions (Davidson et al., 1990). He postulated that this effect is congruent with approach-withdrawal mechanisms. Therefore, it is conceptualized that stimuli that evoked positive emotion may produce an approach response, whereas stimuli that evoked negative emotion may produce a withdrawal response. This has led to the development of the “hemispheric valence hypothesis”, or also known as “frontal alpha asymmetry”, which states that the left frontal cortex is largely involved during approach-related emotions while the right prefrontal cortex is largely involved in withdrawal-related emotions (Davidson, 1995; Heilman, 1997). Consequently, research on music and emotion focused on examining frontal alpha asymmetry when investigating valence in music-evoked emotions and also demonstrated similar neural patterns of emotional valence elicited by music (e.g., Aftanas et al., 1996; Coan & Allen, 2004; Davidson, 1995; Schmidt & Trainor, 2001; Trochidis & Bigand, 2012).

Trochidis and Bigand (2013) investigated the effects of mode and tempo on emotional responses, and showed that consistent with current literature, musical modes influence the valence of emotion, with major mode being evaluated as happier and more serene as compared to minor and locrain modes, which induced strong feelings of sadness and anger. In terms of EEG, they found that major mode (happy and serene emotions) was associated with an increased alpha activation in the left frontal region as compared to minor and locrain modes. In contrast, minor and Locrian modes induced increased activation in the right frontal region. This finding is consistent with the hemispheric valence hypothesis (Davidson, 1988), where music conditions eliciting greater relative left EEG activity are considered happy, while music conditions eliciting greater relative right EEG activity are considered sad.

More recently, Daly et al. (2019) employed an EEG-fMRI technique to investigate the relationship between EEG-based neural correlates of frontal asymmetry in response to music and changes in the sub-cortical emotional response network. They found that EEG in the prefrontal cortex reflects changes in cortical activity in the amygdala, posterior temporal cortex and cerebellum. Moreover, the magnitude of the asymmetry was reflective of brain activity in the limbic and paralimbic networks. Specifically, changes in prefrontal EEG asymmetry in response to music-induced emotions was associated with brain activity in several sub-cortical regions such as the amygdala, posterior temporal cortex and cerebellum. This provides evidence that EEG asymmetry magnitude reflects emotional responses elicited by music, and also shows that it is possible to infer activity in the limbic and paralimbic systems from prefrontal EEG asymmetry, suggesting that it is a reliable neural indicator of changes in activity in the sub-cortical regions as a result of changes in music-induced affect. In sum, EEG asymmetry in the prefrontal region could be indicative of sub-cortical neural changes induced by music.

Other Index of Valence: Frontal Midline Theta

Besides frontal alpha asymmetry, studies have also established the relationship between frontal midline theta and emotional valence. Frontal midline theta is thought to reflect heightened mental effort and sustained attention, which is required across a multitude of cognitive processes (for reviews, see Inanaga, 1998; Schacter, 1977). The functional relevance of frontal midline theta in attention is evidenced by EEG and magnetoencephalography (MEG) source modelling studies that show converging evidence that frontal midline theta activity recorded at the scalp originates from the medial frontal cortex, especially within dorsal anterior cingulate cortex (ACC). Given that the ACC is part of a neural emotion circuit (Devinsky et al., 1995) and is connected to various brain regions which are involved in different cognitive and affective functions such as attention, decision making and information processing (Pardo et al., 1990; Posner & Petersen, 1990; Wang et al., 2005), frontal midline theta is hence thought to also be involved in emotion processing. Indeed, Aftanas and Golocheikine (2001) reported an increase of frontal midline theta power during “blissful positive states” achieved during meditation.

Similarly, Sammler et al. (2007) also found that pleasant music (as represented by consonance) elicited an increase of frontal midline theta (as compared to unpleasant music). Specifically, mid-frontal power was found to increase linearly with pleasantness ratings. Moreover, frontal midline power was also reported to be able to distinguish two negative emotions (anger and fear) elicited by music (Zhao et al., 2018). Taken together, these studies provide compelling evidence that frontal midline theta is modulated by emotion.

Heller's Model (1993)

A more established model describing the neural correlates of arousal is put forth by Heller (1993). In general, Heller (1993) argued for the specialization of the right parietotemporal regions in emotional information processing. In addition, the right parietotemporal regions are also critical in the experience of emotion as it constitutes a system involved in modulating autonomic and behavioral arousal in emotional states. Evidence for this comes from electrophysiological and brain damage studies that have demonstrated the involvement of right parietotemporal region in the evaluation and interpretation of emotional information (Borod et al., 1992; Heller, 1990; Silberman & Weingartner, 1986; Tucker & Williamson, 1984).

Heller (1993) further postulates that the right hemisphere operates in conjunction with a system localized to the frontal lobes that is involved in modulating the emotional valence of the experience. Specifically, the pattern of asymmetric activation of the frontal regions is such that cheerful emotional states are associated with higher relative activation over left frontal regions while depressed emotional states are associated with higher relative activation over right frontal regions (Davidson, 1992b; Heller, 1990). This is the same model as proposed by Davidson (1984, 1988, 1992a).

Therefore, according to Heller's (1993) model, higher right parietotemporal brain activity is related to increased arousal, and activation of the left relative to right frontal region is associated with positive emotions. This model of neural organization of emotional processing is consistent with psychological theories that states that emotional processing constitutes two fundamental aspects: (1) cognitive appraisal and (2) subjective experience (Lazarus, 1982; Zajonc, 1984).

More recently, Rogenmoser et al. (2016) suggests that arousal is associated with suppressed right posterior alpha power, while valence is associated with increased left frontal theta power. In addition, Daly et al. (2019) found that activity in the posterior temporal cortex exhibited concomitant changes together with arousal level, thus providing support for Heller's model of the involvement of the right parieto-temporal region for arousal.

Heilman's Model (1997)

Different theories and models have been put forth to describe the specific functional roles of the left and right hemispheres in emotional processing. Heilman (1997) proposed a model of modular cortical network which regulates limbic system activities and mediates emotional experience. Accordingly, the frontal lobes are crucial for emotional valence: positive emotions are mediated by the left frontal lobe while negative emotions are mediated by the right frontal lobe. In contrast, the arousal systems are activated by the right hemisphere, particularly the parietal lobe, while the left hemisphere modulates inhibition of the arousal systems. In addition, the orbito-frontal regions were postulated to mediate avoidance-related behaviors, and the parietal lobes mediate approach-related behaviors. These brain regions have close interconnections with the limbic system, the basal ganglia and reticular systems.

Arousal and Absolute Frontal Alpha EEG Activity

A number of researchers (e.g., Davidson et al., 1979; Dawson, 1994) have argued that absolute frontal alpha EEG activity may reflect the intensity of emotional experience. This pattern of neural organization was also observed by Schmidt and Trainor (2001), who reported an association between overall frontal activation and intensity of emotions elicited by music. Specifically, greater overall frontal activity was observed as the intensity of affective music stimuli increased.

Emotion Classification

Other studies have applied machine-learning algorithms to categorize EEG dynamics during music listening with considerable success (see Latha & Hema, 2012 for a review). For instance, Lin, Wang, et al. (2010) employed support vector machine (SVM) to classify four emotional states (joy, anger, sadness and pleasure) and obtained an averaged classification accuracy of 82.29 percent across 26 subjects.

2.4. Psychological Approach

Existing neurobiological literature has provided insight into the neural organization of music-evoked emotions. To gain a more holistic understanding of *why* and *how* music evokes emotion, it is necessary to look beyond brain-behavior associations and examine underlying psychological mechanisms of music-evoked emotions. In this regard, Juslin and Västfjäll (2008) described a comprehensive research framework, consisting of seven mechanisms: brain stem reflex, rhythmic entrainment, evaluative conditioning, contagion, visual imagery, episodic memory, musical expectancy, consequently termed as the BRECVEM model.

BRECVEM Framework

In this model, it is postulated that music evokes emotions through either one, or a combination, of the mechanisms. In addition, these mechanisms can be categorized in terms of the extent of which they are influenced by environment or learning. Mechanisms that are more ‘hard-wired’ responses to simple musical features are considered to not much affected by learning. In contrast, mechanisms that are differentially influenced by music that varies from one culture to another are thought to have a high extent of learning.

Mechanisms Low in Extent of Learning

Brain stem reflex is the process whereby the brain stem receives fundamental acoustic characteristics of the music and signals to other brain regions that a potentially important and urgent event requires attention, resulting in an induction of emotion (Davis, 1984). This process is usually automatic, quick and unlearned. They are usually evoked by loud, sudden or dissonant sounds in music and increase arousal and elicit feelings of surprise in the listener.

Rhythmic entrainment is when the music’s rhythm influences the body’s internal rhythm (e.g., heart rate), such that the internal bodily rhythm adjusts toward and eventually synchronizes with the external rhythm to a common periodicity, thus eliciting an emotion (Clayton et al., 2005). Rhythmic entrainment, evident in techno or march music, is often associated with increased arousal and feelings of connectedness (Bell, 1914), and emotional bonding (Gabrielsson, 2010).

Emotional contagion is the process where the individual perceives music’s emotional expression, and subsequently imitates the expression internally through the mirror-neuron system, thereby inducing emotions (Rizzolatti & Craighero, 2004). Indeed, Koelsch et al. (2006) found that music listening activated brain regions involved in pre-motor representations for production of vocal sounds, thus suggesting that individuals become aroused by voice-like features in the music as if they came from emotional expressions produced by a human voice (Juslin, 2001; Juslin & Laukka, 2003).

Mechanisms High in Extent of Learning

Evaluative conditioning is a process whereby emotions are induced as a result of frequent pairings between the stimulus and other stimuli with positive or negative emotional valence. For instance, a specific piece of music or song may have occurred repeatedly together in time with a specific event that always makes you sad. Through repeated pairing over time, the music itself will eventually arouse sadness, even in the absence of the event. As such, evaluative conditioning involves subconscious and effortless processes that can be subtly affected by musical events (Razran, 1954).

Visual imagery refers to a process whereby an emotion is evoked in the listener because he/she conjures up inner images during music listening. In this regard, the listener conceptualizes the music in terms of non-verbal associations between musical metaphors and various mental schemas (Kövecses, 2000; Lakoff & Johnson, 1980). Feelings of pleasure (Juslin et al., 2008) and deep relaxation (McKinney et al., 1997) are often associated with visual imagery during music listening.

Episodic memory refers to a process whereby music elicits an autobiographical memory of a specific event in the individual’s life, thus inducing an emotion (Baumgartner, 1992). When the memory is evoked, the emotions that are associated with the memory are evoked as well. These emotions may be intense, plausibly due to the physiological patterns in response the original events being stored in the memory, along with the content

(Lang, 1979). Music-evoked emotions linked to episodic memories are often experienced as feelings of nostalgia (Janata et al., 2007; Juslin et al., 2008).

Musical expectancy can be defined as a response to the gradual unfolding of music and its expected or unexpected continuation. More specifically, musical expectancies involve syntactical relationships between different parts of the musical structure (Narmour, 1991; Patel, 2003) and does not refer to other unexpected events that might occur in relationship to the music. Since musical expectancy reflects learned schema for specific musical styles that differ from one culture to another, listeners from different cultural background are likely to respond differently to the same piece of music (Juslin, 2012).

Additional Notes on Musical Expectancy

Musical expectancy is one of the mechanisms that have been most thoroughly investigated (Meyer, 1956). As described in the preceding section, it refers to a process whereby emotions are induced in listeners because a specific musical feature violates, delays, or confirms the listeners' expectations about the continuation of the music (Meyer, 1956). These expectations are based on the listeners' prior exposure and experience of the same musical style (Carlsen, 1981; Krumhansl et al., 1999). Meyer's influential theory received support from an fMRI investigation by Steinbeis et al. (2006), which used subjective and physiological measures to capture emotional responses to unexpected harmonic progressions in a Bach chorale. Furthermore, theoretical accounts of musical expectancy have been studied in terms of temporal structure (Jones, 1987; Jones & Boltz, 1989), melodic intervals (Cuddy & Lunney, 1995; Krumhansl, 1995; Krumhansl et al., 1999; Pearce & Wiggins, 2006) and harmonic expectancies

(Schmuckler, 1989). In general, musical emotions related to violation of expectancies include anxiety (Meyer, 1956) and surprise (Huron, 2006). More recently, Pearce (2018) suggests that fundamental to musical expectancy are the cognitive processes of statistical learning and probabilistic prediction. This will be further elaborated in Chapters 3 and 4.

Reciprocal Feedback Model of Musical Response

The reciprocal feedback model of musical responses (Hargreaves et al., 2005) consists of three main determinants of a specific response to a given musical stimulus: the music, the listener and the listening situation. Accordingly, there are bi-directional influences among any one of these three main determinants of musical response (Fig. 2-3).

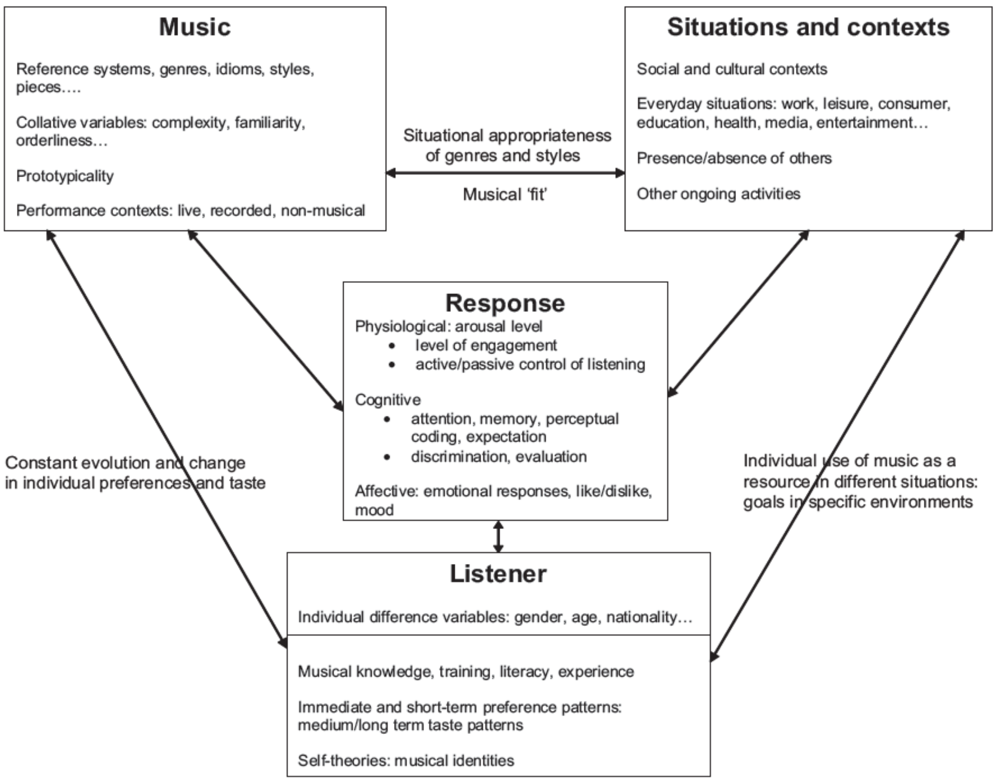


Figure 2-3. Reciprocal feedback model of musical response. *Adapted from Hargreaves et al. (2005).*

Musical response can be described in terms of physiological, cognitive and affective response. Physiological response is commonly measured in the form of autonomic arousal level, which is thought to be reflected in behavioral outcomes such as listener's level of engagement with the music. Cognitive response refers to the involvement of cognitive mechanisms in musical response, such as attention, memory, perceptual coding, expectation. Lastly, affective response includes emotional responses, liking and mood.

Relationship between 'Music' and 'Situations and Contexts'

Different musical genres and styles are seen as varying degrees of appropriateness depending on the listening situation. Situations and contexts can vary in many aspects, such as type of social and cultural context, type of everyday situations (e.g., work, leisure), and presence or absence of others (depicted in Fig. 2-3 as a reciprocal feedback relationship between music and situation/context).

Relationship between 'Listener' and 'Situations and Contexts'

Accordingly, individuals are thought to use music as a resource to achieve certain psychological states in different situations (depicted in Fig. 2-3 as a reciprocal feedback relationship between listener and situation/context).

Relationship between 'Music' and 'Listener'

Individual difference factors include age, gender, personality, other variables related to music, such as musical training, knowledge and experience. These are important factors to take note of in the study of music and emotion as there is some evidence that they are closely interrelated. In this model, listeners are thought to have immediate and short-term responses to particular music, as reflected by distinctive patterns of preferences. Over time, these accumulate to form fairly stable longer-term musical taste patterns. The long-term development of these patterns subsequently give rise to the concept of musical identity. While the musical taste patterns are fairly stable, they continue to develop and change as listeners are exposed to new musical pieces and styles (depicted in Fig. 2-3 as a reciprocal feedback relationship between music and listener).

In sum, each of the determinant informs one another and the relationship among music, listener and situation is constantly updated based on exposure, or changes in musical taste according to age.

Individual Differences: Absorption Trait

A robust body of literature has documented the relationship between personality and music preference (Rentfrow & Gosling, 2003; Vella & Mills, 2017); personality and music-evoked emotions (Chamorro-Premuzic et al., 2010; Silvia et al., 2015); music preference and music-evoked emotions (Schäfer & Sedlmeier, 2010); empathy and music-evoked emotions (Eerola et al., 2016). In recent years, there is increasing support for the role of absorption in aesthetic experience in general, which is extended to musical emotions as well. Absorption as a general trait is defined as "a capacity for absorbed and self-altering attention" (Tellegen & Atkinson, 1974). Existing studies have shown that absorption is related to a number of aesthetic experiences, such as abstract art (Combs et al., 1988) and dances (Bachner-Melman et al., 2005). While individual differences in personality, music preferences and musical expertise have been studied relatively extensively, there is a paucity of research that investigates absorption trait and emotional responses to music. It is therefore of interest to further examine the effect of absorption so as to gain a better understanding of this construct. Literature pertaining to absorption will be further elaborated in Chapter 6.

2.5. Theoretical Motivation and Research Framework

In sum, the field of music and emotion has grown tremendously since the 1980s. Researchers have taken different approaches such as music analytic, neurobiological and psychological approaches in the quest of addressing *why* and *how* music elicits emotion. The music analytic approach primarily aims to map different musical features (e.g., pitch, tempo, mode) to emotions. On the other hand, researchers from the neurobiological approach seeks to understand the neural correlates of music-evoked emotions. More specifically, they sought to establish the involvement of particular brain regions and networks (e.g., auditory cortex, limbic network), as well as reliable electrophysiological markers (e.g., frontal alpha asymmetry, frontal midline theta) of music-evoked emotions. Lastly, researchers from the psychological approach are mainly interested in the underlying mechanisms that are involved in emotion induction, and the relationship between music, listener and situation. Thus far, the most comprehensive research frameworks that have emerged are the BRECVEM model (Juslin & Västfjäll, 2008) and the reciprocal feedback model (Hargreaves et al., 2005).

While each research approach contributes uniquely to the scientific inquiry of music and emotion, this field could benefit from a multi-disciplinary approach, where findings from one research approach informs another. For instance, the psychological and individual differences literature has documented the importance of considering listener characteristics (e.g., personality, music preference and absorption trait) in emotional response. However, the role of listener characteristics is often neglected in studies employing machine learning, as their main concern lies with developing and selecting most reliable features and refining algorithms. As such, a multi-disciplinary approach could thus extend the findings from the psychological literature to other scientific communities, and vice-versa. In so doing, this helps to consolidate and refine future research themes and directions. This thesis therefore aims to bridge the gap between music, psychology and neuroscience in a series of three studies, which will be detailed next.

In terms of measurement, a majority of existing studies employed measures of self-reports (Eerola & Vuoskoski, 2013). The use of self-reports poses certain limitations in understanding music-evoked emotions as the relationship between self-reported emotions and the actual experience of emotion is often not a linear association. This comes from observations of behavioral manifestation of an emotion being covertly expressed in different manner across different individuals. In this regard, neuroimaging (e.g., fMRI, EEG) and psychophysiological studies (e.g., skin conductance, heart rate) could provide a more objective measure of emotion. Therefore, this thesis adopts a combination of self-report and EEG measures to study music-evoked emotions.

In the BRECVEM model (Juslin & Västfjäll, 2008), mechanisms differ on the extent to which they are influenced by music that varies from one culture to another. For instance, some mechanisms are proposed to be more hard-wired and innate (e.g., brain stem reflex, emotional contagion), while other mechanisms are more influenced by learning and the environment (e.g., musical expectancy). It is of interest to study how mechanisms with a higher dependency on learning and environment has on emotion as it allows us to see how learning could shape emotional responses, and consequently how this could inform more personalized applications of music.

Studying mechanisms which are more influenced by learning and the environment alludes to cross-cultural studies of music and emotion, which investigate if emotions elicited from culturally familiar or unfamiliar music would differ. Conventionally, researchers compared two distinct and homogenous cultures (e.g., Egermann et al., 2015), of which both cultures studied do not have any exposure to each other. The increasingly heterogeneity of modern societies as a result of globalization and internet poses a challenge in finding cultures that really have no exposure to another culture. As such, I propose that another suitable method to study mechanisms which are more influenced by learning and the environment could be to select familiar musical styles *vs* unfamiliar musical styles and examine this effect on music-evoked emotions. This is addressed in a pilot behavioral experiment (Study 1), which developed music stimuli of a familiar and unfamiliar musical style. Thereafter, an EEG experiment was conducted where electrophysiological recordings were taken as music stimuli which elicited the most emotional intensity of targeted emotions (taken from Study 1) were presented to participants. From this EEG experiment, three research objectives were explored in a series of three studies (Studies 2A, 2B and 2C). Firstly, given the increasing number of studies that reported involvement of other brain regions besides the frontal cortex, Study 2A aimed to clarify the neural correlates of music-evoked emotions. Subsequently, Study 2B extends the neurobiological understanding of the relationship between listener and music by examining the neural correlates of effect of familiarity with musical style on music-evoked emotions. Lastly, in the reciprocal feedback model of musical response (Hargreaves et al., 2005), the authors highlighted that emotion induced by music is not simply a product of music itself, but a result of the interactions between music, listener and situation. Therefore, it is important to incorporate measures of individual differences in the study of music and emotion, which is often neglected in neurobiological and machine learning studies. Common individual differences examined include personality (Vuoskoski & Eerola, 2011), music preferences (Rentfrow & Gosling, 2003) and music experience (Bigand & Poulin-Charronnat, 2006; Bigand et al., 2005). While there is increasing support for the association of absorption trait and emotional response (Sandstrom & Russo, 2013), it has received less extensive investigations as compared to the former variables. Therefore, I chose to study the role of absorption trait as an individual difference variable in music-evoked emotions (Study 2C).

Taken together, this thesis adopts the theoretical framework of considering interactions between music, listener and situation in the study of music and emotion. A pilot behavioral experiment (Study 1) first developed suitable music stimuli to be used for the subsequent EEG experiment, which clarified the electrophysiological correlates of music-evoked emotions (Study 2A), examined the effects of familiarity with musical style on emotion (Study 2B) and studied the role of listener characteristics in the relationship between music and emotional response by investigating the effects of absorption trait on emotion (Study 2C) (Fig. 2-4).

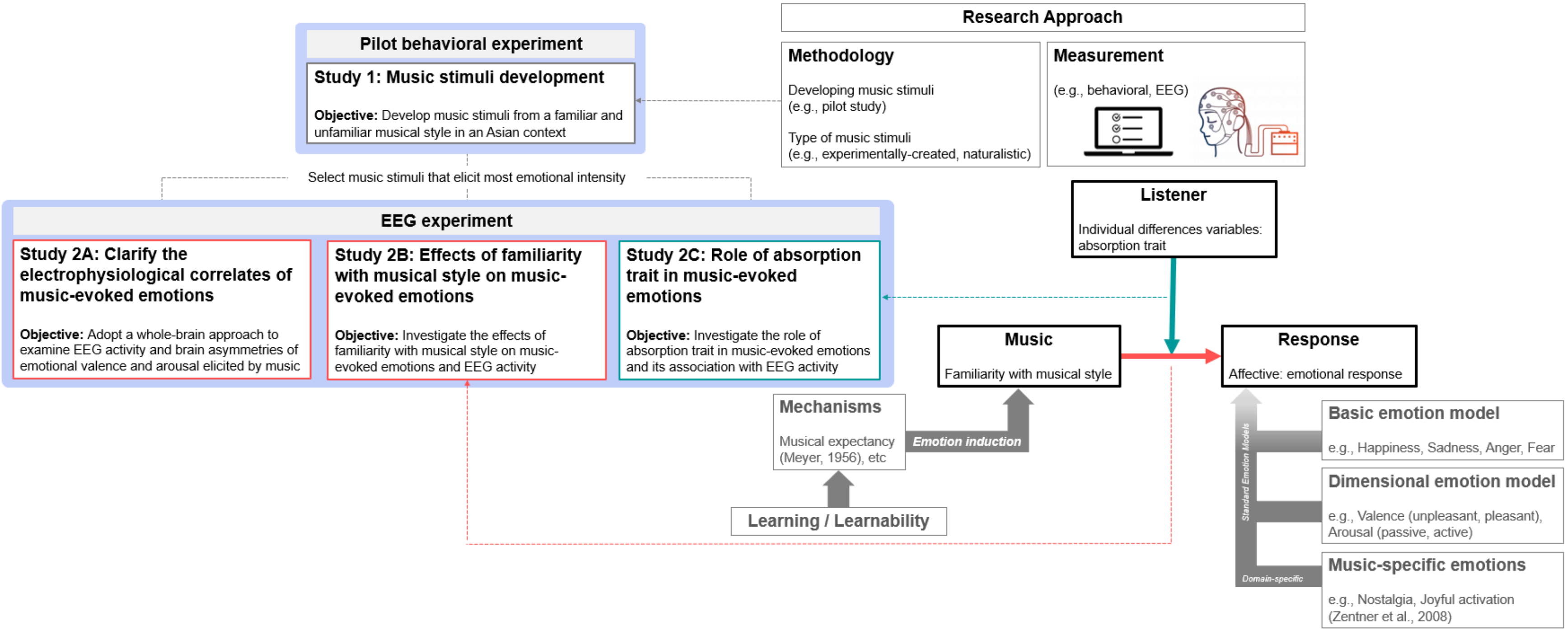


Figure 2-4. Overarching research framework organized according to music, listener and response. ***Study 1 (grey).*** Pilot behavioral experiment that develops music stimuli (naturalistic) of familiar and unfamiliar musical styles. ***Studies 2A (pink), 2B (pink) and 2C (green).*** EEG experiment that (A) systematically examined neural activity and asymmetries at each brain region across alpha, theta and beta frequency bands, (B) investigated the effects of familiarity with musical style on music-evoked emotions and (C) examined the role of absorption trait in music-evoked emotions. Literature reviewed (underlying mechanisms and emotion models) are in light grey. Bolded solid lines indicate directionality between variables. Dashed lines indicate the theoretical or methodological basis of each study.

CHAPTER III: STUDY 1

DEVELOPMENT OF MUSIC STIMULI OF FAMILIAR AND UNFAMILIAR MUSICAL STYLES

3.1. Development of Music Stimuli of Familiar and Unfamiliar Musical Styles

As one of the primary objectives of this thesis is to investigate the effects of familiarity with musical style on music-evoked emotions, there is first a need to select appropriate music stimuli. As such, this chapter will introduce first relevant literature pertaining to the mechanisms underlying familiarity with musical styles, namely musical expectancy, statistical learning and probabilistic prediction. Next, a pilot behavioral study (i.e., Study 1) which establishes a set of music stimuli of a familiar and unfamiliar musical style in an Asian context will be presented. Music stimuli that evoked the highest emotional intensities were selected for a subsequent experiment (more discussed in Chapters 4, 5 and 6).

As described in Chapter 2 (Literature Review), musical expectancy can be defined as a reaction to the gradual unfolding of music and its expected or unexpected continuation (Juslin & Västfjäll, 2008; Meyer, 1956). Using a computational approach to further Meyer's theoretical proposals, Pearce (2018) showed that a broad range of psychological processes involved in music perception (e.g., expectation, emotion, memory, similarity, segmentation and meter) can be understood in terms of a single underlying process of probabilistic prediction using learned statistical models.

According to Pearce (2018), internal mental and cognitive models of regularities that define a musical style's syntax are acquired through implicit statistical learning, which can be gained through passive exposure to such music. Individuals then generate probabilistic predictions which underlie perception and emotional experience of music based on the learned internal cognitive model. Thus, Pearce (2018) argues that probabilistic prediction can be conceptualized as the fundamental mechanism underlying perception and emotional experience of music, instead of other distinct cognitive mechanisms currently proposed (Juslin & Västfjäll, 2008; Lerdahl & Jackendoff, 1983; Temperley, 2001). He also demonstrated that the same computational model is effective in simulating enculturation and generating predictions about individual differences in music perception and experience as a result of enculturation in different musical styles.

Despite the growing number of studies investigating music-evoked emotions, the majority of these studies employed Euro-American art music (Eerola & Vuoskoski, 2013; Tirovolas & Levitin, 2011; Västfjäll, 2002) and there is a comparatively lack of studies using music from other musical styles or cultures. As illustrated that the meaning and emotions derived from music is not universal, but dependent on the location and context of the individuals, relying on Euro-American art music poses a challenge in developing a holistic and comprehensive understanding of music and emotions in non-Western countries.

Selection of Familiar and Unfamiliar Musical Styles

Selection of Familiar Musical Style

As a result of globalization, Singapore has a mix of influences from Western countries, East Asia and Southeast Asia countries. This is evident in the entertainment industry, where influences include popular music (e.g., Japanese-pop, Korean-pop, cosplay event music) and movie soundtracks (e.g., Japanese animation soundtracks, Korean drama soundtracks). Moreover, Chin (2016) reported that Singaporean adolescents selected Popular musics, Dance and Techno soundtracks and theme songs more frequently as their preferred music, as compared to folk and indies. Therefore, popular music soundtrack genres are a suitable choice to be considered as familiar musical style as they are more preferred and more frequently listened to. Given the increasing availability and exposure to Japanese animation original soundtracks (OST) in Singapore, this is selected as a familiar musical style.

In choosing Japanese animation OSTs as music stimuli for the subsequent electrophysiological study, I have adopted a referentialist perspective, which argues that music derives its meaning by reference to extramusical contexts such as love, suspense or violence (Meyer, 1956). This is in contrast with an absolutist perspective, which postulates that meaning in music is derived exclusively from the relationships set form within the musical piece (Meyer, 1956). With that in mind, caution should be taken in the interpretation of results and attributions to solely musical properties of the music stimuli used, since Japanese animation OSTs could also have reference to the generic visual images or narrative they suggest (e.g., love story, war epic). Nevertheless, the use of Japanese animation OSTs provide better ecological validity as compared to MIDI-generated stimuli.

Selection of Unfamiliar Musical Style

A common approach in the selection of an unfamiliar musical style is to consider how much exposure participants in the study have to the musical style of interest. This method is more straightforward in societies with a rather distinct and homogenous culture. For instance, Balkwill and Thompson (1999) investigated cross-cultural perception of emotion in music by presenting to Japanese music (as familiar musical style) and Hindustani music (as unfamiliar musical style) to a group of Japanese participants. In another study, Egermann et al. (2015) reported universal emotion-related psychophysiological responses to music by presenting Western music to an isolated population of Mebenzélé Pygmies (who do not have any experience with Western music and culture), and conversely, presenting Pygmy music to Western listeners (who have no exposure to Congolese music).

While this approach in determining unfamiliar musical style suffices for societies with homogenous culture, it is more difficult to implement in societies that are multi-cultural, like Singapore. In other words, it would not be feasible to use music of a minority cultural group to be considered as unfamiliar musical style, since other ethnic groups may also have exposure to that musical style. As such, I relied on a genre that is not frequently listened to amongst Singaporeans, and chose music that is from a location that is geographically distant from Singapore to be considered as an unfamiliar musical style.

I surveyed existing music datasets and decided on the Greek Music Dataset (Makris et al., 2015). Based on results from the National Music Consumption Survey conducted by the National Arts Council (2017) and Chin (2016), there were indications that Greek Laïkó music were less likely to be listened to by Singaporeans. I selected the music from the genre Laïkó, which comprises Greek folk songs from the time period 1940. This dataset contains 1400 songs from various Greek genres, of which audio content in YouTube is provided. A group of annotators (3M 2F; age: 23- to 30-years-old; musical background: three students of the Music Department of the Ionian University and two sound producers) manually annotated labels pertaining to genre styles of music. In addition, they also listened to and read the lyrics for each song, rating emotions elicited on the valence-arousal model. In their study, arousal values correspond to moods such as “angry” and “exciting” to ‘tired” and “serene” from 1-4. Valence values correspond to moods such as “sad” and “upset” to “happy” and “content” from A-D (Fig. 3-1). The reliability of an annotation was reflected by inter-annotator agreement (Boisen et al., 2000). The collection of metadata and audio, lyrics and symbolic features is freely available for download at: http://di.ionio.gr/hilab/gmd. For more details, please refer to Makris et al. (2015).

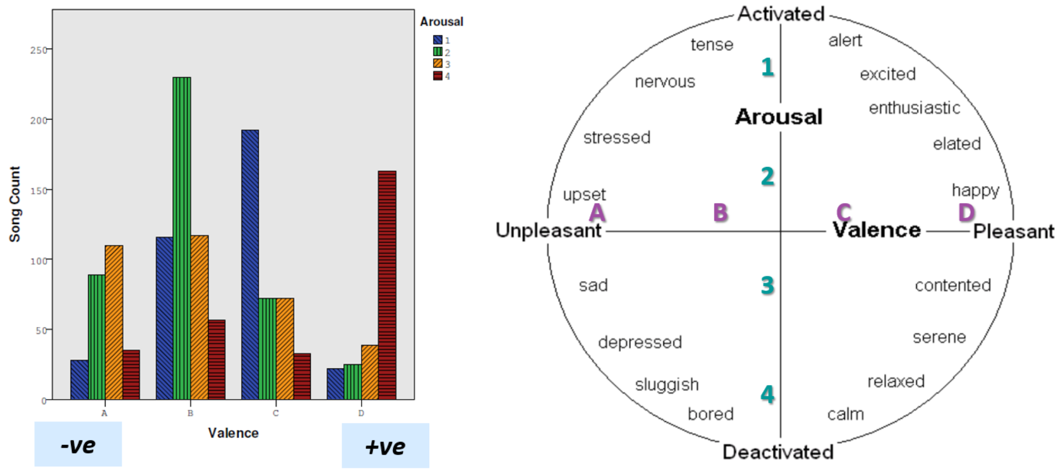


Fig. 3-1. Left. Distribution of mood annotations in the Greek Music Dataset. *Right.* Valence and arousal values. *Adapted from Makris et al. (2015).*

3.2. Methods

Participants

A total of 74 young, healthy adults (41M 33F, age: *M* = 22.51, *SD* = 1.28) were recruited for this study, which was approved by the Nanyang Technological University Institutional Review Board (NTU-IRB; IRB-2015-09-012) (Appendix A-1). They have no history of mood, psychiatric or neurological problems, and have normal hearing. They are all right-handed and are all considered non-musicians. They were only selected to participate in this study if they frequently engaged in music-related activities (e.g., music listening or watch television/drama series) as individuals who use music in everyday life would be more likely to be experientially engaged by a music listening task in an experimental setting. Prior to the experiment, participants completed the informed consent form (Appendix A-2).

Music Stimuli

In general, each musical excerpt should not contain lyrics, dialogues or sound effects such as car sound, and should not be well-recognized by participants, so as to reduce involving episodic memory processes (Vuoskoski & Eerola, 2011). As Daly et al. (2014) previously used music stimuli of 12-seconds to investigate EEG activity and music-induced emotions using excerpts taken from the same dataset of film music, the current study will use music stimulus of at least 12-seconds long. All musical excerpts were normalized to ensure equal loudness across excerpts. Each musical excerpt begins with a 1-sec fade-in and ends with a 1-sec fade-out so as to smoothen the start and end of each excerpt. These were implemented with the WavePad Audio Editing Software.

Familiar Musical Style

A total of 29 musical excerpts from Japanese animation OSTs composed between the years 2006 to 2016 were selected by the author (Appendix A-3). The selection of musical excerpts was limited to those published within the last two decades so as to maintain relative homogeneity of sound quality among musical excerpts. All musical excerpts were of 45 seconds.

Unfamiliar Musical Style

A total of 18 songs were selected from the Greek Music Dataset, Laïkó genre (Appendix A-4). Four musical excerpts were selected from each valence-arousal quadrant. Only the instrumental portions of the songs were chosen, resulting in a range of duration between 15 and 45 seconds.

Procedure

Musical excerpts were developed in four stages and sets. The first set of stimuli consisted of eight musical excerpts and were presented to participants from Stages 1 to 4. As a result, all 74 participants rated these eight musical excerpts. Three participants had missing data for the discrete emotions, and hence were excluded from subsequent analyses. Therefore, a total of 71 responses (39M 32F, age: $M = 22.51$, $SD = 1.28$) were analyzed for these eight musical excerpts.

The second set of stimuli consisted of seven musical excerpts and were presented to participants in Stages 2 and 3. As a result, a subset of 35 participants rated these seven musical excerpts. Seven participants had missing data for the discrete emotions, and hence were excluded from subsequent analyses. As such, a total of 28 responses (14M 14F, age: $M = 22.51$-years-old, $SD = 1.50$) were analyzed for these seven musical excerpts.

The third set of stimuli consisted of 14 musical excerpts. These were presented to participants in Stage 3. As a result, a subset of 30 participants rated these 14 musical excerpts. Five participants had missing data for the discrete emotions, and hence were excluded from subsequent analyses. As such, a total of 25 responses (14M 11F, age: $M = 22.52$-years-old, $SD = 1.29$) were analyzed for these 14 musical excerpts.

The fourth set of stimuli consisted of 18 musical excerpts from the Greek music dataset. These were presented to participants in Stage 4. As a result, a subset of 15 participants (10M 5F, age: *M* = 22.73-years-old, *SD* = 1.39) rated these 18 musical excerpts. A summary of demographics is provided in Table 3-1.

The number of participants in each of the subset is comparable with the range of sample size commonly used in studies of music and emotion (Tirovolas & Levitin, 2011).

Table 3-1: Music stimuli development timeline and corresponding demographics.

	Japanese animation OST (Familiar musical style)			**Greek Laïkó music** (Unfamiliar musical style)
	Set #1	Set #2	Set #3	Set #4
No. of musical excerpts presented	8	7	14	18
Stage 1	x			
Stage 2	x	x		
Stage 3	x	x	x	
Stage 4	x			x
Total no. of participants recruited	74	35	30	15
No. of participants excluded	3	7	5	0
Final *n*	**71**	**28**	**25**	**15**
Demographics				
Gender (M : F)	39 : 32	14 : 14	14 : 11	10 : 5
Age [years: Mean (*SD*)]	22.51 (*1.28*)	22.51 (*1.50*)	22.52 (*1.29*)	22.73 (*1.38*)
Formal musical training : Self-taught / no musical training	29 : 42	13 : 15	12 : 13	5 : 10

Notes. 'x' indicates musical excerpts presented to participants in each development stage.

Task Paradigm

Participants were first familiarized with using the Dual Axis Rating and Media Annotation software (DARMA; Girard & Wright, 2018; see Appendix A-5) to rate their felt emotions continuously as they listened to the music. Valence was represented on the horizontal axis (unpleasant – pleasant), while arousal was represented on the vertical axis (deactivated – activated) (Fig. 3-2).

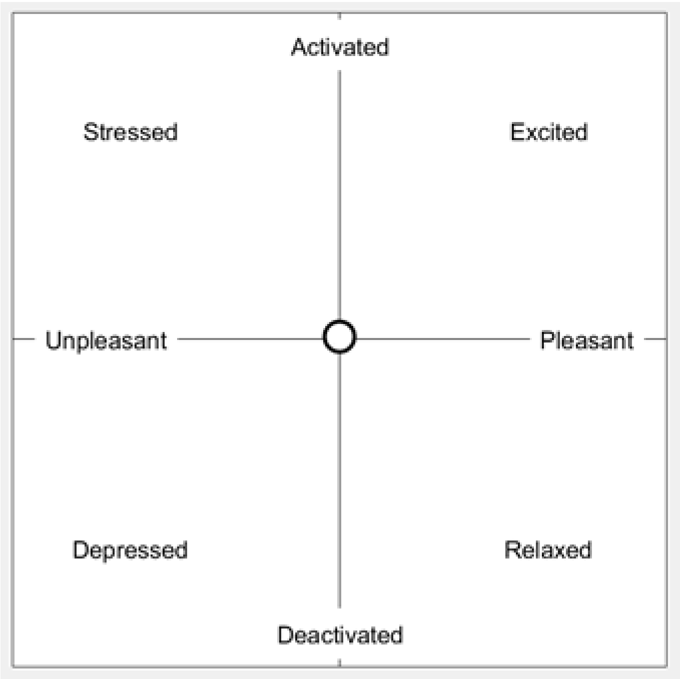


Fig. 3-2. Graphic interface that participants were presented with the rate their emotions. Valence: unpleasant – pleasant; Arousal: deactivated – activated.

Next, they completed the emotion rating task where they were instructed to rate their felt emotions (and not perceived emotions). For each musical excerpt, they rated their felt emotions continuously using DARMA as they listened to the music (Appendix A-6).

After each musical excerpt was played, participants completed a pen-and-paper emotion rating questionnaire which required them to rate the intensity with which they felt the emotions from a scale of 1 (not at all) to 5 (very much) for the following 14 emotion terms (comprised of basic emotion model and domain-specific model): happy, fear, anger, surprise, disgust, sadness, amazement, solemn, tenderness, nostalgia, calmness, power, joyful activation and tension. Emotion terms in the domain-specific model were provided with descriptions of the terms (Appendix A-7). Participants also rated how likely they are to recognize ("Have you heard this tune before?") and anticipate ("Are you able to anticipate what is coming next in the music") the music, with 1 being definitely not and 5 being definitely yes (see Fig. 3-3). Thereafter, they completed a demographic questionnaire which consists of questions relating to their musical background (Appendix A-8).

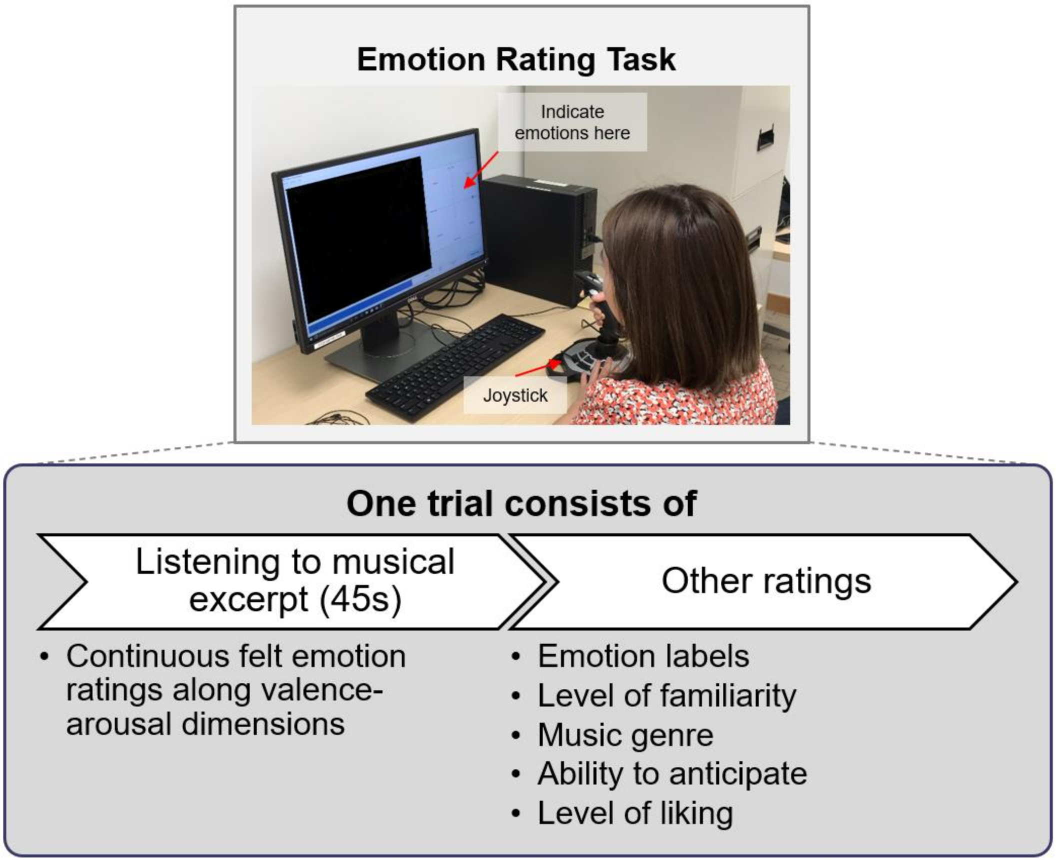


Fig. 3-3. Emotion rating task. Participants used a joystick to indicate their felt emotions.

Data Analyses

Mean valence and arousal ratings are plotted on a two-dimensional space to visualize the distribution of emotional ratings. As a measure of interrater reliability, intraclass correlation coefficient (ICC) was calculated for each musical excerpt. ICC is a good measure of reliability as it reflects both degree of correlation and agreement between measurements. In particular, interrater reliability can be defined as reflecting variation between two or more raters who measure the same group of subjects (Koo & Li, 2016). The consistency definition of ICC is used in this study, which is concerned if raters' scores to the same group of subjects are correlated in an additive manner (McGraw & Wong, 1996). According to Koo and Li (2016), values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability.

In addition, mean recognition score was also calculated for each excerpt. Subsequently, four musical excerpts that elicited the highest intensity for each emotional state were first selected for the subsequent experiment. These excerpts also had to meet the following criteria: (1) demonstrate good interrater reliability, as indexed by ICC and (2) not well-recognized (to minimize episodic memory processes), as calculated by a mean recognition score. Should a musical excerpt that elicited the highest intensity does not have good reliability or is recognized by a majority of participants, it is not chosen and the stimuli that elicits the next highest intensity will be chosen.

3.3. Results

Japanese animation OSTs elicited three distinct emotional states: (1) negative valence/high arousal, (2) positive valence/high arousal, and (3) positive valence/low arousal (Fig. 3-4).

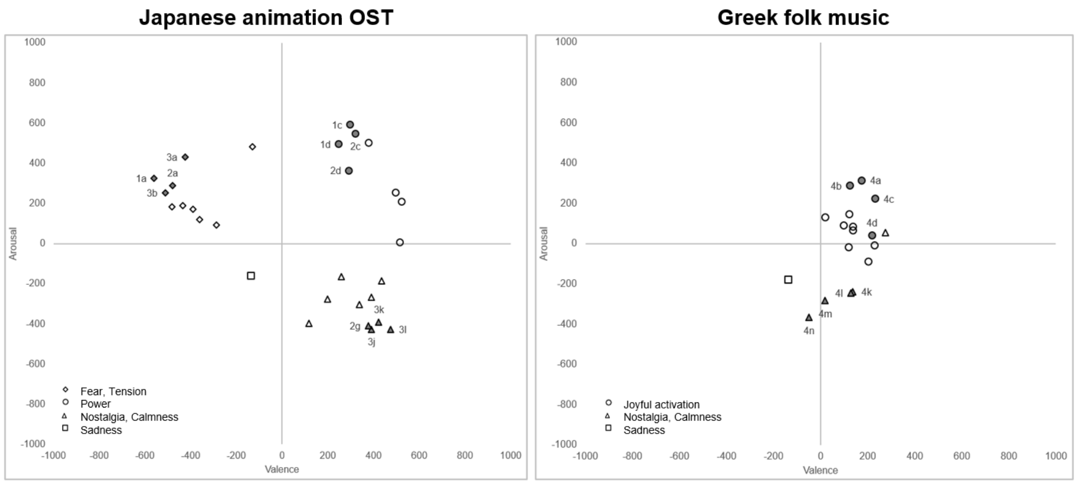


Fig. 3-4. Valence-arousal ratings of musical excerpts. (**Valence:** -1000 = unpleasant; 0 = neutral; 1000 = pleasant. **Arousal:** -1000 = very passive; 0 = neutral; 1000 = very active).
Selected pieces for subsequent study are shaded in grey.

A total of ten musical excerpts were rated as negative valence/high arousal and were also felt as eliciting emotions of Fear and Tension. Another eight musical excerpts were rated as positive valence/high arousal and had highest mean rating on the emotion of Power (feeling strong, heroic, triumphant, energetic). Lastly, a remaining of ten musical excerpts were rated as positive valence/low arousal and these music were felt to evoke emotions of Nostalgia and Calmness (Fig. 3-5a). As only one musical excerpt was experienced as negative valence/low arousal, it was not included in subsequent analyses.

In contrast, the majority of Greek Laïkó musical excerpts were experienced as positive valence. While there is some distinction between levels of arousal, the intensity of arousal evoked is not as high as compared to that of the Japanese animation OSTs (Fig. 3-4). A total of ten musical excerpts were rated as higher arousal and mostly felt as eliciting emotions of Joyful activation (feels like dancing, bouncy feeling, animated, amused). The remaining eight musical excerpts were rated as lower arousal and mostly felt as eliciting emotions of Nostalgia and Calmness (Fig. 3-5b).

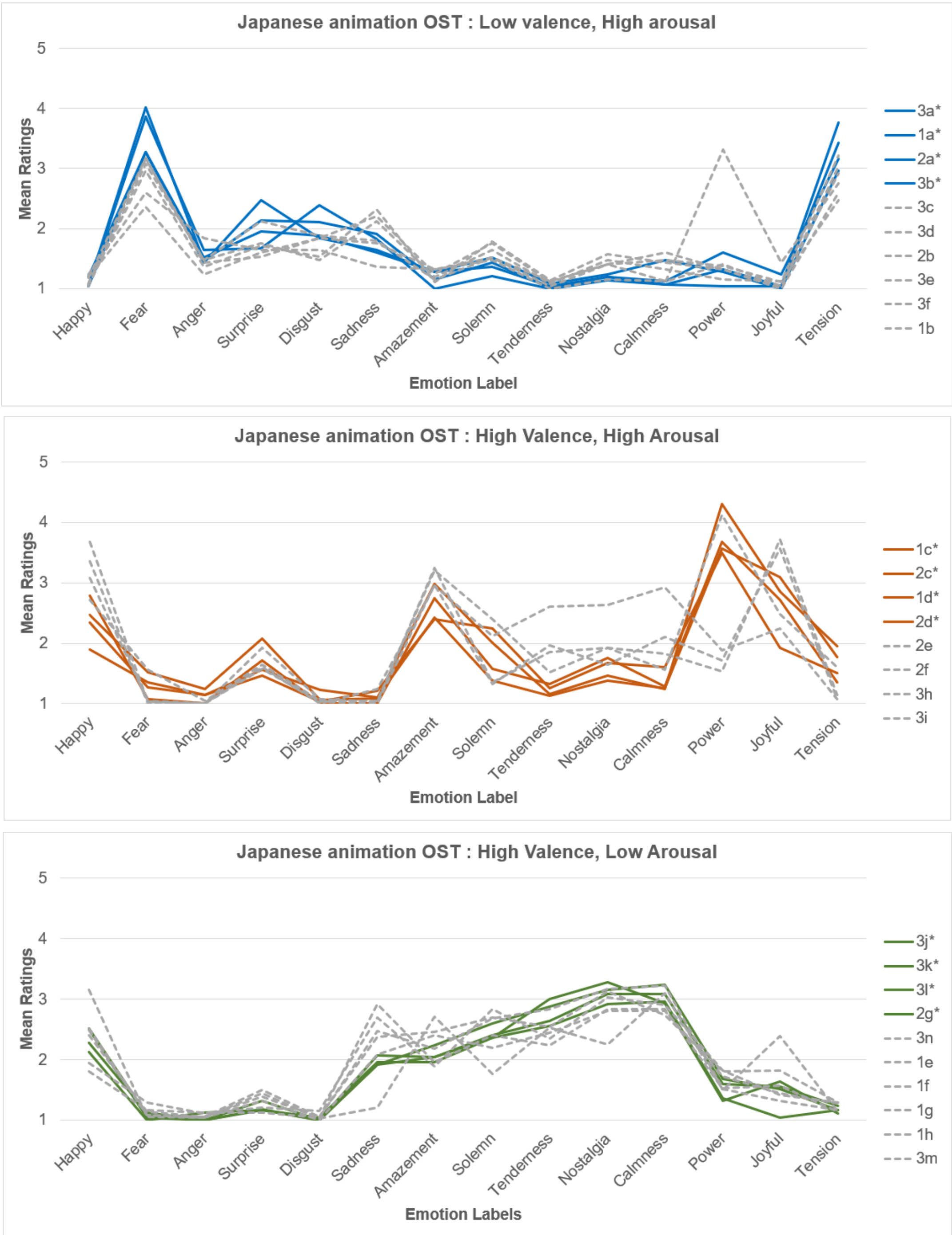


Fig. 3-5a. Discrete emotions for Japanese animation OST. *(1 = not at all; 5 = very much)*

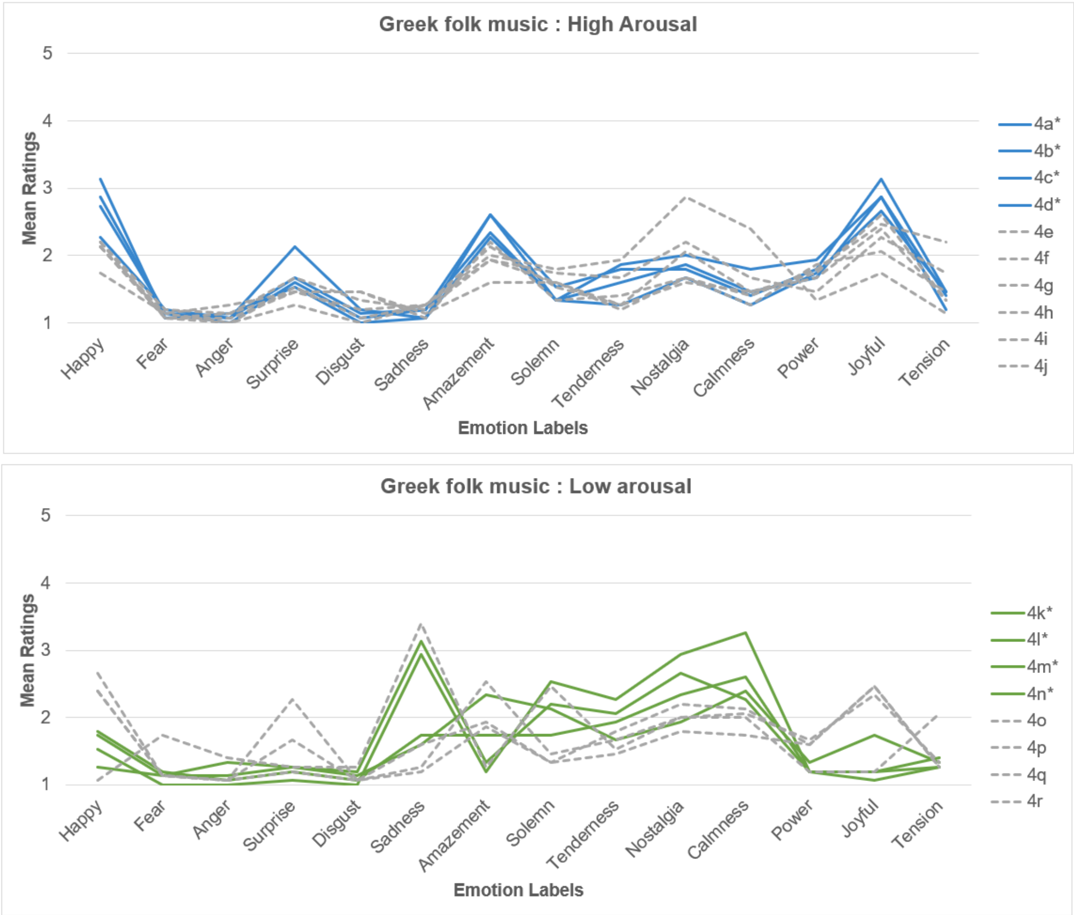


Fig. 3-5b. Discrete emotions for Greek Laïkó music. *(1 = not at all; 5 = very much)*

The final list of musical excerpts is shown in Table 3-2a and 3-2b, and shaded in grey in Fig. 3-5a and 3-5b. Musical excerpts from the Japanese Animation OSTs are 45-sec while musical excerpts from the Greek Laïkó music are between 20- to 45-sec (M = 29 sec, SD = 8.04). Selected musical excerpts demonstrate good to excellent reliability (ICC range: .79 to .99) and were mostly not recognizable to participants (range of mean recognition score: 1.79 to 3.11) (Table 3-3).

Table 3-2a: List of selected music stimuli for familiar musical style (Japanese animation OSTs).

No.	Musical Excerpt ID	Composer	Track Name	Album Name	Track No.	Min: Sec	Youtube Link	Date of release
Negative valence, High arousal								
1	1a	Akira Senju	Pride	Fullmetal Alchemist Brotherhood OST 2	3	0:11 - 0:56	https://www.youtube.com/watch?v=oMLl29K33fk	2010
2	2a	Yuki Hayashi	Aku no shinri (Evil Of Psychology)	My Hero Academia OST	27	0:00 - 0:45	https://www.youtube.com/watch?v=uHf69Vt2Z4Y&t=50s	2016
3	3a	Shiro Sagisu	Crumbling Idee Fixe	Berserk Original Soundtrack	6	0:00 - 0:45	https://www.youtube.com/watch?v=MKa5xLoy2BE	2016
4	3b	Yutaka Yamada	Transplantation	Tokyo Ghoul Original Soundtrack	5	1:05 - 1:50	https://www.youtube.com/watch?v=FhKCS6n9lgE	2015
Positive valence, High arousal								
1	1c	Tatsuya Kato	Shokugeki Start!	Shokugeki no soma OST 1	30	1:54 - 2:39	https://www.youtube.com/watch?v=iZd99_wxiOA	2015
2	1d	Hiroyuki Sawano	Exorcist Concerto Second Movement: X	Blue Exorcist OST 1	2	2:53 - 3:38	https://www.youtube.com/watch?v=0tIAO8LZc0Q	2011
3	2c	Yasuharu Takanashi	Fairy Tail Main Theme	Fairy Tail OST 1	1	1:15 - 2:00	https://www.youtube.com/watch?v=cjnl3lfaoEo	2010
4	2d	Yuki Hayashi	Plus Ultra	My Hero Academia OST	18	0:00 - 0:45	https://www.youtube.com/watch?v=FvPWLLzHrSA	2016
Positive valence, Low arousal								
1	2g	Yukari Hashimoto	After school without a plan	Gekkan Shojo Nozaki Kun Vol. 4	1	0:53 - 1:39	https://www.youtube.com/watch?v=XgSAn658Lyo	2014
2	3j	Masaru Yokoyama	Bye	Plastic Memories Original Soundtrack Vol. 1	8	0:45 - 1:30	https://www.youtube.com/watch?v=4XjejmAVUEE	2015
3	3k	REMEDIOS	Dynamic Sunset	Anohana: The Flower We Saw That Day	3	2:02 - 2:47	https://www.youtube.com/watch?v=bUz3n90O04E	2011
4	3l	S.E.N.S. Project	Story of Mind	Ore Monogatari (My Love Story) Original Soundtrack	7	1:03 - 1:48	https://www.youtube.com/watch?v=OcEorer4yx4	2015

Notes. The numeric value assigned to the musical excerpt represents which musical set it belongs to.

Table 3-2b: List of selected music stimuli for unfamiliar musical style (Greek Laïkó music).

No.	Musical Excerpt ID	Composer	Track Name	Min:Sec	Youtube Link
High arousal					
1	4a	Tolhs Voskopoulos	H valitsa	0:00 - 0:22	http://www.youtube.com/watch?v=Jez0DQRaxWk
2	4b	Giwrgos Ntalaras	Alla mou len ta matia sou	0:00 - 0:23	http://www.youtube.com/watch?v=PVibsgTbKKI
3	4c	Tolhs Voskopoulos	Edw kai kamposo kairo	0:00 - 0:30	http://www.youtube.com/watch?v=RLTC8Q8veUc
4	4d	Mixalhs Violarhs	Zakynthinia mou komissa	0:03 - 0:23	http://www.youtube.com/watch?v=vKxrdPo6ayo
Low arousal					
1	4k	Anna Vissi	Sagapw	0:02 - 0:35	http://www.youtube.com/watch?v=e_m-qFxuCDs
2	4l	Pantelhs Thalassinos	Ta smyrneika tragoudia	0:34 - 1:13	http://www.youtube.com/watch?v=9IbN9NKHTLM
3	4m	Margarita Zorbala	Margarita Magiopoula	0:00 - 0:24	http://www.youtube.com/watch?v=3rPaehCyhWU
4	4n	Maria Dhmhtriadh	To treno feugei stis 8	0:00 - 0:41	http://www.youtube.com/watch?v=CbVJ4tMB8Bw

Notes. The numeric value assigned to the musical excerpt represents which musical set it belongs to.

Table 3-3: Recognition score and ICC of selected music stimuli

No.	Musical Excerpt	Recognition Score [Mean, (*SD*)]	Intraclass Correlation Coefficient
Japanese animation OST (Familiar musical style)			
Low Valence High Arousal (JPN_Fear)			
1	1a	2.87 (*1.26*)	.99
2	2a	1.79 (*1.03*)	.98
3	3a	2.04 (*1.31*)	.95
4	3b	1.92 (*1.12*)	.95
High Valence High Arousal (JPN_Power)			
1	1c	2.94 (*1.18*)	.99
2	1d	2.45 (*1.16*)	.99
3	2c	3.11 (*1.34*)	.97
4	2d	2.57 (*1.23*)	.95
High Valence Low Arousal (JPN_Nostalgia)			
1	2g	2.61 (*1.23*)	.97
2	3j	2.84 (*1.18*)	.96
3	3k	2.36 (*1.22*)	.95
4	3l	3.08 (*1.41*)	.95
Greek Laïkó music (Unfamiliar musical style)			
High Valence High arousal (GRK_Joy)			
1	4a	2.93 (*1.44*)	.91
2	4b	2.40 (*1.06*)	.86
3	4c	2.53 (*1.25*)	.91
4	4d	2.47 (*1.13*)	.88
High Valence Low Arousal (GRK_Nostalgia)			
1	4k	2.40 (*1.30*)	.89
2	4l	2.47 (*1.06*)	.79
3	4m	2.80 (*1.15*)	.94
4	4n	2.67 (*1.05*)	.93

Notes. Recognition score. 1 = definitely not; 3 = not sure; 5 = definitely yes. Intraclass correlation coefficient (ICC) reflects consistency. *Poor reliability*: < 0.5; *Moderate reliability*: between 0.5 and 0.75; *Good reliability*: between 0.75 and 0.9; *Excellent reliability*: > 0.9 (Koo & Li, 2016).

3.4. Discussion

This study aimed to establish a suitable set of musical excerpts from a familiar and unfamiliar musical style in an Asian context. Based on music listening trends of Singaporean listeners, the Japanese animation OST was selected as a familiar musical style and the Greek Laïkó music genre was selected as an unfamiliar musical style. Emotion ratings of the musical excerpts were evaluated in terms of the valence-arousal framework and discrete emotion framework (consisting of basic emotion model and music-specific emotion model). Musical excerpts from the Japanese animation OST were distributed in three emotional states: negative valence/high arousal, positive valence/high arousal and positive valence/low arousal. On the other hand, musical excerpts from Greek Laïkó music predominantly elicited emotions of positive valence which varies in level of arousal. Of interest, emotional intensity in the familiar musical style (Japanese animation OST) were higher as compared to the unfamiliar musical style (Greek Laïkó music).

For both musical styles, participants predominantly selected emotion terms from the domain-specific model rather than basic model, as they felt emotions of Power and Nostalgia in Japanese animation OSTs and emotions of Joyful activation and Nostalgia in Greek Laïkó music. This suggests that the domain-specific model is more relevant in describing music-evoked emotions as compared to the basic model, a finding consistent with Zentner et al. (2008).

Several limitations should be taken note from this study. First, the sets of musical excerpts were rated by different number of participants. Nonetheless, the demographics of participants in each set of musical excerpts emotion rating are mostly comparable in terms of age, gender and musical background.

Second, a theoretical (rather than empirical) was adopted to select Japanese animation OST as familiar musical style and Greek Laïkó music as unfamiliar musical style. In this perspective, there was a lack of measure regarding how familiar participants were with Japanese animation OST and Greek Laïkó music. Nevertheless, mean recognition score reported in this study showed that while participants are mostly unable to recognize all selected musical excerpts, a higher proportion definitely did not recognize most of the Greek Laïkó music as compared to Japanese animation OST. This provides some support that participants in this study were not as familiar with Greek Laïkó music as compared to Japanese animation OST. Lastly, musical excerpts from the unfamiliar musical style (Greek Laïkó music) are of variable time duration. While there is a lack of uniformity in length, emotions elicited in each musical excerpt is singular (Appendix A-6) and not mixed (i.e., more than one emotion elicited in the time course of the musical excerpt). This provides a valid basis to use these musical excerpts for the subsequent electrophysiological study.

In sum, the current study established a set of musical excerpts from the Japanese animation OST and Greek Laïkó music that can be used for investigations of effects of familiarity with musical style on music-evoked emotions. While there are some methodological limitations, both examples nevertheless constitute one of the pioneers in establishing a set of musical excerpts from musical styles that are not frequently investigated in the field of music and emotion. By exploring the use of other musical styles for a study on musical emotion, this study contributes to the generalizability of current music and emotion findings.

CHAPTER IV: STUDY 2A

CLARIFYING THE ELECTROPHYSIOLOGICAL CORRELATES OF MUSIC-EVOKED EMOTIONS

4.1. Clarifying the Electrophysiological Correlates of Music-evoked Emotions

Studies employing the electrophysiological technique have provided valuable insight into the temporal dynamics of neural activity underlying music-evoked emotions. Findings from EEG studies have been thought to represent a more objective measurement of emotion as compared to the subjectivity of self-reports. Existing neurobiological studies have reported the following common electrophysiological models of emotions in general as well as music-evoked emotions (see Chapter 2 for more details): (1) right hemisphere hypothesis (Borod et al., 1998); (2) hemispheric valence hypothesis (Davidson, 1984, 1988, 1992a) which states that greater relative left frontal activity for positive emotions and greater relative right frontal activity for negative emotions, also termed as *frontal alpha asymmetry*; (3) Heller's (1993) model: in addition to hemispheric valence hypothesis, the involvement of right parietal region for arousal; (4) Heilman's (1997) model: in addition to hemispheric valence hypothesis, the involvement of right parietotemporal region for arousal. In addition, several electrophysiological markers of emotions have been established as well: frontal midline theta reflective of emotional valence (Aftanas & Golocheikine, 2001; Sammler et al., 2007) and absolute frontal alpha EEG activity reflective of arousal (Dawson, 1994).

However, several studies (e.g., Altenmuller et al., 2002; Nemati et al., 2019; Trochidis & Bigand, 2012) examining music-evoked emotions did not find similar neural patterns. Instead, these studies showed a collective trend of the involvement of other brain regions and asymmetries in other frequency bands. As such, the current chapter first details more literature from the neurobiological approach, before describing the EEG study conducted to clarify the neural correlates of music-evoked emotions.

The involvement of other brain regions in music processing or music-evoked emotions have been documented by several existing studies (e.g., Altenmuller et al., 2002; Chang et al., 2015; Lin, Duann, et al., 2010; Trochidis & Bigand, 2012). More recently, Ara and Marco-Pallarés (2020) showed that theta phase synchronization between the right frontal and temporal regions increased with the degree of pleasure experienced by participants, suggesting that slow fronto-temporal loops play a key role in music-evoked pleasantness.

Besides the involvement of other brain regions in music-evoked emotions, studies have also shown asymmetries in other frequency bands. For instance, Trochidis and Bigand (2012) found that negative emotions are associated with lesser theta power in the right fronto-central regions as compared to positive emotions such as happiness and serenity. In addition, Daly et al. (2019) employed EEG-fMRI and found that self-reported valence was significantly related to EEG beta asymmetry, of which EEG beta band asymmetry had significant associations with blood-oxygen-level-dependent (BOLD) activity in amygdala, posterior temporal cortex and cerebellum.

Taken together, cumulative evidence from electrophysiological studies on musical emotions show that emotional responses during music listening could involve other brain regions besides the frontal cortex and are possibly related to asymmetries of other brain regions other than the frontal cortex (i.e., frontal alpha asymmetry). However, the lack of studies that adopted a whole-brain approach in examining music-evoked emotions across alpha, beta and theta frequency bands has made it difficult to ascertain the neural correlates of music-evoked emotions. Therefore, there is a need to compare results of frontal alpha asymmetry with indices derived in other brain regions and frequency bands. This can be addressed by adopting a whole-brain approach across different frequency bands to systematically examine EEG asymmetries at each brain region study the electrophysiological correlates of music-evoked emotions. Results from this study will thus be helpful in refining current understanding of music-evoked emotions for the purposes of emotion-recognition work employing music as stimuli.

As such, the main objective of Study 2A is to clarify the electrophysiological correlates of music-evoked emotions by systematically examining EEG asymmetries at each brain region across the alpha, beta and theta bands. For this study, comparison of different emotional responses elicited by music of a familiar musical style, that were the Japanese animation original soundtracks (OSTs) in Study 1 (Chapter 3) identified, will be conducted. Based on findings from Study 1 (Chapter 3), I expected that the music stimuli will elicit three emotional states: (1) low valence and high arousal: “JPN_Fear”; (2) high valence and high arousal: “JPN_Power”; and (3) high valence and low arousal: “JPN_Nostalgia”.

It is hypothesized that musical excerpts employed in the study would elicit similar patterns documented in current literature, specifically:

Emotional Valence:

1) According to the hemispheric valence hypothesis (Davidson, 1984, 1988, 1992a):

a) A significant valence by hemisphere interaction is expected in the alpha frequency band: pleasant music (JPN_Power) will elicit greater relative left frontal EEG activity while unpleasant music (JPN_Fear) will elicit greater relative right frontal EEG activity.
b) Asymmetry Index in the frontal alpha frequency band will be correlated with valence ratings.

2) Based on literature that demonstrated associations between pleasantness and frontal midline theta power, pleasant music (JPN_Power) is hypothesized to elicit an increase of frontal midline theta power as compared to unpleasant music (JPN_Fear).

Emotional Arousal:

1) Based on studies that documented associations between absolute frontal activity and emotional arousal (Dawson, 1994; Schmidt & Trainor, 2001), the current study hypothesizes that music with a higher level of arousal (JPN_Power) will show greater absolute frontal activity as compared to music with lower level of arousal (JPN_Nostalgia)
2) According to Heller's (1993) model, it is hypothesized that susic with a higher level of arousal (JPN_Power) will show higher right parietal activation as compared to music with lower level of arousal (JPN_Nostalgia)

In addition, the following exploratory analyses were conducted:

1) Comparisons of emotional valence and arousal in temporal and occipital regions across frequency bands

2) Correlations between brain activity in alpha, beta and theta frequency bands and emotion ratings (valence and arousal scores).

4.2. Methods

Participants

A total of 68 participants were recruited for the EEG experiment. Given that Japanese animation OSTs were chosen to represent familiar musical style in this experiment, participants were only selected if they most frequently listened to either soundtracks or pop music (operationalized by ranking pop music or soundtracks as one of the top three musical genres they listen to), which is a similar musical genre as Japanese animation OSTs. Music listening information of participants are detailed in Appendix B-1. They have no self-reported history of mood, psychiatric or neurological problems, and have normal hearing. They are all right-handed and are all not professional musicians.

For the final analyses, participants were excluded if (1) they scored high on the Depression subscale in the baseline mood measure (n = 1); (2) there was any technical issues or excessive motion artifact (n = 6); or (3) did not feel any emotions for one or more musical excerpts (as reflected by the ratings of "not at all" for emotion labels) (n = 12). Thus, the final analyses consisted of 49 participants (28M 21F; age: M = 23.94, SD = 3.46). 23 participants have formal musical training, and 26 does not have formal musical training. 20 participants were involved in music-related co-curricular activities (CCAs), and 29 were not involved in music-related CCAs.

Data from these 49 participants were employed to address the respective research questions for Studies 2A, 2B and 2C. Based on power analysis using

G*Power (version 3.1.9.2; Faul et al., 2007), it is estimated that a sample size of at least 43 participants would be needed to detect statistically significant differences of effect size = 0.25 at $\alpha = 0.05$ and 95 % power. Therefore, the number of participants ($n = 49$) included for the final analyses was deemed sufficient.

Music Stimuli

The final selection of music stimuli for this experiment were those that met all of the following criteria in Study 1 in Chapter 3: (1) elicited the most intensity of the emotional state, (2) good reliability, (3) were not recognized by most participants. As a brief recap, the general criteria of the music stimuli were that they (1) should not contain lyrics, dialogues or sound effects, and (2) should not contain popular tunes that are familiar with episodic memory.

As the current study in this chapter is primarily concerned with clarifying the electrophysiological correlates of music-evoked emotions, I examined the emotional states elicited by music of a familiar musical style (Japanese animation OSTs: JPN_Fear, JPN_Power, JPN_Nostalgia), given that emotions are more likely to be elicited by music of a familiar musical style as compared to music of an unfamiliar musical style (Greek Laïkó music). Each emotional state consists of four music stimuli, and all the musical excerpts were 45-seconds (inclusive of 1-second fade in and 1-second fade out), and normalized to ensure equal loudness across excerpts:

(1) Low valence, High arousal (JPN_Fear): 4 stimuli

(2) High valence, High arousal (JPN_Power): 4 stimuli

(3) High valence, Low arousal (JPN_Nostalgia): 4 stimuli

For more details of the music stimuli, please refer to Appendix A-3.

Materials

Baseline Mood Measure

The Abbreviated Profile of Mood States (POMS; Grove & Prapavessis, 1992) was employed to measure baseline mood prior to the experiment. The POMS measured tension, depression, fatigue, vigor, confusion, anger, and esteem-related affect (Appendix B-2). In particular, Depression subscale consists of six items: hopeless, helpless, sad, worthless, miserable and discouraged. Participants were asked to rate if they are feeling this on a 5-point Likert scale with 0 = not at all; 4 = extremely. While the Abbreviated POMS is originally developed in Australia, a pilot study was conducted to establish the validity of this questionnaire in Singapore (Oh, 2019).

Emotion Rating Questionnaire

In this experiment, participants were instructed to rate the intensity of their felt emotions in response to listening to the music on a 9-point Likert scale after the music ends (Appendix B-3). This is in contrast to Study 1 where participants provided felt emotion ratings continuously while listening to the music, using the dual axis rating and media annotation software (DARMA; Girard & Wright, 2018). Several reasons were taken into account for the change in measurement: (1) minimize motion-related artefact as a result of using DARMA, and (2) DARMA does not allow for time-synchronization with other forms of recording. Participants then completed ratings on discrete emotions (basic emotion model and domain-specific model) that were similar to the questionnaire used in Study 1.

Procedure

All 49 participants completed the following procedure in this EEG experiment, of which data from different components of the experiment are extracted for Studies 2A, 2B and 2C. After written informed consent is obtained from the participant (Appendix B-4), the POMS is administered to them. Next, EEG measurements were set up for the participants (details described in next section "EEG recording").

As a baseline control, participants were instructed to rest for five minutes with eyes-closed, before starting the music listening experiment. They were told to close their eyes and rest for five minutes, and during the five minutes, to not think about anything in particular but simply try to stay awake.

Thereafter, a practice trial was given so as to familiarize the participant with the music listening task and to adjust the volume of the music to a level that is comfortable for them.

Subsequently, participants performed the emotion rating tasks of familiar and unfamiliar musical styles. The order of presenting familiar and unfamiliar music is counterbalanced. Within each music listening task, music of a similar emotional state was not consecutively presented. As such, music stimuli were not presented in a randomized fashion, but in two versions: the second version is a reversed order of the first version so as to account for order effects. There is a 15-seconds break between each music excerpt.

For the emotion rating task, participants are instructed to provide ratings of how the music makes them feel. Specifically, they were given the following instructions: "Do not describe the music (e.g., the music is happy) or what the music may be expressing (e.g., this music expresses happiness). Keep in mind that a music can be happy or can sound happy without making you feel happy". They rated on a 9-point Likert scale for valence and arousal: whether they felt unpleasant (1) – pleasant (9), and very passive (1) – very active (9) respectively. In addition, they rated on a 5-point Likert scale for discrete emotion terms, with 1 being not at all and 5 very much. Thereafter, recognition of the music stimuli is measured with the question "Have you heard this tune before?" and anticipation is measured with the question "Are you able to anticipate what is coming next in the music?", with 1 being definitely not, 2 being probably not, 3 being not sure, 4 being probably yes, 5 being definitely yes. Lastly, participants completed questionnaires regarding absorption trait.

Data from different measures are extracted to address difference research questions of Studies 2A, 2B and 2C. Specifically, Study 2A aims to clarify the electrophysiological correlates of emotional valence and arousal during music listening, and thus examines data from the music listening task where music of a familiar musical style (Japanese animation OST) were presented (Fig. 4-1a). Study 2B investigates the neural correlates of familiarity with musical style, and therefore utilizes data from both familiar (Japanese animation OST) and unfamiliar (Greek Laiko music) musical styles (Fig. 4-1b). Lastly, Study 2C investigates the role of absorption trait in music-evoked emotions, and thus examines the data from the absorption questionnaire and compares it with both familiar and unfamiliar musical styles (Fig. 4-1c).

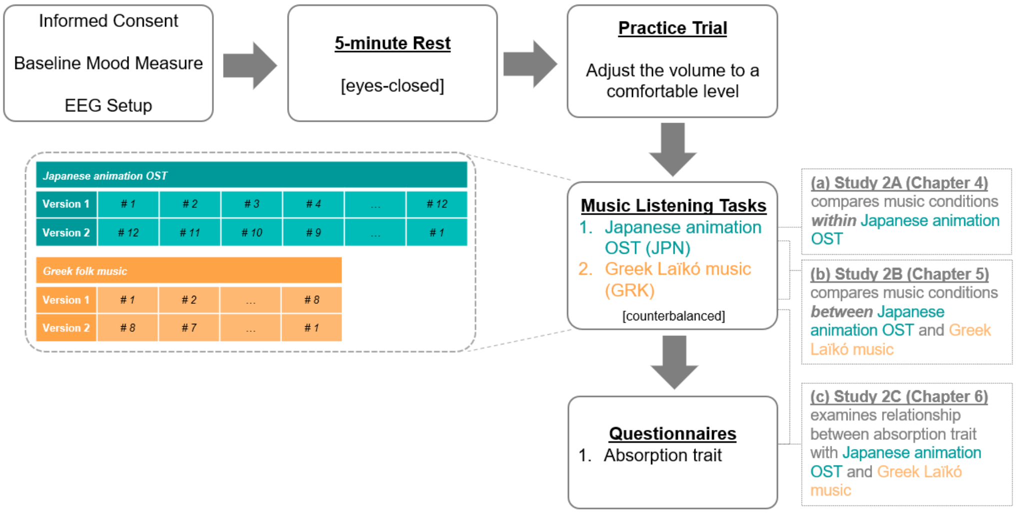


Fig. 4-1. Overview of task paradigm for Studies 2A, 2B and 2C.

Notes. (a) Study 2A investigates neural correlates of music from Japanese animation OST (JPN). (b) Study 2B examines the effect of familiarity with musical style on emotion. (c) Study 2C investigates the role of absorption trait in music-evoked emotion. All studies are based on the same sample (*n* = 49).

EEG Recording

The EEG was recorded using the TruScan 64 EEG system from Deymed Diagnostics (TruScan, 2017). The electrodes were placed according to the international 10-20 placement standards. The ground electrode is placed on the center of the participant's forehead, and two reference points were placed at each mastoid (Fig. 4-2). These regions were first cleaned with skin preparation gel (NuPrep) to ensure better signal quality. Each electrode was then filled with electrolyte gel for signal transduction. Impedence was kept below 20 kΩ. Data recording was done with a sampling rate of 200 Hz, which is more than twice the required rate according to the Nyquist-Shannon sampling theorem to measure theta to beta frequency bands (4 – 30 Hz). Horizontal electroculograms (EOGs) were recorded bipolarly with electrodes placed on the outer canthus of each eye.

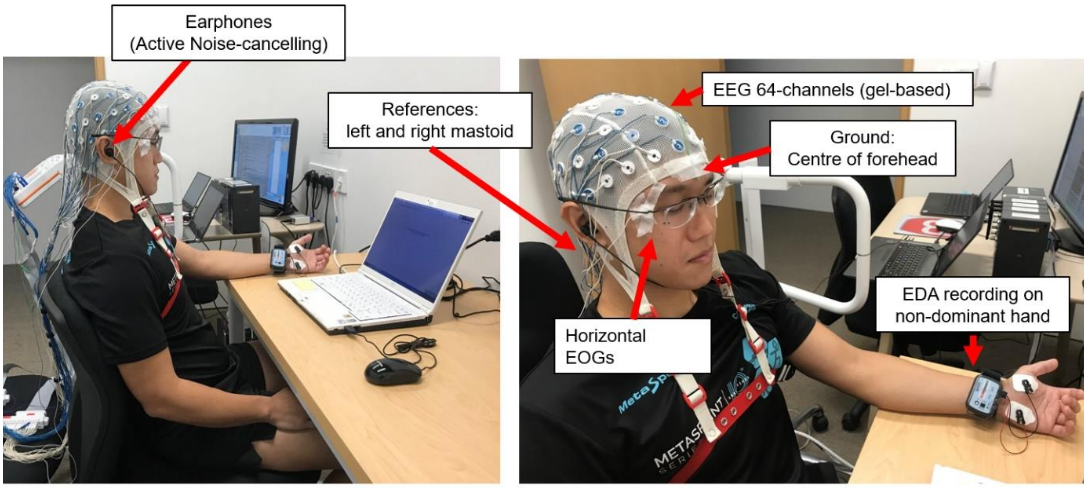


Fig. 4-2. EEG setup.

Notes. Electrodermal (EDA) measurements were taken during the experiment as well, but EDA data is not included in this thesis.

Follow-up Survey

In a subsequent survey, participants indicated how familiar they are with the music genres of Japanese Anime music, Folk music and Greek Laïkó music specifically, with the questions being “How familiar are you with the music of Japanese Anime?”, “How familiar are you with Folk music?” and “How familiar are you with Greek Laïkó music in particular?” on a 5-point Likert scale, with 1 being not familiar at all, 2 being slightly familiar, 3 being moderately familiar, 4 being very familiar, 5 being extremely familiar.

Behavioral Data Analysis

Behavioral data analyses were conducted with SPSS Version 26 and R version 4.0.3. R package ggplot2 (Wickham, 2016) was employed for data visualization.

Baseline Mood Measure (POMS)

Participants with a high rating on the Depression subscale of the POMS are first excluded. One participant with a high rating on the Depression subscale of the POMS (*Mean score* = 19 out of 20) was excluded.

Emotion Rating Task

Mean scores were computed for discrete emotion labels. To evaluate the difference in emotional valence while controlling for arousal level, music conditions which are both high in arousal but differ in terms of pleasantness will be used for subsequent analyses. This is denoted by the contrast “JPN_Fear (unpleasant, high arousal) *vs* JPN_Power (pleasant, high arousal)”. To evaluate the differences in emotional arousal while controlling for valence, music conditions which are both pleasant but differ in terms of arousal level will be used for subsequent analyses. This is denoted by the contrast “JPN_Power (pleasant, active) *vs* JPN_Nostalgia (pleasant, passive)”. Paired *t*-tests are employed to examine differences between the music conditions. Should the assumption of normality be violated, Wilcoxon signed rank test will be used.

Follow-up Survey

To establish that the majority of participants in the current study are familiar with the musical style Japanese Anime, frequencies of responses to the question “How familiar are you with the music of Japanese Anime?” will be reported in this chapter. Other responses (e.g., descriptives and responses to familiarity with Greek Laïkó music) of the follow-up survey will be reported in Chapter 5.

EEG Data Analysis

Pre-processing

Data was first pre-processed with EEGLAB (version 13.4.4b; Delorme & Makeig, 2004). One channel (Iz) was removed as it is not required for further analysis. Next, a bandpass filter of 1 to 30 Hz was applied and noisy channels were removed. Channels were considered to be noisy if they were above the recommended kurtosis threshold of 5. Data was then average re-referenced and a baseline correction with 1-second time window before start of stimulus was applied to individual epochs. Epoched data were subsequently re-epoched from 0 second (i.e., start of stimulus) to the end of stimulus duration. Thereafter, independent component analysis (ICA) was conducted via the 'runica' function, which uses the infomax ICA algorithm (Bell & Sejnowski, 1995). Following which, independent components (ICs) related to eye-blinks and muscle artefacts were identified and removed with the MARA pipeline (Winkler et al., 2011). In essence, MARA employs a linear pre-trained classifier for automatic IC classification. It is based on six features which were determined in a feature selection procedure described in Winkler et al. (2011): One feature aims to detect outliers in the time series of an IC, three features are extracted from the spectrum, and two features extract information from the scalp map of an IC. On average, seven ICs (11.48%) were rejected from each music condition. After rejecting noisy ICs, EOG channels were removed. Lastly, channels were interpolated to the original 61 scalp channels (Fig. 4-3).

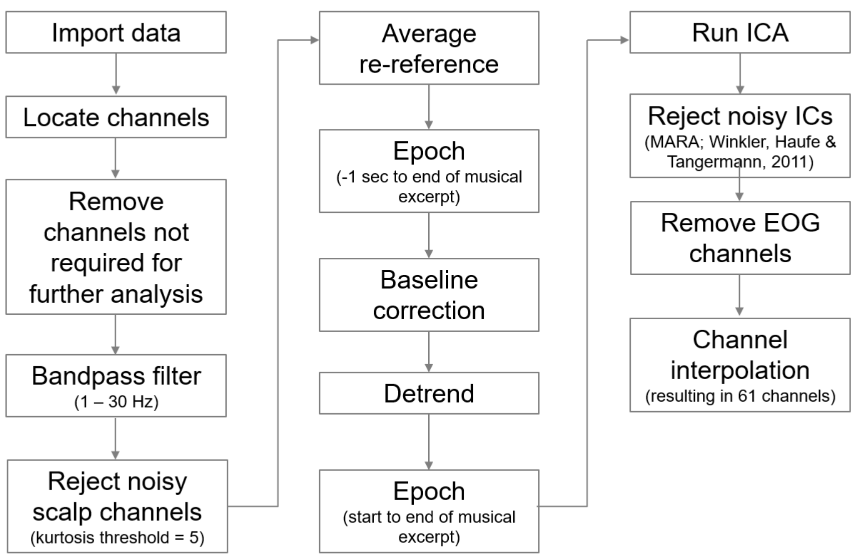


Fig. 4-3. EEG pre-processing pipeline.

EEG Power Spectrum Analysis

Power spectra was calculated for alpha (8 – 13 Hz), beta (13 – 30 Hz) and theta (4 – 8 Hz). Power spectra using Fast Fourier Transformation (FFT) was computed using the ‘spectopo’ function, with a Hamming window of window length 512 and no overlap. At each frequency bands, power spectra were calculated for the following regions, adapted from Teipel et al. (2017):

Brain region	**Hemisphere: Left / Right**	**Electrodes**
Frontal	Left	Fp1, AF3, AF7, F1, F3, F5, F7, FC1, FC3, FC5
	Right	Fp2, AF4, AF8, F2, F4, F6, FC2, FC4, FC6
Parietal	Left	C1, C3, C5, CP1, CP5, P1, P3, P5
	Right	C2, C4, C5, CP2, CP4, CP6, P2, P4, P6
Temporal	Left	FT7, T3, T5, TP7
	Right	FT8, T4, T6, TP8
Occipital	Left	O1, PO3, PO7
	Right	O2, PO4, PO8

In addition, frontal midline theta comprised electrodes AFz, Fz and FCz (based on Sammler et al., 2007) (Fig. 4-4).

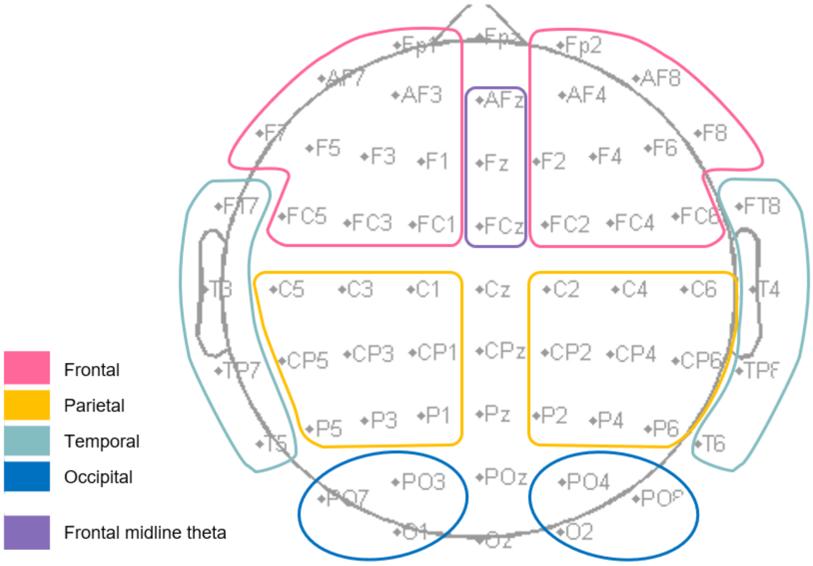


Fig. 4.4. Selected electrodes to represent frontal region (pink), parietal region (orange), temporal region (green), occipital region (blue), and frontal midline theta (purple).

For analyses of power spectra computed at brain regions, a log10 transformation was first performed given the positive skew nature observed in the EEG data. Thus, subsequent power spectra analyses were conducted on log10 transformed data using SPSS Version 26.

If the normality assumption is not violated, two-way repeated-measures ANOVAs with music condition (e.g., high arousal *vs* low arousal) x hemisphere (left *vs* right) were conducted separately for each brain region across frequency bands to investigate the neural correlates of music-evoked emotional valence and arousal separately.

Asymmetry Index (AI) Analysis

Next, asymmetry index (AI) was computed for each frequency band using the following formula as in Schmidt and Hanslmayr (2009):

$$AI_i = \frac{POW_{right_i} - POW_{left_i}}{POW_{baseline_i}}$$

Where Pow_{right} is the mean power of all electrodes in right of selected region, Pow_{left} is mean power of all electrodes in left of selected region, $Pow_{baseline}$ is mean power of all electrodes in the selected region. This formula accounts for individual differences in power by normalizing this difference on the individual baseline power. Therefore, a positive value indicates greater right-sided power and negative value reflects greater left-sided power in the specific frequency band.

Paired *t*-tests were conducted between music conditions for each brain region separately.

Correlation Analysis

Lastly, to investigate the relationship between EEG activity and emotion ratings, correlation coefficients were computed for behavioral ratings with (1) all 61 scalp channels, (2) each brain region (frontal, parietal, temporal, occipital), and (3) AI calculated for each brain region. These correlations were conducted for alpha, beta and theta frequency bands.

4.3.Results

Behavioral Results

Familiarity with Japanese animation OSTs

38 participants (21M 17F; age: $M = 24.16$, $SD = 3.82$) completed the follow-up survey on level of familiarity with Japanese animation OSTs. 10 participants (26.32%) reported that they were not familiar at all; nine participants reported that they were slightly familiar (23.68%); 11 participants (28.95%) reported that they were moderately familiar; six participants (15.79%) reported that they were very familiar; and two participants reported that they were extremely familiar (5.26%) with Japanese animation OSTs (Fig. 4-5).

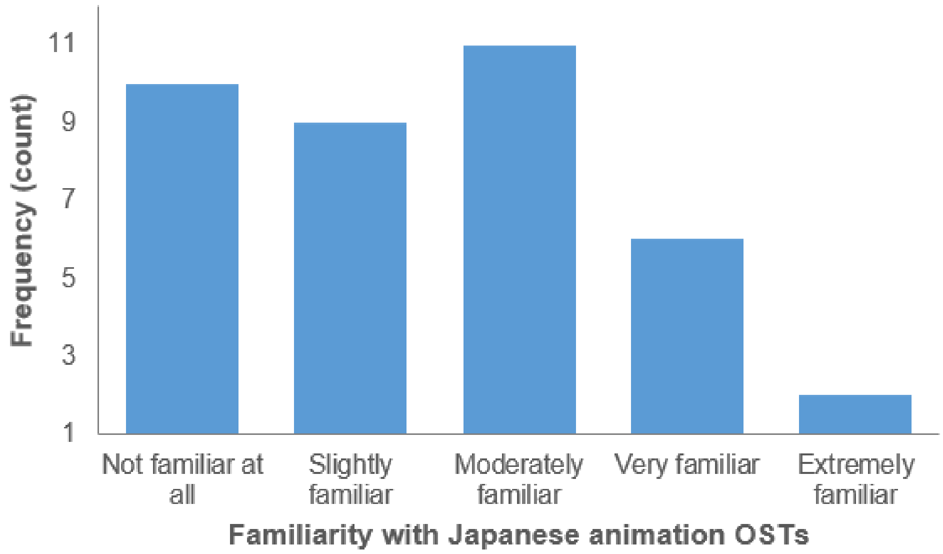


Fig. 4-5. Level of familiarity with Japanese animation OSTs. ($n = 38$)

Recognition and Anticipation Scores of Japanese animation OSTs

Overall, participants scored a mean of 2.07 (SD = .87) for recognition and a mean of 2.56 (SD = 0.95) for anticipation. Mean recognition scores for each of the music stimuli ranged from 1.57 to 2.86, suggesting that participants mostly do not recognize the music stimuli presented (Fig. 4-6a). Mean anticipation scores for each of the music stimuli presented ranged from 2.02 to 3.14, suggesting that participants are not able to anticipate well what is coming next in the music (Fig. 4-6b).

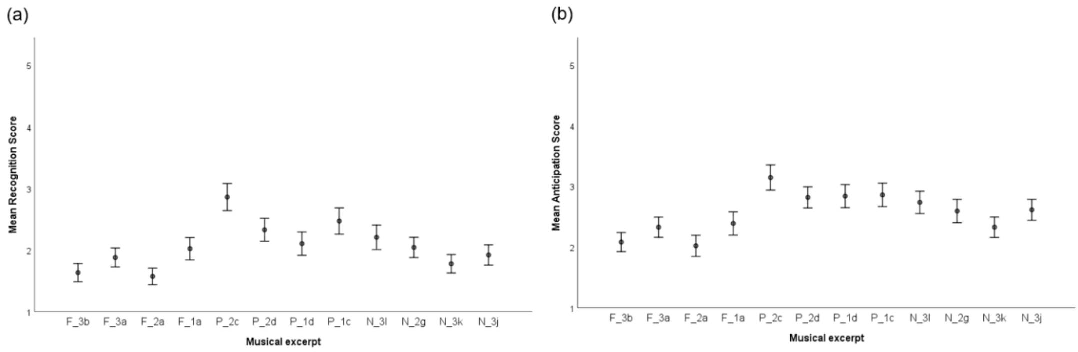


Fig. 4-6. (a) Mean recognition scores of each music stimuli from Japanese animation OSTs. (b) Mean anticipation scores of each musical excerpt. Error bars represent +/- 1 * standard error.

Notes. Musical excerpts that elicit Fear are: F_3b, F_3a, F_2a, F_1a. Musical excerpts that elicit Power are: P_2c, P_2d, P_1d, P_1c. Musical excerpts that elicit Nostalgia are: N_3l, N_2g, N_3k, N_3j.

Emotion Rating

Mean valence and arousal ratings are plotted in Fig. 4-7. Shapiro-wilk tests were first conducted to check for normality. For variables that are not normally distributed, non-parametric tests will be used. As a result, parametric tests are used for (1) arousal analyses; while non-parametric tests are used for (1) valence analyses.

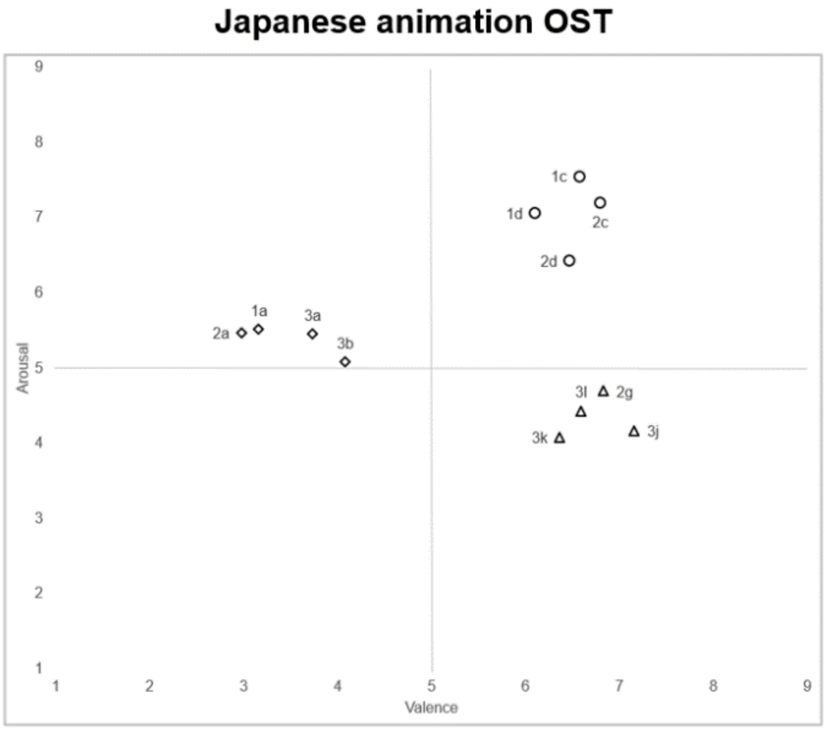


Fig. 4-7. Valence-arousal ratings of each musical excerpts. Each point represents a musical excerpt. Points in diamond shape are felt as Fear (JPN_Fear); points in circle shape are felt as Power (JPN_Power); points in triangle shape are felt as Nostalgia (JPN_Nostalgia).

Emotional Valence (Unpleasant vs Pleasant)

Wilcoxon signed rank test showed that mean valence ratings of JPN_Power is significantly higher than (Z = 5.51, p <.001). In other words, JPN_Power music was felt as significantly more pleasant as compared to JPN_Fear music (Fig. 4-8a).

Next, paired t-test was conducted to examine if JPN_Fear and JPN_Power differed in terms of arousal level. Paired t-test showed that JPN_Power music (M = 7.06, SD = 0.93) is felt as significantly more active as compared to JPN_Fear music (M = 5.38, SD = 1.72) (t(48) = 6.74, p < .001) ((Fig. 4-8b)). As such, arousal ratings of both music condition were included as a predictor in subsequent multiple regression analyses of EEG data to control for the differing level of arousal in these two music conditions.

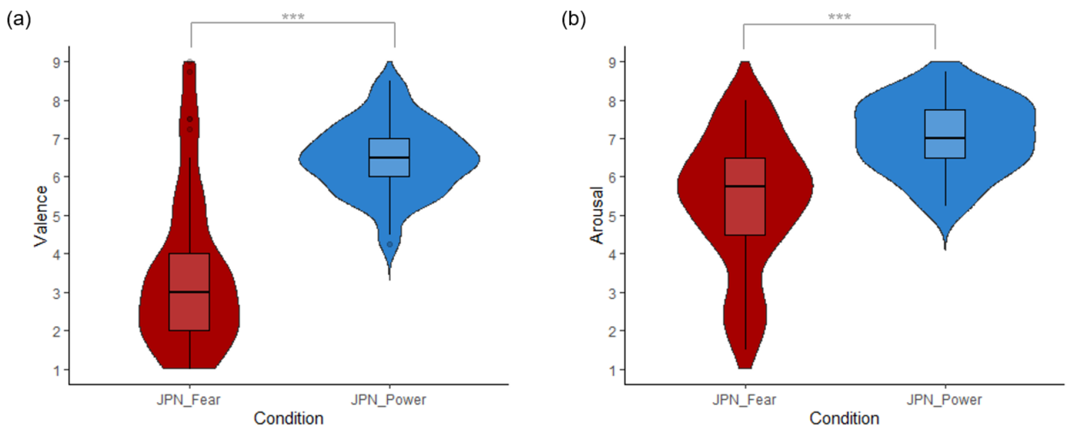


Fig. 4-8. Emotion ratings for music conditions: JPN_Fear and JPN_Power. Violin plot with boxplot representations of (a) valence ratings and (b) arousal ratings.

*** $p < .001$

Emotional Arousal (Passive vs Active)

Paired *t*-test showed that arousal ratings for JPN_Power ($M = 7.06$, $SD = 0.93$) is significantly higher than that of JPN_Nostalgia ($M = 4.34$, $SD = 1.56$) ($t(48) = 10.76$, $p < .001$) (Fig. 4-9a).

Likewise, Wilcoxon signed rank test was conducted to examine if JPN_Power and JPN_Nostalgia differed in terms of valence. Results showed no significant difference between valence ratings of JPN_Power ($M = 6.48$, $SD = 0.93$) and JPN_Nostalgia ($M = 6.74$, $SD = 1.52$) ($Z = 776$, $p = .103$) (Fig. 4-9b). As such, both music conditions differed only on the level of arousal.

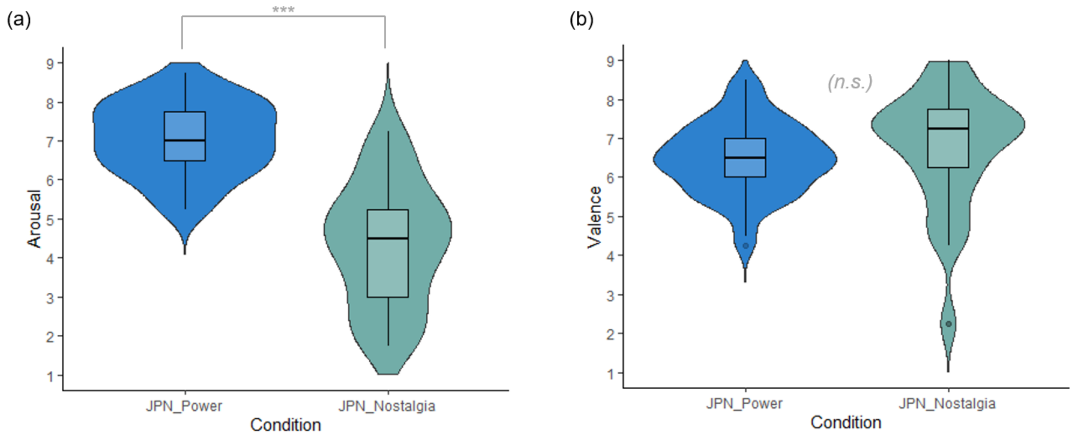


Fig. 4-9. Emotion ratings for music conditions: JPN_Power and JPN_Nostalgia. Violin plot with boxplot representations of (a) arousal ratings and (b) valence ratings. *** $p < .001$

Discrete Emotions

Music stimuli elicited the targeted emotions in both discrete and dimensional terms. In particular, low valence and high arousal music were felt more as Fear and Tension (consequently termed JPN_Fear); high valence and high arousal music were felt more as Power (consequently termed JPN_Power); and high valence and low arousal music were felt more as Nostalgia and Calmness (consequently termed JPN_Nostalgia) (Fig. 4-10).

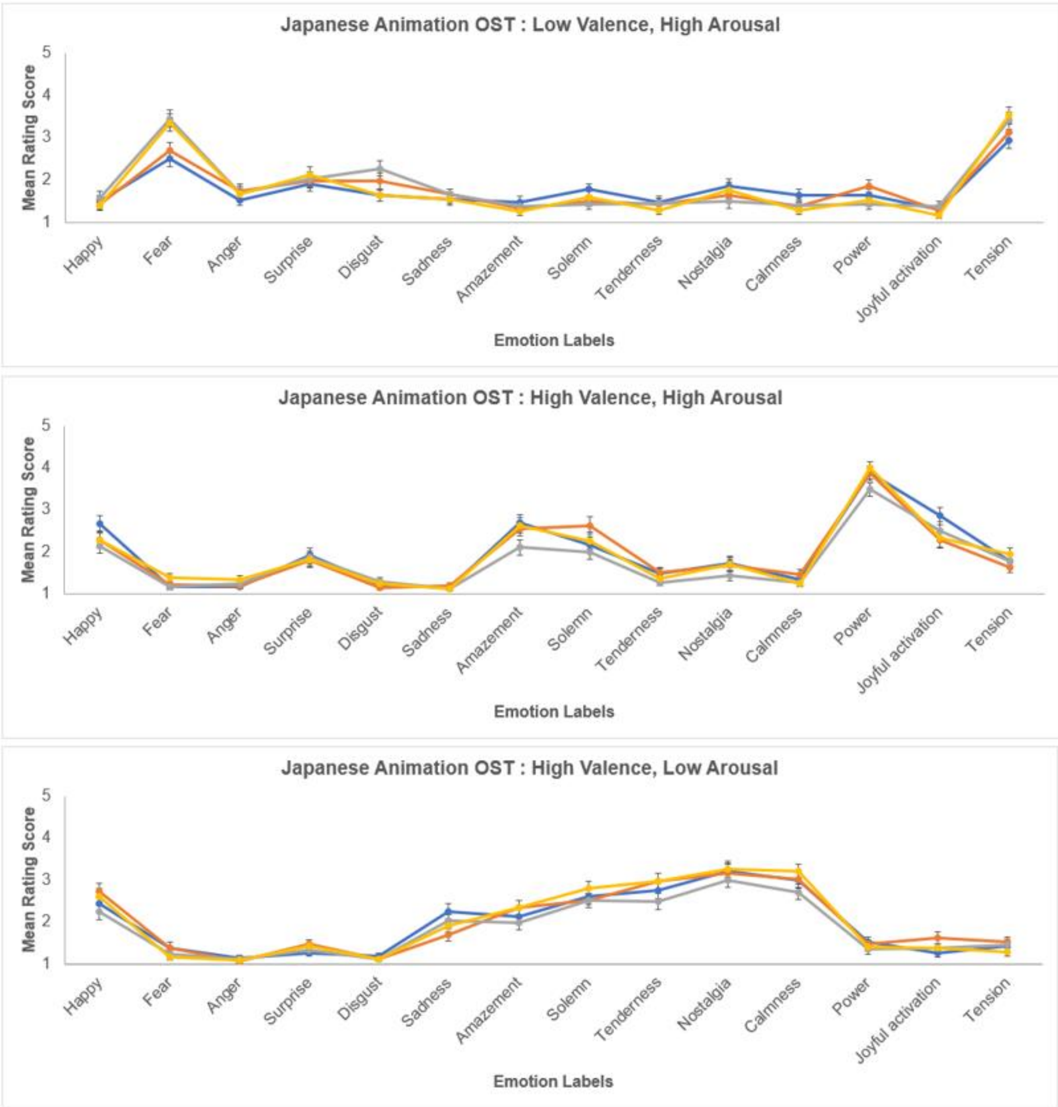


Fig. 4-10. Discrete emotion ratings. Error bars represent +/- 1 * standard error. Each line denotes a musical excerpt.

EEG Results

Emotional Valence (Unpleasant vs Pleasant)

Visual inspection of the topographic scalp maps shows that pleasant music (JPN_Power) showed higher theta and alpha power in the fronto-temporo-occipital regions as compared to unpleasant music (JPN_Fear). Also, pleasant music (JPN_Power) showed higher beta power in bilateral frontoparietal regions, with a preponderance to the right frontal region. These observations are depicted in Fig. 4-11.

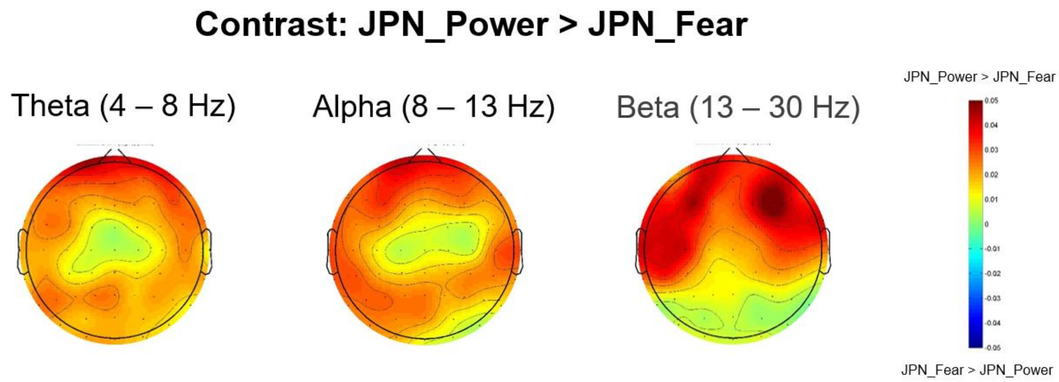


Fig. 4-11. Topographic maps for JPN_Power > JPN_Fear

As mentioned in the preceding section, arousal ratings needed to be controlled for when studying the effects of emotional valence as JPN_Power and JPN_Fear have elicited different levels of arousal. Given that arousal ratings is a condition-varying covariate, repeated-measures ANCOVA cannot be employed. Instead, the regression framework is adopted where the outcome variable, EEG spectral power, is predicted by music condition ("0" referring to JPN_Fear and "1" referring to JPN_Power), hemisphere, interaction between music condition and hemisphere, and arousal ratings. In addition, the cluster-robust standard error is applied to correct for the standard error as the assumption of independence is violated using the sandwich R package (Zeileis et al., 2020). With that, a resulting regression equation is as follows:

$$power_{r \cdot f} = \beta_0 + \beta_1 Condition + \beta_2 Hemisphere + \beta_3 Condition * Hemisphere + \beta_4 Arousal + \varepsilon$$

This regression model was conducted for each brain region and across alpha, beta, theta frequency bands separately. For frontal midline theta power, the following regression model was conducted:

$$power_{r \cdot f} = \beta_0 + \beta_1 Condition + \beta_2 Arousal + \varepsilon$$

***A priori* hypothesis 1: Frontal alpha asymmetry.** After controlling for arousal ratings, only hemisphere significantly predicted frontal alpha power (β = -0.032, $t(44) = -2.65$, $p = .0087$), and not music condition or the interaction term at Bonferroni-corrected $\alpha = .0125$ (Fig. 4-12). Specifically, alpha power was significantly higher in the left frontal region as compared to right frontal region in both music conditions (i.e., relatively greater brain activity in right frontal region). Given the lack of interaction effect in the frontal region, support for the frontal alpha asymmetry hypothesis was not found.

***A priori* hypothesis 2: Frontal midline theta.** Music condition was also not a significant predictor of frontal midline theta power ($\beta = 0.025$, $t(44) = 0.74$, $p = .46$), after controlling for arousal ratings at Bonferroni-corrected $\alpha = .0125$ (Fig. 4-12). Thus, the frontal midline theta hypothesis is not supported as well.

Exploratory analyses. In the theta frequency band, only hemisphere significantly predicted theta power in the parietal ($\beta = 0.069$, $t(44) = 4.75$, $p < .001$) and occipital ($\beta = -0.045$, $t(44) = -3.47$, $p = .00065$) regions after controlling for arousal ratings, but not music condition or the interaction term at Bonferroni-corrected $\alpha = .0125$. Specifically, both music conditions showed higher theta power in right parietal and left occipital regions as compared to their counterparts. No significant effects were observed in the frontal or temporal regions at Bonferroni-corrected $\alpha = .0125$ (Appendix B-5; Table S4-2).

In the alpha frequency band, music condition significantly predicted alpha power in the frontal ($\beta = 0.13$, $t(44) = 2.04$, $p = .043$), temporal ($\beta = 0.14$, $t(44) = 2.40$, $p = .017$) and occipital ($\beta = 0.16$, $t(44) = 2.17$, $p = .031$) regions, after controlling for arousal ratings. However, these effects did not remain statistically significant after adjusting for multiple comparisons. Instead, only hemisphere significantly predicted alpha power in the parietal ($\beta = 0.15$, $t(44) = 6.54$, $p < .001$) and temporal ($\beta = 0.13$, $t(44) = 4.46$, $p < .001$) at Bonferroni-corrected $\alpha = .0125$. Specifically, in both music conditions, alpha power is significantly higher in right parietal and temporal regions as compared to their left counterparts. In other words, brain activity is lesser in right parietal and temporal regions (as alpha power is inversely related to brain activity). No significant effects were observed in the occipital region at Bonferroni-corrected $\alpha = .0125$ (Appendix B-5; Tables S4-1, 2).

In the beta frequency band, only hemisphere significantly predicted beta power in the parietal region ($\beta = 0.046$, $t(44) = 3.10$, $p = .0022$) after controlling for arousal ratings, and not music condition or the interaction term at Bonferroni-corrected $\alpha = .0125$. Specifically, beta power was significantly higher in right as compared to left parietal region in both music conditions. No significant effects were observed in the frontal, temporal or occipital regions at Bonferroni-corrected $\alpha = .0125$ (Fig. 4-12; Appendix B-5, Table S4-2).

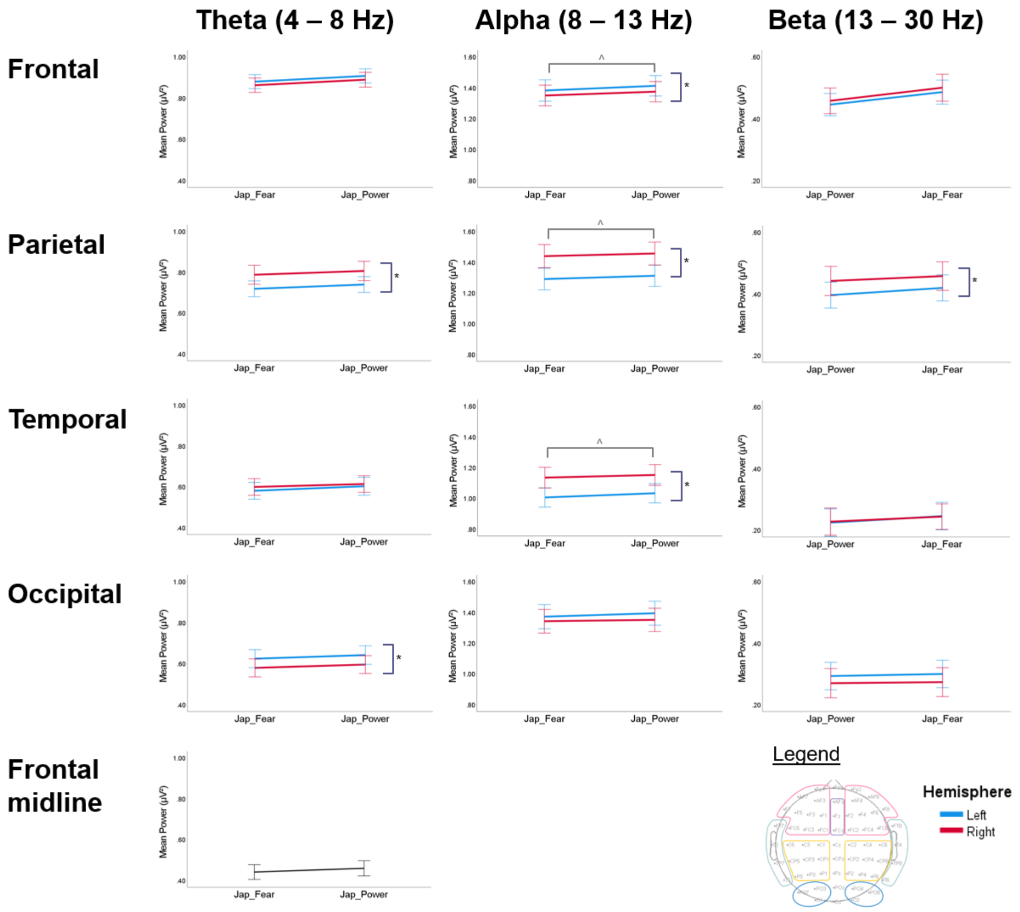


Fig. 4-12. Log theta, alpha and beta power for music conditions JPN_Power (pleasant) and JPN_Fear (unpleasant) in frontal, parietal, temporal and occipital regions. Hypothesized effects of frontal alpha asymmetry and frontal midline theta were not observed. Music condition predicted alpha power in frontal, parietal and temporal regions at $p < .05$, but this effect did not remain statistically significant after adjusting for multiple comparisons. Legend: *scalp map*. Frontal (pink), parietal (yellow), temporal (green), occipital (blue). Error bars represent +/- 1 * standard error.
^ $p < .05$, * $p < .001$

Asymmetry Index (AI) analysis. Across frequency bands, AI was highest in parietal and temporal regions in the alpha frequency band. Paired *t*-tests did not yield any significant differences between AI scores of JPN_Power and JPN_Fear in any brain regions across alpha, theta and beta frequency bands at Bonferroni-corrected α = .0125 (Fig. 4-13, Appendix B-6). As such, the hypothesis that frontal AI will be correlated with emotional valence is not supported.

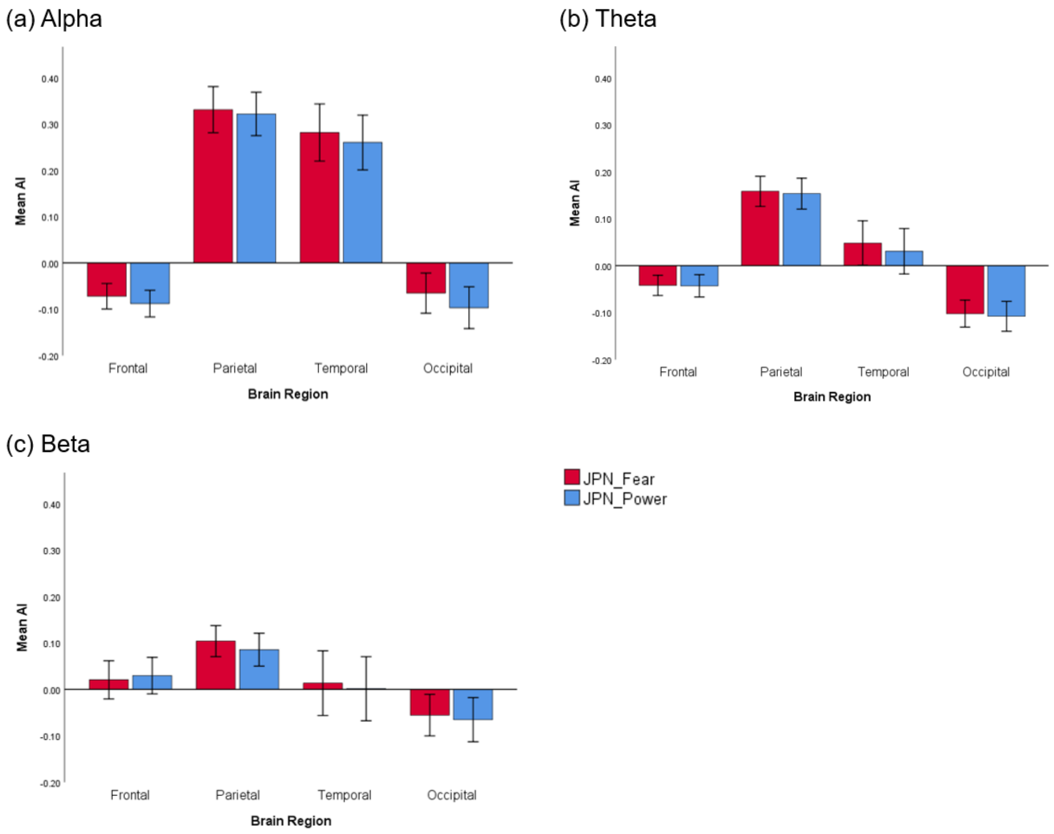


Fig. 4-13. Asymmetry index (AI) for music conditions JPN_Fear (unpleasant) and JPN_Power (pleasant). Positive values indicate greater right-sided power; negative values reflect greater left-sided power. No significant differences between JPN_Fear and JPN_Power were found for brain region and frequency band at Bonferroni-corrected α = .0125. Error bars represent +/- 1 * standard error.

Emotional Arousal (Passive vs Active)

Visual inspection of the topographic scalp maps shows that music with high degree of arousal (active; JPN_Power) is associated with lower theta power in the right parietal region as compared to music with low degree of arousal (passive; JPN_Nostalgia). In addition, active music (JPN_Power) shows widespread lower alpha power (i.e., higher brain activity) as compared to passive music (JPN_Nostalgia). Lastly, active music (JPN_Power) is associated with increased beta power in fronto-temporal regions, with a preponderance in the left temporal region (Fig. 4-14).

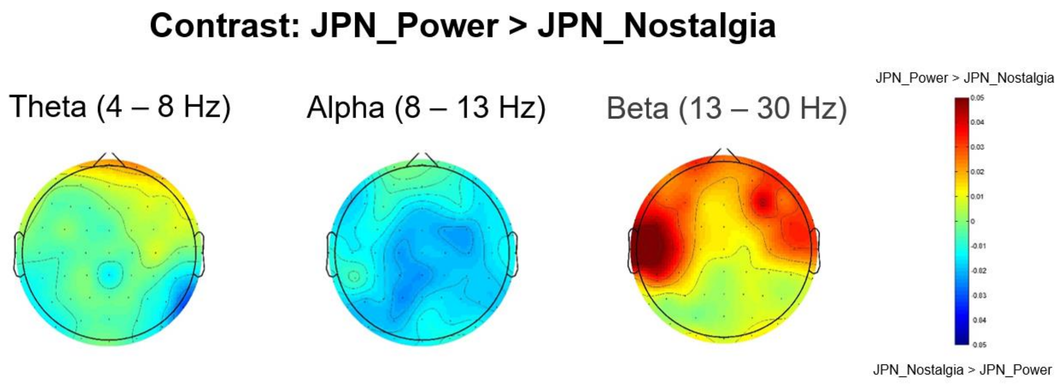


Fig. 4-14. Topographic maps for JPN_Power > JPN_Nostalgia

To examine the effects of arousal, 2 (music condition: JPN_Power (high arousal) *vs* JPN_Nostalgia (low arousal)) x 2 (hemisphere: left *vs* right) repeated-measures ANOVA were conducted for each brain region separately across alpha, beta and theta frequency bands.

***A priori* hypothesis 1: Absolute frontal alpha power.** After adjusting for multiple comparisons, only a significant main effect of hemisphere was found in the frontal region ($F(1,48) = 8.89$, $p = .004$, $\eta_p^2 = .16$). Specifically, alpha power was significantly higher in the left frontal region as compared to right frontal region (i.e., brain activity is relatively higher in right frontal region in both music conditions). No significant main effect of music condition or interaction effect was observed. Thus, the hypothesis that absolute frontal activity can distinguish level of arousal is not supported in the current study (Fig. 4-15).

***A priori* hypothesis 2: Right parietal activity.** After adjusting for multiple comparisons, only a significant main effect of hemisphere was found in the parietal region ($F(1,48) = 46.21$, $p < .001$, $\eta_p^2 = .49$). Specifically, alpha power was significantly higher in the right parietal region as compared to the left parietal region (i.e., brain activity is relatively higher in left parietal region in both music conditions). No significant main effect of music condition or interaction effect was observed. Thus, the hypothesis that music with a higher degree of arousal (i.e., JPN_Power) will show greater right parietal activity is not supported in the current study (Fig. 4-15).

Exploratory analyses: In the theta frequency range, no significant main effect of music condition or interaction effect was observed at any of the brain regions at Bonferroni-corrected $\alpha = .0125$. Instead, significant main effects of hemisphere were observed in the frontal ($F(1,48) = 5.97$, $p = .018$, $\eta_p^2 = .11$), parietal ($F(1,48) = 19.39$, $p < .001$, $\eta_p^2 = .29$) and occipital ($F(1,48) = 12.49$, $p = .001$, $\eta_p^2 = .21$) regions, but not temporal region. However, the effect at frontal region did not remain statistically significant after adjusting for multiple comparisons. As such, right parietal and left occipital regions showed significantly higher theta power as compared to their respective counterparts in both music conditions (Fig. 4-15; Appendix B-7, Table S4-7).

Likewise, no significant main effect of music condition or interaction effect was observed at any of the brain regions in the alpha frequency band at Bonferroni-corrected $\alpha = .0125$. Instead, significant main effects of hemisphere were found in the temporal ($F(1,48) = 19.13$, $p < .001$, $\eta_p^2 = .29$) and occipital ($F(1,48) = 6.67$, $p = .013$, $\eta_p^2 = .12$) regions. However, the effect at occipital region did not remain statistically significant after adjusting for multiple comparisons. As such, the right temporal region showed significantly higher alpha power (i.e., lesser brain activity) as compared to the left temporal region in both music conditions (Fig. 4-15; Appendix B-7, Table S4-7).

In the beta frequency range, there was a significant main effect of music condition only in the frontal region ($F(1,48) = 4.09$, $p = .049$, $\eta_p^2 = .079$), where frontal beta power was higher in JPN_Power as compared to JPN_Nostalgia. However, this effect did not remain statistically significant after adjusting for multiple comparisons. Instead, a significant main effect of hemisphere was observed only in the parietal region ($F(1,48) = 9.61$, $p = .003$, $\eta_p^2 = .17$) at Bonferroni-corrected $\alpha = .0125$, where beta power is significantly higher in right parietal region as compared to left parietal region. No interactions were found at Bonferroni-corrected $\alpha = .0125$ (Fig. 4-15; Appendix B-7, Tables S4-6, 7).

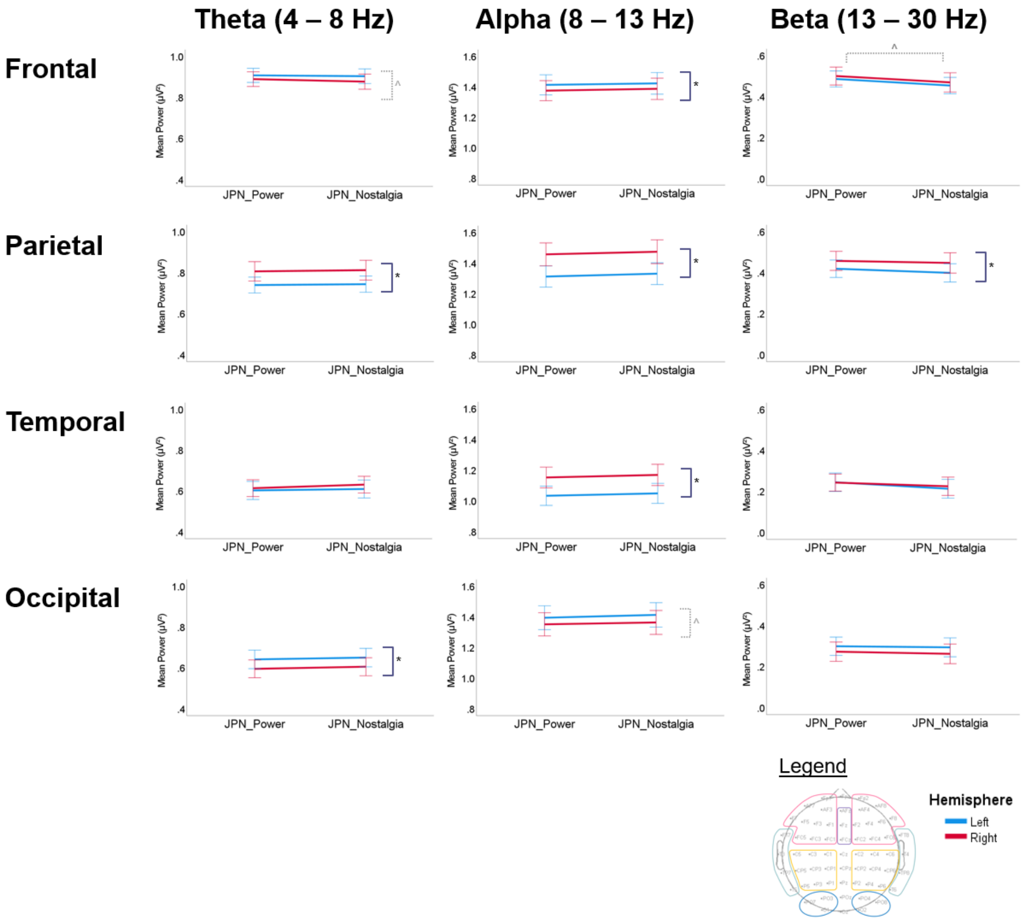


Fig. 4-15. Log theta, alpha and beta power for music conditions JPN_Power (high arousal; active) and JPN_Nostalgia (low arousal; passive) in frontal, parietal, temporal and occipital regions. Hypothesized effects of emotional arousal with absolute frontal alpha and right parietal activity were not observed. **Legend: *scalp map.*** Frontal (pink), parietal (yellow), temporal (green), occipital (blue). Error bars represent +/- 1 * standard error.
^ $p < .05$, * $p < .001$

Asymmetry Index (AI) analysis. Across frequency bands, AI was highest in parietal and temporal regions in the alpha frequency band. Paired *t*-tests did not yield any significant differences between AI scores of JPN_Power and JPN_Nostalgia in any brain regions across alpha, theta and beta frequency bands at Bonferroni-corrected α = .0125 (Fig. 4-16, Appendix B-8).

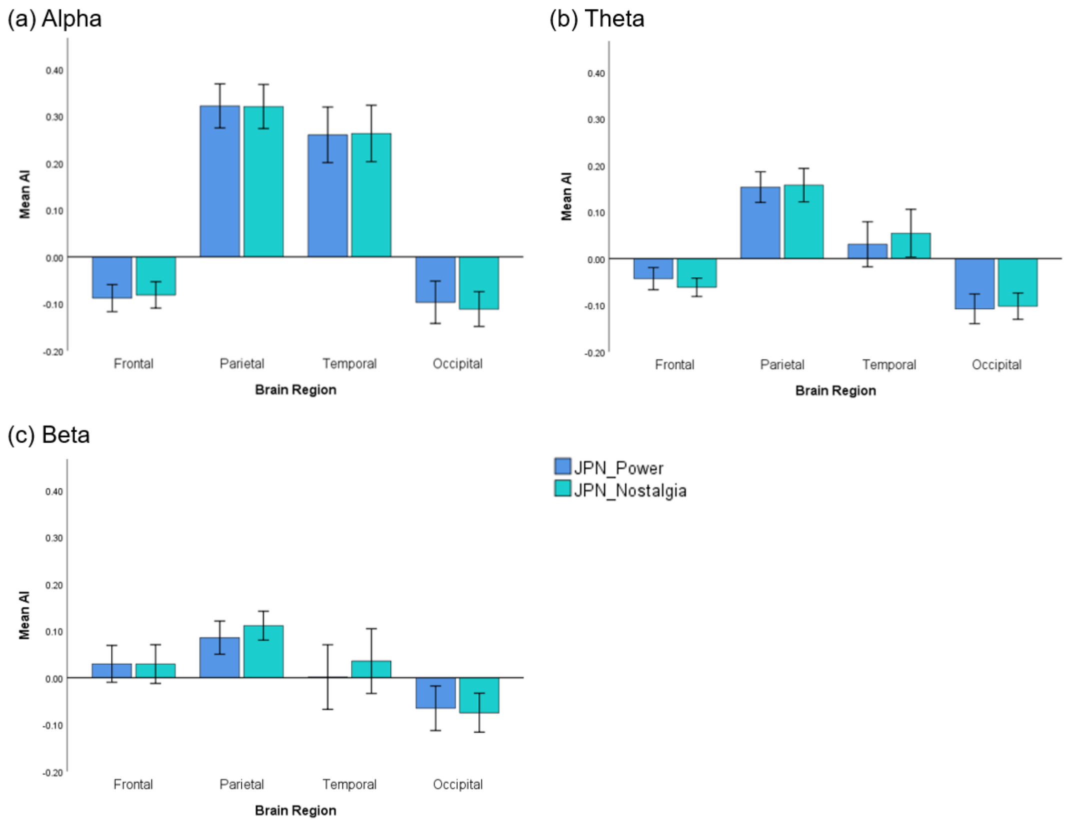


Fig. 4-16. Asymmetry index for music conditions JPN_Power (high arousal; active) and JPN_Nostalgia (low arousal; passive). Positive values indicate greater right-sided power; negative values reflect greater left-sided power. No significant differences between JPN_Power and JPN_Nostalgia were found for brain region and frequency band at Bonferroni-corrected $\alpha = .0125$. Error bars represent +/- 1 * standard error.

Spearman Correlations of Emotion Rating with Scalp Channels, Brain Regions and Asymmetry Index (AI)

For all frequency bands, log EEG spectral power from all scalp channels was not significantly correlated with valence or arousal ratings with false discovery rate (FDR) corrected $p < .05$ (Appendix B-9). In addition, log EEG spectral power as computed with brain regions was not significantly correlated with valence or arousal ratings in each frequency band at FDR-corrected $p < .05$ (Appendix B-10; Table S4-10). Lastly, AI was also not significantly correlated with valence or arousal ratings at Bonferroni-corrected $p < .05$ (Appendix B-10; Table S4-11).

4.4. Discussion

In the current study, music stimuli elicited the targeted emotions in both discrete and dimensional terms. In particular, low valence and high arousal music were felt more as Fear and Tension (JPN_Fear); high valence and high arousal music were felt more as Power (JPN_Power); and high valence and low arousal music were felt more as Nostalgia and Calmness (JPN_Nostalgia).

Comparison of Emotional Valence (Unpleasant *vs* Pleasant)

To investigate the electrophysiological correlates of emotional valence (unpleasant – pleasant), I compared the music conditions JPN_Power and JPN_Fear. Results showed that JPN_Power was felt as significantly more pleasant as compared to JPN_Fear, although the music conditions differed in terms of arousal level. After controlling for arousal ratings in the subsequent analyses, the hypothesized electrophysiological correlates corresponding to the hemispheric valence hypothesis or associations in frontal midline theta were not observed, even though JPN_Power was felt as significantly more pleasant as compared to JPN_Fear,

Relating to the Hemispheric Valence Hypothesis

According to the hemispheric valence hypothesis (Davidson, 1984, 1988, 1992a), positive emotion (i.e., JPN_Power) is hypothesized to be associated with greater relative left frontal brain activity (i.e., lower alpha power in left frontal region), while negative emotion (i.e., JPN_Fear) is hypothesized to be associated with greater relative right frontal brain activity (i.e., lower alpha power in the right frontal region) (e.g., Balasubramanian et al., 2018; Schmidt & Trainor, 2001; Trochidis & Bigand, 2013; Zhao et al., 2018). However, results from the current study did not support this hypothesis given the lack of significant interaction effect between music condition and hemisphere in the frontal region for the alpha frequency band, suggesting the difference in brain activity between music condition were the same in both hemispheres. This finding is similar to previous studies that did not find frontal alpha asymmetry (e.g., Baumgartner et al., 2006; Chang et al., 2015; Sammler et al., 2007).

Instead, the current study found that alpha power was significantly higher in the left frontal region as compared to right frontal region, irrespective of valence. In other words, brain activity was relatively higher in the right as compared to left frontal region for both negative and positive emotions elicited by the music (as alpha power is inversely related to brain activity). According to the hemispheric valence hypothesis (Davidson, 1984, 1988, 1992a), the frontal asymmetry is thought to reflect emotional valence, where positive emotions are often associated with approach-related motivation and negative emotions associated with withdrawal-related motivation. As emotional valence and motivational direction are often correlated, it is difficult to ascertain whether valence or motivation is more likely to be the fundamental mechanism underlying frontal asymmetry (Spielberg et al., 2008). To address this issue, Harmon-Jones and Allen (1998) studied the electrophysiological correlates of anger (a negative emotion which is commonly assumed to have an approach-related motivational tendency) and found that anger was associated with greater left- than right-frontal activity (i.e., approach-related motivation). Thus, they argued that frontal asymmetry varies as a function of motivational direction rather than emotional valence. Similar findings have been documented in other studies (see Harmon-Jones, 2003, 2006; Hewig et al., 2004; Rybak et al., 2006; Wacker et al., 2003). Following this line of reasoning, it would suggest that in both low- and high-valenced music conditions in the current study, there is a tendency for withdrawal-related motivation. However, participants did experience both pleasant and unpleasant emotions based on their self-reported emotion ratings, rendering the co-occurrence of pleasant emotions and withdrawal-related motivation unlikely.

Thus, results from the current study are more likely to lend support to the right hemisphere hypothesis (Borod et al., 1998), which suggests a right-hemispheric dominance in music processing in general. Accordingly, the right-biased brain activity observed in the current study could reflect general music processing. Alternatively, it is possible that music stimuli of more intense emotional valence are required to show the frontal alpha asymmetry pattern.

Lastly, it should also be noted that a majority of studies reporting significant associations between frontal alpha asymmetry and emotion valence used static affective stimuli such as images (Davidson, 1992a; Davidson et al., 1990) instead of dynamic ones such as music. Therefore, it might be possible that the pattern of frontal alpha asymmetry might be more robust and stable in the visual modality than auditory modality.

Relating to Frontal Midline Theta

Based on previous studies documenting the association between frontal midline and pleasantness (e.g., Sammler et al., 2007), I hypothesized that increased valence is associated with increased frontal midline theta. However, results from the current study did not find significant differences between frontal midline theta power of JPN_Power and JPN_Fear. A plausible explanation for this lack of effect could be that the while the music stimuli employed in this study were intense enough to elicit differences in fronto-temporo-occipital regions in alpha frequency band, they might not have been robust enough to elicit a frontal midline effect.

Comparison of Emotional Arousal (Passive *vs* Active)

To investigate the electrophysiological correlates of emotional arousal (low arousal, passive – high arousal, active), I compared the music conditions JPN_Power and JPN_Nostalgia. Results showed that JPN_Power was felt as significantly more active as compared to JPN_Nostalgia, and they are comparable in terms of emotional valence. While JPN_Power was felt as significantly more active as compared to JPN_Nostalgia music, EEG results lend partial support for the hypothesized electrophysiological correlates of arousal in terms of absolute frontal activity: absolute frontal activity was significantly different in the beta frequency band, and not alpha band. In addition, the expected association between right parietal region and arousal was not observed, given the lack of main effects of music condition (low arousal *vs* high arousal) in the parietal region.

Absolute Frontal Power

While I did not find significant main effects of arousal in the alpha band was not found, results showed a significant main effect of arousal in the beta band in the frontal region. This provides partial support for the hypothesis that absolute frontal power could distinguish between high and low arousal levels. In addition, this is consistent with studies that reported an association between frontal region and beta, gamma bands (Daly et al., 2019). Results of frontal beta power where there is higher frontal beta power in high arousal music condition as compared to low arousal music condition is consistent with Daly et al. (2015)’s study where the authors reported the behavioral component of energy-arousal to be predicted by beta band powers over the centre of the frontal cortex and the left motor cortex.

Fronto-occipital Asymmetry

In both music conditions, alpha and theta power were found to be higher in the left fronto-occipital regions. The observed left-biased power towards fronto-occipital region is consistent with studies that have shown neural assembly networks of music-induced emotions to show sparse long range connections involving both pre-frontal and occipital regions which are modulated by tension induced by the music (Daly et al., 2014). This further highlights findings reported elsewhere (Costa et al., 2006) that induced emotions involve a broad network of cortical activation.

Common Electrophysiological Correlates Irrespective of Degree of Emotional Valence and Arousal

Higher Beta Power in Right Parietal Region

Irrespective of valence and arousal, beta power is significantly higher in right parietal region as compared to the left parietal region. The right-biased beta power in parietal region in both music conditions could be attributed to a general state of arousal. The lack of differences between music conditions is a similar finding to other studies that did not find parietal associations in levels of arousal in music-evoked emotions. However, this does not support the model postulated by Heller (1993) where right parietal region is associated with arousal. Instead, findings from the current study are similar to Schmidt and

Trainor (2001), where they did not find differences in parietal activity during the presentation of the musical excerpts as a function of intensity. To account for this, they suggested that music stimuli might have elicited an internal focus rather than an external focus to environmental stimuli. The parietal effects may require attention to the external world. Another plausible explanation could be that right parietal region could possibly be reflective of the relationship between tempo entraining activity in the motor cortex (Daly et al., 2014; Daly et al., 2015).

It is also possible that the right-biased beta power in the parietal region is reflective of behavioral component of tension-arousal. Daly et al. (2015) reported that the behavioral component of tension-arousal is observed to be predicted by beta power over right motor cortex and parietal cortex.

Parieto-temporal Asymmetries in Alpha and Theta Bands

Irrespective of valence and arousal, both music conditions elicited higher alpha and theta power in the right parieto-temporal regions. The parieto-temporal network is similar to Koelstra et al. (2010), although not in a similar hemispheric direction. Likewise, this provides support for the role of parieto-temporal regions of the right hemisphere in constituting a system that is integrally involved in the experience of emotion. These regions of the right hemisphere are equipped with qualities that make them uniquely suited to interpret emotional information and to distribute attention across both sides of space. As a corollary, this right-hemisphere system appears to exercise a special command over the autonomic arousal functions associated with emotional states (Heller, 1993).

Comparison of Frequency Bands Associated with Music-evoked Emotions

In the current study, the alpha band is observed to be more related to emotional valence and arousal as compared to the beta and theta bands (Appendices B-5, Table S4-4; B-7, Table S4-9). This is evident from results of hemisphere being significant predictors of emotional valence and arousal in fronto-temporo-parietal regions in the alpha band, as compared to being a significant predictor of emotional valence and arousal only in parieto-occipital regions in the theta band, and parietal region in the beta band. The finding of alpha band being more related to emotional valence is consistent with existing studies that reported alpha to be more strongly related to behavior than power in other frequency bands (Davidson & Hugdahl, 1996).

Limitations

The current study did not include a neutral music condition to compare against with. In addition, in an effort to minimize motion-related artefacts and additional cognitive workload not related to music listening, I did not have a measure of attention or engagement during the music listening task. Therefore, this poses certain constraints on the inference that can be made regarding the parietal activity observed in the results.

Summary and Future Directions

In sum, the current study did not find support for the conventional electrophysiological markers, such as the association of emotional valence with frontal alpha asymmetry or frontal midline theta, or the association of emotional arousal with absolute frontal alpha activity or right parietal activation. Instead, a common pattern of left-biased power in fronto-occipital regions and right-biased power in parieto-temporal regions were observed in both music conditions. Taken together, results from the current study showed that electrophysiological correlates of music-evoked emotions are not limited to frontal regions or the alpha frequency band. More specifically, there might be greater involvement of temporal and parietal regions than previously thought. Hence, future studies should take these into account.

CHAPTER V: STUDY 2B

EFFECTS OF FAMILIARITY WITH MUSICAL STYLE ON MUSIC-EVOKED EMOTIONS

5.1. Effects of Familiarity with Musical Style on Music-evoked Emotions

Building on Study 1 which developed music stimuli from familiar and unfamiliar musical styles (Chapter 3), this chapter will further study the underlying electrophysiological correlates of music-evoked emotions from both musical styles. A brief recap of the motivation for the topic of investigation is first presented, followed by its postulated association mechanisms, relevant neuroimaging literature related to familiarity with musical styles, and finally the empirical study conducted in this thesis.

In Chapter 2 (Literature Review), I emphasized that understanding *why* and *how* music evokes emotion is not simply dependent on mapping the relationship between musical features and emotions, but there is a necessity in considering the relationship between the listener and the music (reciprocal feedback model, Hargreaves et al., 2005). Psychological mechanisms that were postulated to underlie music-evoked emotions were also discussed, and these can be broadly categorized into two groups: mechanisms that are more dependent on learning (e.g., musical expectancy, episodic memory) and those that are more innate (e.g., brainstem reflex, rhythmic entrainment, emotional contagion) (Juslin & Västfjäll, 2008).

For this thesis, I am interested in aspects of music-evoked emotions that are more dependent on learning, as it encapsulates well the necessity of considering the relationship between listener and music. Such musical experience can be studied by investigating listeners' familiarity with musical style or in terms of recognition. In Chapter 3, I posited that the mechanisms underlying effects of familiarity with musical styles are broadly thought to be:

musical expectancy (Meyer, 1956), statistical learning and probabilistic prediction (Pearce, 2018).

Familiarity in Terms of Cultural Familiarity

Using graph theory approach, a technique suggested to elucidate brain network properties, Li et al. (2014) investigated global and local network properties of music perception with culturally different styles of music: Chinese traditional, western classical, and light music with Chinese listeners. They found that small-world properties (i.e., effective neural resource allocation) appeared when perceiving culturally unfamiliar music (light music and western classical music) as compared to culturally familiar music (Chinese traditional music). Based on this finding, it was suggested that unfamiliar music required higher attention, a similar conclusion observed by Nan et al. (2006).

In addition, Madsen et al. (2019) provided evidence for higher engagement with unfamiliar musical styles as compared to familiar musical styles. In their study, they investigated engagement with music after repeated exposure in familiar music and unfamiliar musical styles. They found that listener engagement tends to decrease across repeated exposures of familiar music, but that unfamiliar musical styles can sustain an audience's interest, particularly for individuals with some musical training. This therefore also provides support for the notion that unfamiliar musical styles involve higher engagement levels as compared to familiar musical styles.

Besides, existing studies have shown that emotional valence is more dependent on the type of musical style, whereas emotional arousal shows less genre-specificity (Eerola, 2011). Moreover, Egermann et al. (2015) showed that emotional valence might be meditated by cultural learning, while changes in arousal might involve a more basic, universal response to low-level acoustical characteristics of music.

Familiarity in Terms of Recognition

Familiarity with music, as conceptualized in terms of recognition of musical material, has been shown to activate the limbic, paralimbic and reward circuitries (Pereira et al., 2011). In addition, van den Bosch et al. (2013) showed that familiarity with music creates certain levels of expectation and predictability, which is crucial in the experience of emotional and physiological arousal in response to music. Familiarity with musical melodies was also observed to be correlated with an N400 event-related potential component (a marker of conceptual processing) in the fronto-central regions. Specifically, melodies with a higher degree of familiarity produced more negative potentials as compared with less familiar melodies (Daltrozzo et al., 2010). Consequently, Daltrozzo et al. (2010) suggest that familiarity with musical melodies could be accompanied by other cognitive processes at the conceptual level.

Besides, existing studies have reported stronger cortical activity in response to the periodic rhythm of unfamiliar as compared to familiar music (Meltzer et al., 2015). Using piano melodies, Kumagai et al. (2017) showed that the magnitude of pronounced peaks in EEG activity was significantly larger when listening to unfamiliar and scrambled music as compared to familiar music. This provides evidence for stronger cortical response to unfamiliar as compared to familiar music.

Traditionally, the emotion-recognition community are largely interested in classifying different emotional states. Studies in this field have achieved quite considerable success (for more details, see Chapter 2). However, the majority of these studies have overlooked the role of music familiarity effects. Only recently, that some studies in the machine learning field have started to highlight the importance of considering familiarity with musical excerpts. For instance, Hadjidimitriou and Hadjileontiadis (2013) conducted an EEG-based emotion classification that compared classification accuracy across three classes: regardless of familiarity, familiar music only and unfamiliar music only. They found that classification accuracy was best when only familiar music were considered, suggesting that familiarity with music would have some influence on brain activity.

Shahabi and Moghimi (2016) investigated EEG connectivity patterns among EEG electrodes in different frequency bands while participants listened to classical and Iranian musical excerpts. Using the connectivity indices between different cortical areas and support vector machine (SVM), they showed that they could distinguish trials in terms of the familiarity of the musical genres with an accuracy of 83.04% ± 1.47%. While they provided evidence that it is plausible to accurately distinguish familiarity of the musical genres, their comparison was a post-hoc analyses that compared the classification of two classical music compositions (which was a mix of positive and negative valence) against two Iranian musical excerpts. It is therefore not a systematic manipulation to investigate the classification with familiar or unfamiliar musical style, and therefore provides an impetus for the current study to expand on this line of investigation.

Current Study

As such, studies that consider the relationship between listener and music can be broadly thought of as either focusing on examining behavioral and neural correlates of familiarity with music in terms of recognition, or at the other end of the spectrum, investigating cultural differences in two very distinct cultures. Studies examining familiarity in terms of recognition are usually concerned with changes in terms of liking of the music, and mechanisms of episodic memory is likely to co-occur given that long-term memory processes will be involved. On the other hand, globalization has made it increasingly challenging to access two cultures that are completely not exposed to each other.

Therefore, studying the effects of familiarity with musical style on the response of cortical activity provides a good trade-off between these two ends of the spectrum. In this regard, I proposed that another method to study effects of familiarity to musical style, could be to operationalize familiarity in the following manner: familiar musical style – a musical style or genre that is relevant to the sample that is being studied; unfamiliar musical style – a geographical distant counterpart of a musical style or genre that is least popular or frequently listened to by the sample.

Thus far, relatively few studies have conceptualized familiarity with musical style in a similar manner, and thus research has yet to show that mechanisms of musical expectancy or learning could also be evidence in familiarity with different musical styles. Therefore, investigating whether music-evoked emotions and brain activity are different depending on familiarity with different musical styles could help to shed light on the neural activity and underlying mechanisms involved in music-evoked emotions.

With that, I have selected Japanese animation OSTs as familiar musical style and Greek Laïkó music as unfamiliar musical style. Results from Study 1 showed that both the high valence and low arousal quadrants of Japanese animation OSTs and Greek Laïkó music are felt as Nostalgia/Calmness. As such, these two music conditions are selected for further analyses in this chapter. Following which, the current study poses the following research questions: Firstly, how does familiarity with musical style affect music-evoked emotions in terms of behavioral responses? Secondly, how does familiarity with musical style affect EEG activity? Lastly, can EEG patterns based on familiarity with musical style be distinguished?

For the first research question, I hypothesized that music from both familiar and unfamiliar musical styles are able to elicit emotions. However, this effect would be differentiated for emotional valence and arousal such that:

1) Music of the familiar musical style (JPN_Nostalgia) will be felt as more pleasant (i.e., higher valence ratings) as compared to unfamiliar musical style (GRK_Nostalgia), given that emotional valence involves mechanisms of statistical learning and musical expectancy.
2) However, no significant differences in emotional arousal (i.e., arousal ratings) is expected in both musical styles.

For the second research question, based on literature that investigated familiarity (in terms of recognition) with music that found stronger cortical brain activity for unfamiliar as compared to familiar music, it is hypothesized that higher overall brain activity will be elicited by the unfamiliar musical style as compared to familiar musical style. Given that the expected association between frontal midline theta and valence was not observed in Study 2A

(Chapter 4), it is plausible that frontal midline theta power might be more related with attentional processes instead. Following this theoretical perspective, I hypothesized that the unfamiliar musical style would elicit higher frontal midline theta as compared to familiar musical style. Exploratory analyses will also be conducted to examine asymmetries in each brain regions, given that various studies found different types of asymmetry associations in each brain region.

For the last research question, based on literature that showed improved classification accuracy when considering familiarity with music, the current study expects that EEG patterns of familiar and unfamiliar musical style can be distinguished accurately with machine learning approaches.

5.2. Methods

Participants

Participants are the same as in Study 2A, with the following demographic background: Data from 49 participants (28M 21F; age: M = 23.94, SD = 3.46) were included in this study. 23 participants have formal musical training, and 26 does not have formal musical training. 20 participants were involved in music-related CCAs, and 29 were not involved in music-related CCAs. See Chapter 4 for more details of participant inclusion/exclusion criteria.

Music Stimuli

The final selection of music stimuli were those that met all of the following criteria in Study 1 in Chapter 3: (1) elicited the most intensity of the emotional state, (2) good reliability, (3) were not recognized by most participants. As a brief recap, the general criteria of the music stimuli were that they (1) should not contain lyrics, dialogues or sound effects, and (2) should not contain popular tunes that are familiar with episodic memory.

For the familiar musical style, Japanese animation OSTs were chosen to elicit three emotional states. Each emotional state consists of four music stimuli, and all the musical excerpts were 45-seconds (inclusive of 1-second fade in and 1-second fade out), and normalized to ensure equal loudness across excerpts:

(4) Low valence, High arousal (JPN_Fear): 4 stimuli

(5) High valence, High arousal (JPN_Power): 4 stimuli

(6) High valence, Low arousal (JPN_Nostalgia): 4 stimuli

For the unfamiliar musical style, Greek music from the Laïkó genre in the Greek Music Dataset (Makris et al., 2015) were selected to elicit two emotional states. Each emotional state consists of 4 stimuli, musical excerpts ranged from 20 to 41 sec (*M* = 29 sec, *SD* = 8.04 sec), also with 1-sec fade in and 1-sec fade out, and normalized to ensure equal loudness across excerpts:

(1) High valence, High arousal (GRK_Joyful activation): 4 stimuli

(2) High valence, Low arousal (GRK_Nostalgia): 4 stimuli

For more details of the music stimuli, please refer to Appendices A-3 and A-4.

Materials

The baseline mood measure (POMS; Grove & Prapavessis, 1992) and emotion rating questionnaire (see Chapter 4; Appendices B-2 and B-3) are used for this study. In the current study, musical expectancy is operationalized by asking participants to self-report whether they are able to anticipate what is coming next in the music.

Procedure and EEG Recording

Full details of the procedure and EEG recording are described in Chapter 4. This study is primarily concerned with the comparisons of musical styles (Fig. 5-1)

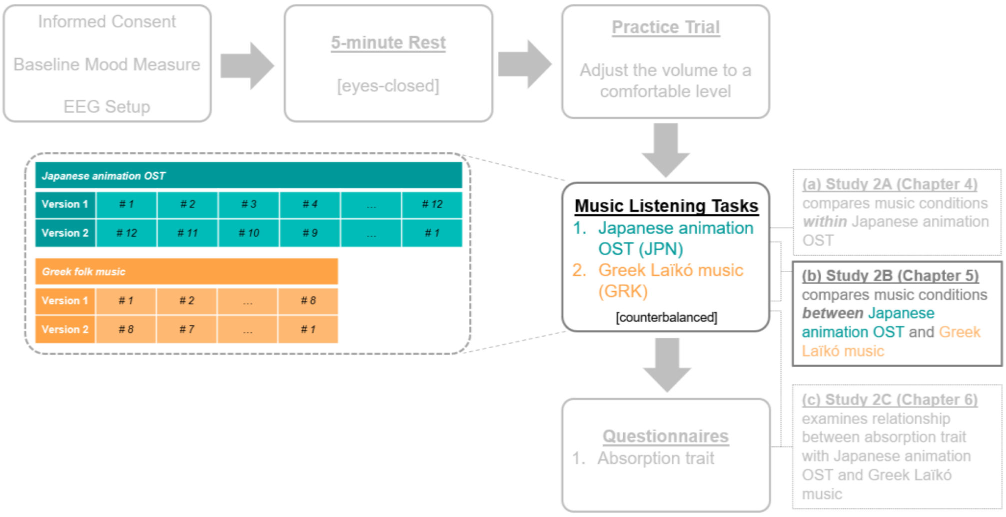


Fig. 5-1. Music conditions examined in Study 2B, extracted from the same EEG task paradigm as described in Chapter 4.

Follow-up Survey

Participants are the same as in Study 2A, with the following demographic background: 38 participants (21M 17F; age: M = 24.16, SD = 3.82) indicated in a subsequent survey how familiar they are with the music genres of Japanese Anime music, Folk music and Greek Laïkó music specifically, on a 5-point Likert scale, with 1 being not familiar at all, 2 being slightly familiar, 3 being moderately familiar, 4 being very familiar, 5 being extremely familiar (see Chapter 4 for more details).

Behavioral Data Analysis

Behavioral data analyses were conducted with SPSS Version 26 and R version 4.0.3. R package ggplot2 (Wickham, 2016) was employed for data visualization.

Emotion Rating Task

Mean scores were computed for discrete emotion labels. To evaluate the effect of familiarity with musical style on emotions, music conditions which elicited similar emotional states (i.e., pleasant and passive, evoked feelings of Nostalgia) in each musical style will be used for subsequent analyses. This is denoted by the contrast "JPN_Nostalgia (familiar musical style; high valence, low arousal) *vs* GRK_Nostalgia (unfamiliar musical style; high valence, low arousal)". Paired *t*-tests are employed to examine differences between the music conditions. Should the assumption of normality be violated, Wilcoxon signed rank test will be used.

Follow-up Survey

Friedman test was conducted to examine if there are differences among the familiarity scores of Japanese animation OST, folk music in general and Greek Laïkó music. Should there be a significant main effect, Wilcoxon signed rank tests were carried out to investigate group differences.

EEG Data Analysis

Pre-processing

Data was first pre-processed with EEGLAB (version 13.4.4b; Delorme & Makeig, 2004). The same pre-processing pipeline detailed in Chapter 4 is used (refer to Fig. 4-3).

EEG Power Spectrum Analysis

The same power spectra calculations as in Chapter 4 were employed. To investigate the effects of familiarity with musical style, comparisons between musical styles which elicits pleasant and passive emotions (i.e., JPN_Nostalgia and GRK_Nostalgia) will be made. For the effects of familiarity with musical style, for all frequency bands, separate 2 (music condition) x 2 (hemisphere) repeated-measures ANOVA were conducted for each brain region. In addition, paired *t*-test was conducted to investigate if there are significant differences in frontal midline theta between both music conditions.

Asymmetry Index (AI) Analysis

Asymmetry index (AI), as introduced in Chapter 4, was computed for each frequency band using the following formula as in Schmidt and Hanslmayr (2009):

$$AI_i = \frac{POW_{right_i} - POW_{left_i}}{POW_{baseline_i}}$$

Where Pow_{right} is the mean power of all electrodes in right of selected region, Pow_{left} is mean power of all electrodes in left of selected region, $Pow_{baseline}$ is mean power of all electrodes in the selected region. This formula accounts for individual differences in power by normalizing this difference on the individual baseline power. Therefore, a positive value indicates greater right-sided power and negative value reflects greater left-sided power in the specific frequency band.

Paired *t*-tests were conducted between music conditions for each brain region separately.

Classification Analysis

To investigate the feasibility of EEG brain dynamics data to categorize emotions elicited from listening to familiar or unfamiliar musical styles, the support vector machine (SVM) was employed to perform a series of binary classification for the type of musical style:

1) Familiar (Japan animation OST) vs Unfamiliar (Greek Laïkó music)
2) positive valence in both musical styles
3) positive valence AND high arousal in both musical styles
4) positive valence AND low arousal in both musical styles

SVM was selected for this study as it is one of the most popular supervised learning algorithms, and has been shown to be a robust algorithm for emotion-recognition detection (Latha & Hema, 2012). The underlying concept of SVM is to project input data onto a higher dimensional feature space via a kernel transfer function, which is easier to be separated than that in the original feature space. The LIMSVM software version 3.11 (Chang & Lin, 2011) was used.

Next, a classification-based approach was employed to evaluate the contribution of four different types of features. Firstly, EEG spectral powers in each frequency band was employed. Secondly, a combination of all EEG spectral powers extracted in the aforementioned section (EEG_Total), leading to 3 (frequency band) x 61 channels = 183 feature dimensions. Thirdly, differential asymmetry (DA) for each pair of electrodes was computed. This index is recommended by Lin, Wang, et al. (2010), who found that this method of calculating asymmetry across frequency bands as compared to other calculation methods (e.g., power division: power of F1/power of F2), was a sensitive metric for characterizing brain dynamics in response to emotional states of joy, anger, sadness and pleasure as elicited by music. The DA is calculated by power subtraction (e.g., power of F1 – power of F2). In total, there were 26 symmetric electrode pairs, namely Fp1 – Fp2, AF7 – AF8, AF3-AF4, F7 – F8, F5 – F6, F3 – F4, F1 – F2, FC5 – FC6, FC3 – FC4, FC1 – FC2, C5 – C6, C3 – C4, C1 – C2, PO3 – PO4, PO7 – PO8, O1 – O2, FT7 – FT8, T3 – T4, TP7 – TP8 and T5 – T6. Across alpha, theta and beta frequency bands, there is a resulting of 3 (frequency band) x 26 electrode pairs = 78 feature dimensions. Lastly, the overall contribution of all the EEG spectral powers and DA (EEG_Total_DA) was evaluated (Table 5-1).

Table 5-1: Number of features in each feature types.

Type of feature	**No. of features**
Alpha	61
Beta	61
Theta	61
Differential asymmetry (DA)	78
EEG_Total	183
EEG_Total_DA	261

Notes. **Differential asymmetry (DA):** calculated by power subtraction (e.g., power of F1 – power of F2). **EEG_Total:** combination of alpha, beta and theta power. **EEG_Total_DA:** combination of all EEG spectral power and DA.

After obtaining the features, a 10-fold cross validation was performed. In a 10-fold cross validation, whole EEG dataset was divided into ten subsets. The SVM were trained with nine subsets of feature vectors, whereas the remaining subset was used for testing. This procedure was repeated ten times with each subset having an equal chance of being the testing data.

5.3. Results

Behavioral Results

Familiarity with Musical Styles

38 participants (21M 17F; age: $M = 24.16$, $SD = 3.82$) completed the follow-up survey on level of familiarity with Japanese animation OSTs and Greek Laïkó music. As the responses are not normally distributed, a Friedman test was conducted to examine if there are significant differences across the familiarity scores of Japanese animation OSTs, Folk music in general, and Greek Laïkó music.

Friedman test showed significant differences among familiarity scores ($\chi^2(2) = 50.87$, $p < .001$). Post-hoc Wilcoxon signed rank test showed that there is a significant difference between familiarity score for Japanese animation OST (*median* = 2.50, $SD = 1.20$) and Folk_General (*median* = 1, $SD = 0.31$) with $Z = -4.64$, $p < .001$. There is also a significant difference between familiarity score for Japanese animation OST (*median* = 2.50, $SD = 1.20$) and Folk_Greek (*median* = 1, $SD = 0.00$) with $Z = -4.68$, $p < .001$. Lastly, there is also a significant difference between familiarity score for Folk_General (*median* = 1, $SD = 0.31$) and Folk_Greek (*median* = 1, $SD = 0.00$) ($Z = -2.00$, $p = .046$) (Fig. 5-2).

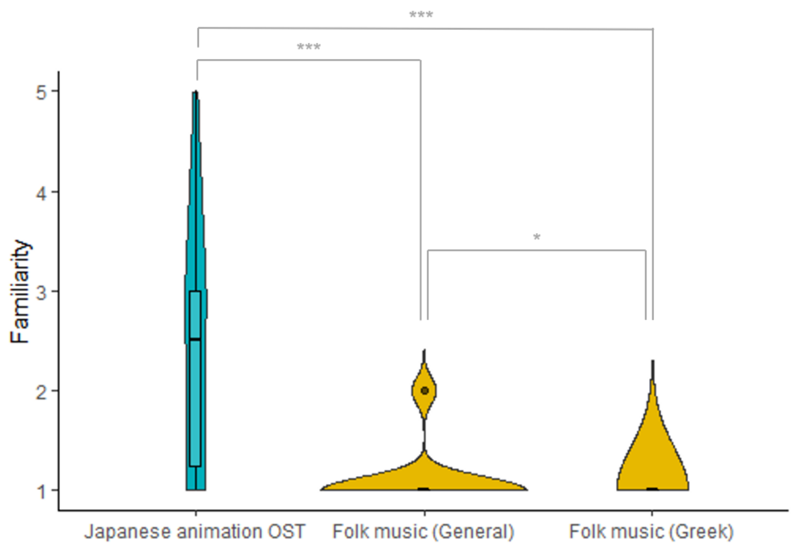


Fig. 5-2. Violin plots with boxplots showing familiarity scores of Japanese animation OST, Folk music (in general) and Greek Laïkó music. (*n* = 38). * *p* < .05 , ** *p* < .01, *** *p* < .001

Recognition and Anticipation Scores

Wilcoxon signed rank test shows that there is a significant difference between recognition scores of Japanese animation OST and Greek Laïkó music (*Z* = -2.26, *p* = .024). Specifically, there is significantly higher recognition score for Japanese animation OST (*median* = 1.92, *SD* = 0.87) as compared to Greek Laïkó music (*median* = 1.63, *SD* = 0.90) (Fig 5-3a). Thus, participants probably do not recognize the music stimuli of both musical styles, but they showed lesser recognition for Greek Laïkó music as compared to Japanese animation OST.

However, there was no significant difference between anticipation scores of Japanese animation OST (*median* = 2.67, *SD* = 0.95) and Greek Laïkó music (*median* = 2.75, *SD* = 1.03) (*Z* = -0.30, *p* = .77) (Fig. 5-3b). Thus, participants are equally unable to anticipate the next tune coming next in the music.

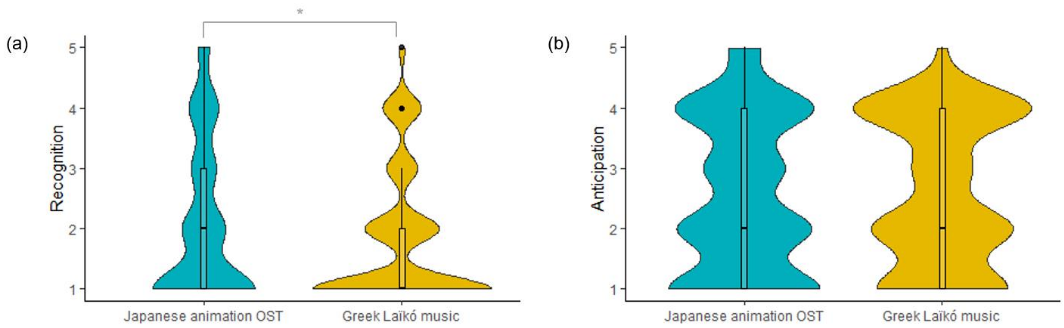


Fig. 5-3. Violin plots with boxplots of (a) recognition scores (b) anticipation scores for Japanese animation OST (familiar musical style) and Greek Laïkó music (unfamiliar musical style). * $p < .05$

Emotion Rating

Valence-arousal ratings of Japanese animation OST and Greek Laïkó music are plotted in Fig. 5-4. Shapiro-wilk tests were first conducted to check for normality. For variables that are not normally distributed, non-parametric tests will be used. As a result, parametric tests are used for (1) arousal analyses; while non-parametric tests are used for (1) valence analyses.

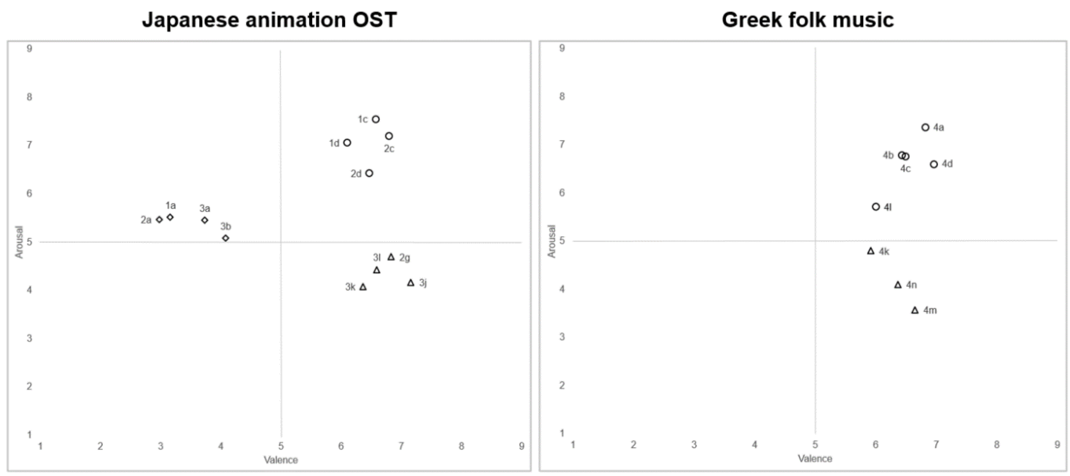


Fig. 5-4. Valence-arousal ratings of each musical excerpts in Japanese animation OST and Greek Laïkó music.

Valence and Arousal Ratings of JPN_Nostalgia and GRK_Nostalgia

Wilcoxon signed rank test showed that JPN_Nostalgia is rated as more pleasant as compared to GRK_Nostalgia ($Z = -2.44$, $p = .009$) (Fig. 5-5a). In contrast, paired sample *t*-test showed that arousal ratings of JPN_Nostalgia and GRK_Nostalgia are not significantly different ($t(48) = 0.86$, $p = .39$) (Fig. 5-5b). Thus, results provide support for the hypotheses that music of a familiar musical style (JPN_Nostalgia) will be felt as more pleasant as compared to unfamiliar musical style (GRK_Nostalgia) but not significant difference between degree of emotional arousal will be observed in both musical styles.

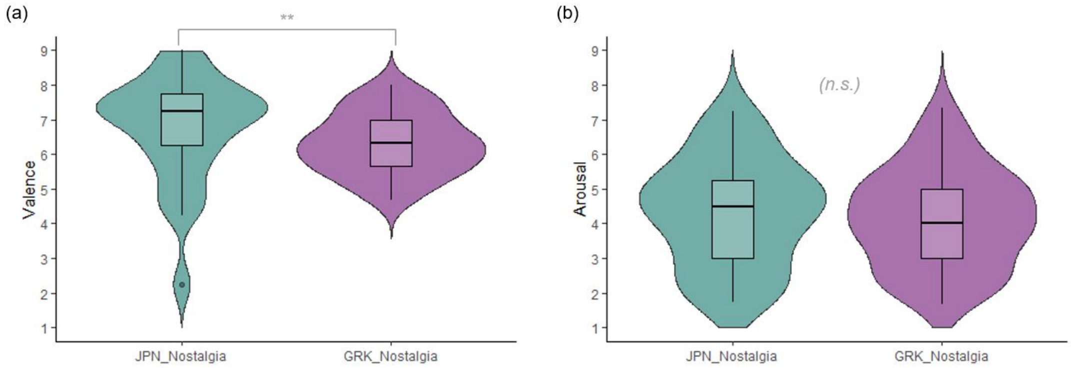


Fig. 5-5. Emotion ratings for music conditions: JPN_Nostalgia and GRK_Nostalgia. Violin plot with boxplot representations of (a) valence ratings and (b) arousal ratings. ** $p < .01$

Discrete Emotions

Discrete emotions of Japanese animation OSTs are previously described in Chapter 4. For Greek Laïkó music, high valence and high arousal music were felt as Joyful activation (GRK_Joy); high valence and low arousal music were felt as Nostalgia and Calmness (GRK_Nostalgia) (Fig. 5-6).

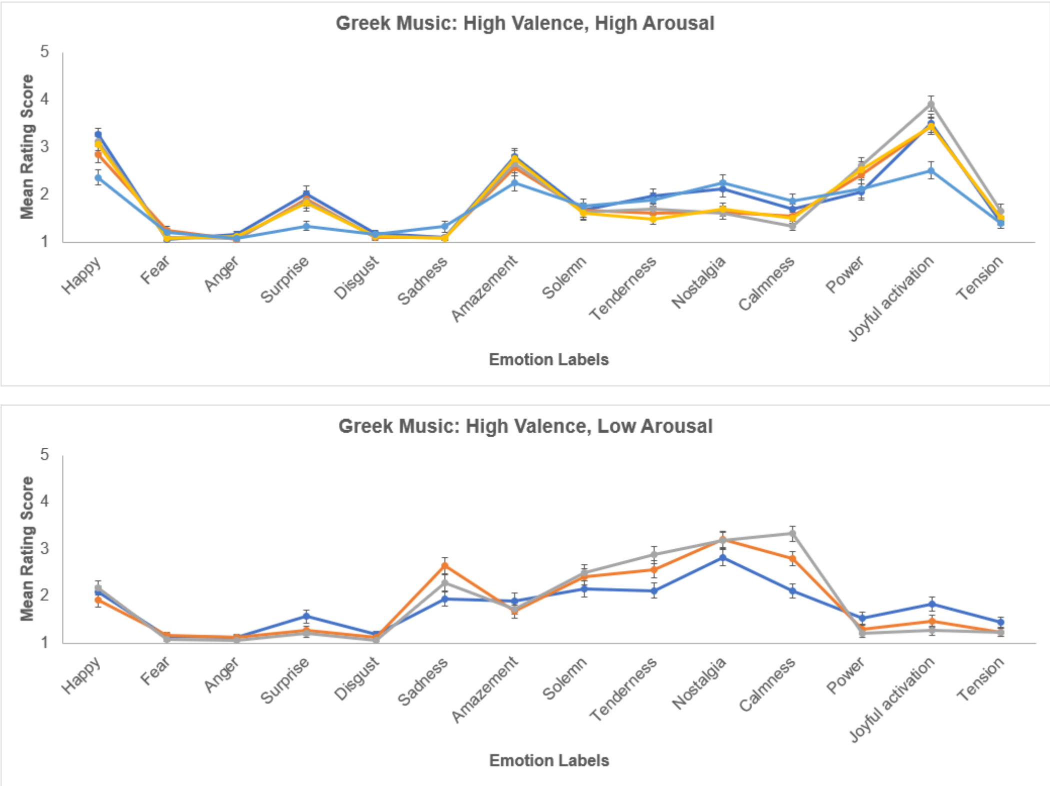


Fig. 5-6. Discrete emotion ratings. Error bars represent +/- 1 * standard error. Each line denotes a musical excerpt.

EEG Results

Power Spectrum Analysis

Visual inspection of the topographic scalp maps shows that JPN_Nostalgia (familiar musical style) elicited lesser frontal theta and beta power as well as lesser bilateral occipital alpha power as compared to GRK_Nostalgia (unfamiliar musical style) (Fig. 5-7).

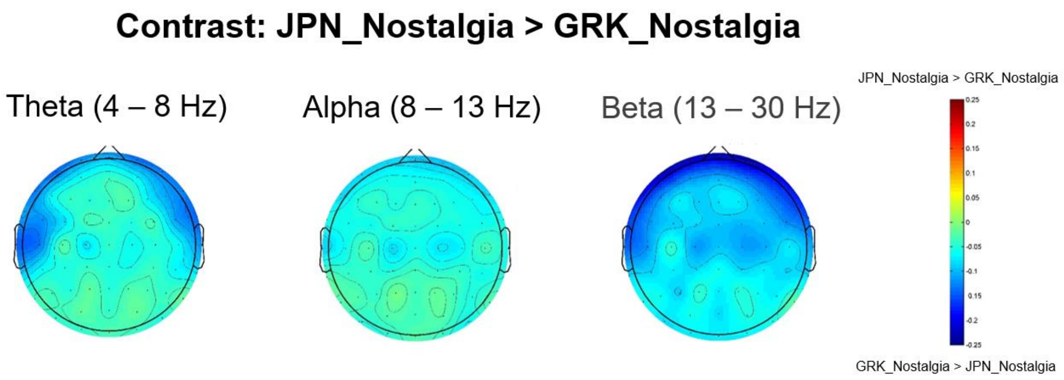


Fig. 5-7. Topographic maps for JPN_Nostalgia (familiar musical style) > GRK_Nostalgia (unfamiliar musical style).

To examine the effects of familiarity with musical style, 2 (music condition: JPN_Nostalgia [familiar musical style] *vs* GRK_Nostalgia [unfamiliar musical style]) x 2 (hemisphere: left *vs* right) repeated-measures ANOVA were conducted for each brain region separately across alpha, beta and theta frequency bands with Bonferroni-corrected $\alpha = .0125$

***A priori* hypothesis 1: Higher overall brain activity in unfamiliar musical style.** In the theta frequency band, significant main effects of musical style were observed in all brain regions at Bonferroni-corrected $\alpha = .0125$. Specifically, theta power is significantly higher in the unfamiliar musical style as compared to familiar musical style in the frontal ($F(1,48) = 36.64$, $p < .001$, $\eta_p^2 = .43$), parietal ($F(1,48) = 17.01$, $p < .001$, $\eta_p^2 = .26$), temporal ($F(1,48) = 16.28$, $p < .001$, $\eta_p^2 = .25$) and occipital ($F(1,48) = 21.485$, $p < .001$, $\eta_p^2 = .31$) regions. In addition, significant main effects of hemisphere were observed in frontal ($F(1,48) = 12.24$, $p < .001$, $\eta_p^2 = .20$), parietal ($F(1,48) = 29.42$, $p < .001$, $\eta_p^2 = .38$) and occipital regions ($F(1,48) = 18.84$, $p < .001$, $\eta_p^2 = .28$) after adjusting for multiple comparisons. Specifically, theta power is relatively higher in left fronto-occipital regions and right parietal region as compared to counterparts. No significant interaction effects were observed in any brain regions at Bonferroni-corrected $\alpha = .0125$ (Fig. 5-8; Appendix C-1, Table S5-1).

In the alpha frequency band, significant main effects of musical style were observed in all brain regions at $p < .05$. However, only the effect at frontal region remained statistically significant at Bonferroni-corrected $\alpha = .0125$. Specifically, overall frontal alpha power is significantly higher in the unfamiliar musical style as compared to familiar musical style ($F(1,48) = 8.98$, $p = .004$, $\eta_p^2 = .16$) (Appendix C-1, Table S5-1). In addition, significant main effects of hemisphere were observed in all brain regions after adjusting for multiple comparisons. Specifically, alpha power is significantly higher in the left frontal ($F(1,48) = 11.85$, $p = .001$, $\eta_p^2 = .20$) and occipital ($F(1,48) = 7.90$, $p = .007$, $\eta_p^2 = .14$) regions as compared to their right counterparts respectively (i.e., brain activity is relatively greater in right frontal and occipital regions). On the other hand, alpha power is significantly higher in right temporal ($F(1,48) = 19.99$, $p < .001$, $\eta_p^2 = .29$) and parietal ($F(1,48) = 59.12$, $p < .001$, $\eta_p^2 = .55$) regions as compared to their left counterparts respectively (i.e., brain activity is relatively greater in left temporal and parietal regions). No significant interaction effects were observed in any brain regions at Bonferroni-corrected $\alpha = .0125$ (Fig. 5-8; Appendix C-1, Table S5-2).

In the beta frequency range, significant main effects of musical style were observed in all brain regions at $p < .05$. However, only the effects at frontal, temporal and occipital regions remained statistically significant at Bonferroni-corrected $\alpha = .0125$. Specifically, beta power is significantly higher in the unfamiliar musical style as compared to familiar musical style in frontal

(F(1,48) = 8.56, p = .005, η_p^2 = .15), temporal (F(1,48) = 7.82, p = .007, η_p^2 = .14) and occipital (F(1,48) = 7.27, p = .01, η_p^2 = .13) regions (Fig. 5-8; Appendix C-1, Table S5-1). Significant main effect of hemisphere was observed only in the parietal region (F(1,48) = 15.03, p < .001, η_p^2 = .24), where beta power is relatively higher in the right parietal as compared to left parietal region. No significant interaction effects were observed in any brain regions at Bonferroni-corrected α = .0125 (Fig. 5-8; Appendix C-1, Table S5-2).

In sum, main effects of musical style were observed in the frontal region across theta, alpha and beta frequencies; parietal region in theta frequency; and temporo-occipital regions in theta and beta frequency bands. This provides partial support for the hypothesis that unfamiliar musical style will elicit higher overall brain activity as compared to familiar musical style is partially supported.

***A priori* hypothesis 2: Frontal midline theta.** Paired t-test showed that frontal midline theta power is significantly higher in unfamiliar musical style as compared to familiar musical style (t(48) = -5.08, p < .001), thus supporting the hypothesis that unfamiliar musical style will elicit higher frontal midline theta as compared to familiar musical style (Fig. 5-8).

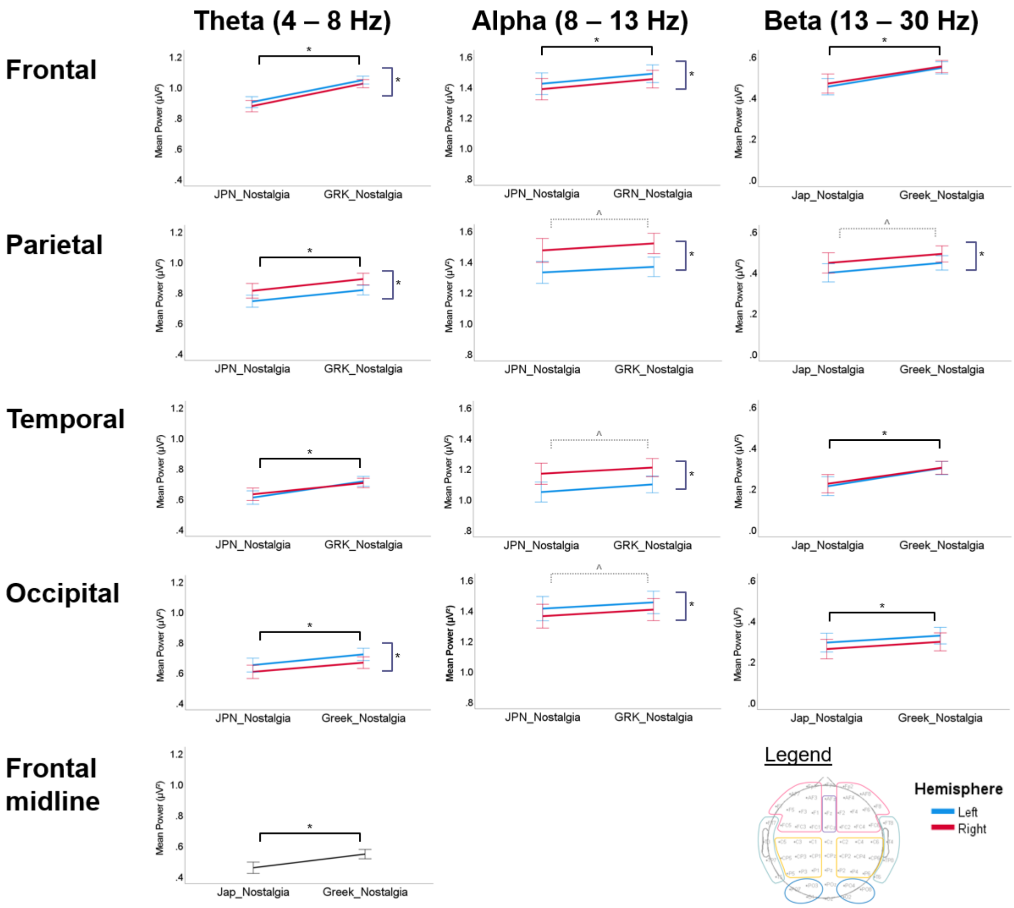


Fig. 5-8. Log theta, alpha and beta power for music conditions JPN_Nostalgia (familiar musical style) and GRK_Nostalgia (unfamiliar musical style) in frontal, parietal, temporal and occipital regions. Hypothesized effects of familiarity with musical style were observed in frontal midline area and fronto-temporo-parietal regions in the theta frequency range. **Legend: *scalp map.*** Frontal (pink), parietal (yellow), temporal (green), occipital (blue). Error bars represent +/- 1 * standard error.

^ $p < .05$, * $p < .001$

Asymmetry Index (AI) analysis. Across frequency bands, AI was highest in parietal and temporal regions in the alpha frequency band. Paired *t*-tests did not yield any significant differences between AI scores of JPN_Nostalgia and GRK_Nostalgia in any brain regions across alpha, theta and beta frequency bands at Bonferroni-corrected α = .0125 (Fig. 5-9, Appendix C-2).

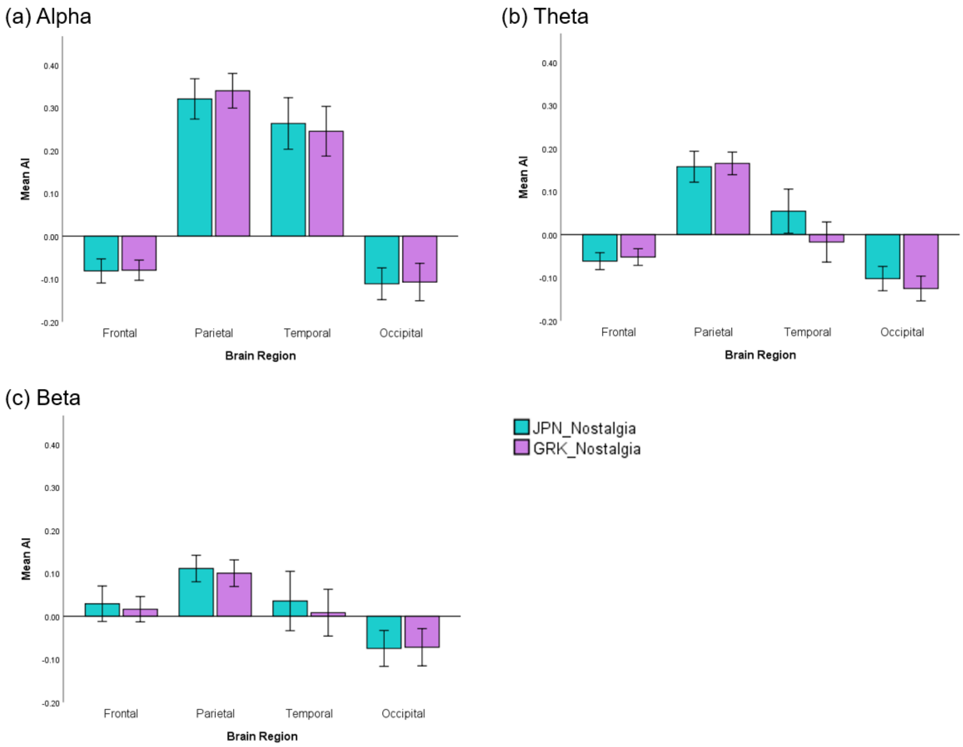


Fig. 5-9. Asymmetry Index (AI) for music conditions JPN_Nostalgia (familiar musical style) and GRK_Nostalgia (unfamiliar musical style). Positive values indicate greater right-sided power; negative values reflect greater left-sided power. No significant differences between JPN_Nostalgia and GRK_Nostalgia were found for brain region and frequency band at Bonferroni-corrected α = .0125.

Error bars represent +/- 1 * standard error.

Classification Analysis

The binary classification accuracies for familiar *vs* unfamiliar musical style ranged between 89.39% to 94.49%, with the highest accuracy being a combination of all bandpower values and differential asymmetry (Table 5-2).

Given that only the familiar musical style contained unpleasant emotions (i.e., JPN_Fear), I further investigated classification performance which considered only positive emotions in both musical styles, regardless of level of arousal. As a result, the binary classification accuracy was between

86.61% and 94.13%, with the highest accuracy being a combination of all bandpower values and differential asymmetry.

To take into account the different levels of arousal, a binary classification of only music conditions which elicited high valence and high arousal in the familiar and unfamiliar musical style (i.e., JPN_Power and GRK_Joy) was conducted. Consequently, the accuracy was between 78% to 87.07%, with the highest accuracy being a combination of all bandpower values and differential asymmetry. Likewise, a binary classification of only music conditions which elicited high valence and low arousal in the familiar and unfamiliar musical style (i.e., JPN_Nostalgia and GRK_Nostalgia) was conducted. This resulted in a range of 74.64% and 87.17% accuracy rates, with the highest accuracy being in the alpha band.

Table 5-2: Accuracy results (in percentage) of classification analyses.

	Total (JPN *vs* GRK)	**Positive Valence only** (JPN_pleasant *vs* GRK_pleasant)	**Positive Valence & High Arousal** (JPN_Power *vs* GRK_Joy)	**Positive Valence & Low Arousal** (JPN_Nostalgia *vs* GRK_Nostalgia)
Alpha	92.14	89.67	85.49	**87.17**
Beta	92.14	89.92	85.03	80.76
Theta	89.39	86.61	78.00	74.64
DA	89.90	86.61	78.68	76.09
EEG_Total	93.98	93.11	86.17	85.13
EEG_Total_DA	**94.49**	**94.13**	**87.07**	86.30

Notes. Highest classification accuracies are bolded.

Differential asymmetry (DA): calculated by power subtraction (e.g., power of F1 – power of F2). **EEG_Total:** combination of alpha, beta and theta power. **EEG_Total_DA:** combination of all EEG spectral power and DA.

5.4. Discussion

In the current study, familiar and unfamiliar musical style elicited different levels of emotional valence, but not arousal. Specifically, valence ratings for familiar musical style (i.e., JPN_Nostalgia) were significantly higher than unfamiliar musical style (i.e., GRK_Nostalgia). This finding supports our hypothesis that valence ratings will be higher for positive emotions in familiar musical style as compared to unfamiliar musical style, and that arousal ratings will be similar in both musical styles. The difference between the emotional valence of the music might be mediated by cultural learning, or mechanisms based on cultural learning such as cognitive appraisal, episodic memory, musical expectancy (Juslin & Västfjäll, 2008; Meyer, 1956), statistical learning and probabilistic predictions (Pearce, 2018). The lack of difference in arousal is consistent with previous studies that also suggested that changes in arousal involve a more basic, universal response to low-level acoustical characteristics of music (Egermann et al., 2015). This finding is also in line with studies that found that musical genres matter for valence, while arousal has less of the genre-specific property (Eerola, 2011).

Familiarity with Musical Styles: Power Spectrum Analysis

Higher EEG Power in Unfamiliar Musical Style

In the current study, music from the unfamiliar musical style (i.e., GRK_Nostalgia) elicited higher EEG power as compared to the familiar musical style (i.e., JPN_Nostalgia). Specifically, significant main effects of musical style were found in all brain regions in theta frequency band, frontal region in alpha frequency band, and fronto-temporo-occipital regions in beta frequency band, with unfamiliar musical style eliciting greater EEG activity as compared to familiar musical style. This provides partial support for the hypothesized effect of unfamiliar musical style eliciting higher brain activity as compared to familiar musical style. In addition, this result is consistent with studies that observed stronger cortical brain activity in response to the periodic rhythm of unfamiliar and scrambled music compared to familiar music (Meltzer et al., 2015), and studies that found stronger neural entrainment for unfamiliar music as compared to familiar music (Kumagai et al., 2017).

Higher Frontal Midline Theta Power in Unfamiliar Musical Style

Results of frontal midline theta power being higher in unfamiliar musical style (GRK_Nostalgia) as compared to familiar musical style (JPN_Nostalgia) is consistent with Thammasan et al. (2017) and other previous reports of enhancement of frontal midline theta rhythm during focused attention (Aftanas & Golocheikine, 2001). Accordingly, frontal midline theta could be more reflective of attention as a fundamental cognitive process, which in turn drives emotional responses of pleasantness, resulting in an association between frontal midline theta and emotional valence (e.g., Sammler et al., 2007).

Brain Asymmetries

Asymmetry analyses in the current study yielded three main findings. Firstly, higher alpha and theta power in left fronto-occipital regions for both musical styles were observed. This pattern of asymmetry was also observed in the valence contrast of Study 2A (see Chapter 4, pg. 107). I suggested that the observed left-biased power towards fronto-occipital region is consistent with studies that have shown neural assembly networks of music-induced emotions to show sparse long range connections involving both pre-frontal and occipital regions which are modulated by tension induced by the music (Daly et al., 2014). This further highlights findings reported elsewhere (Costa et al., 2006) that induced emotions involve a broad network of cortical activation.

Secondly, higher alpha power was found in the right parieto-temporal regions. Likewise, this pattern of asymmetry was also observed in the valence contrast of Study 2A (see Chapter 4, pg. 108). This suggests that the parieto-temporal regions of the right hemisphere constitute a system that is integrally involved in the experience of emotion. These regions of the right hemisphere are equipped with qualities that make them uniquely suited to interpret emotional information and to distribute attention across both sides of space. As a corollary, this right-hemisphere system appears to exercise a special command over the autonomic arousal functions associated with emotional states (Heller, 1993).

Lastly, results showed higher beta power in the right parietal region for both unfamiliar and familiar musical styles. Given that valence was controlled for in this study and that both music conditions differed in terms of level of arousal, results thus suggest that the right parietal region has a role in general state of arousal (wakefulness), rather than different levels of arousal (e.g., high or low arousal).

Familiarity with Musical Styles: Emotion Classification

In the current study, the binary classification results of familiar versus unfamiliar musical style ranged from accuracies of 89.39% to 94.49%. This thus supports the hypothesis that familiar and unfamiliar musical styles can be accurately distinguished with machine learning approaches. Specifically, using a combination of alpha, theta, beta power and differential asymmetry indices achieved the best accuracy for classifying Total (JPN *vs* GRK), High Valence only (JPN_pleasant *vs* GRK_pleasant), and High Valence / High Arousal (JPN_Power *vs* GRK_Joy). For the emotional state of High valence / Low arousal (JPN_Nostalgia *vs* GRK_Nostalgia), binary classification with alpha power as features achieved the highest accuracy.

Limitations

While this study provided evidence of effects of familiarity with musical style on music-evoked emotions, it is not without limitations. In the current study, musical expectancy was operationalized by a self-report question of "Are you able to anticipate what is coming next in the music?" with a Likert-scale of "Definitely not" to "Definitely yes". This might not have been the most objective measure of musical expectancy, given that it is self-reported. An alternative could be to employ probe-tone paradigms to have a quantifiable measure of musical expectancy for music of Japanese animation OST and Greek Laïkó music.

In addition, I opted to employ a passive listening paradigm where participants simply listen to the music passively and not perform any other tasks simultaneously. As in Chapter 4, it was acknowledged that inherent in this methodology is a lack of measurement of attention or engagement that participants had with the task. Hence, there are caveats on our interpretation of the resulting neural activity. In this regard, future studies investigating music-evoked emotions could consider calculating another measure of EEG: inter-subject correlation, which could be considered as a reliable measure of engagement with music (Kaneshiro et al., 2014; Madsen et al., 2019).

Summary and Future Directions

Nonetheless, the current study is a pioneer in demonstrating that comparing emotional responses to familiar and unfamiliar musical style is a suitable approach in investigating learning mechanisms related to music. A potential application of results from this study would be the importance of considering listener's familiarity with musical style in therapeutic settings or neuro-feedback interfaces.

CHAPTER VI: STUDY 2C

ROLE OF ABSORPTION TRAIT IN MUSIC-EVOKED EMOTIONS

6.1. Role of Absorption Trait in Music-evoked Emotions

In Chapter 2 (Literature Review), I emphasized the importance of considering music, listener and context in the study of music-evoked emotions (reciprocal feedback model; Hargreaves et al., 2005). This is also a general consensus in the literature that emotional responses to music are shaped by personality (Barrett & Janata, 2016; Hernandez-Ruiz, James, et al., 2020), music preferences (Yoo et al., 2018), and to a lesser extent, musical expertise (Bigand & Poulin-Charronnat, 2006). Another trait variable of interest that has gained research momentum in the recent years is the role of absorption in aesthetic experience. While several studies have examined this construct (for an overview, see Herbert, 2012), this field of study is still in infancy and results have been somewhat inconclusive. Therefore, the objective of this chapter is to investigate the role of absorption trait in music-evoked emotions. First, literature pertaining to absorption and music will be outlined. Next, the empirical study that examines the relationship between absorption trait and music-evoked emotions will be presented, concluding with a discussion of the findings of the study.

Definitions of Absorption: Trait *vs* State

The construct of absorption trait is closely related to hypnotizability (Glisky et al., 1991), which is commonly measured by the Tellegen Absorption Scale (TAS; Tellegen & Atkinson, 1974). Tellegen and Atkinson (1974) defined absorption as “a capacity for absorbed and self-altering attention”. The main characteristic of the absorption trait is the ability to focus attention on one particular object while completely ignoring other stimuli. Consequently, individuals with high absorption trait should be less disturbed by a laboratory setting during emotion induction because of their ability to "forget" their surroundings. Objects of absorbed attention can include internal (e.g., daydream or a memory) and external events (e.g., a beautiful sunrise or a piece of moving music). Absorption trait is thought to be partly genetically based and stable across different situations and time (Tellegen et al., 1988). Based on an individual's mental disposition, some individuals would show propensity to be absorbed faster or more frequently as compared to others (Tellegen, 1981).

The TAS measures absorption as a general trait and denotes individual differences in the propensity and ability to be absorbed. It consists of 34 questions, which can be categorized as 11 subscales: 1. Reality Absorption, 2. Fantasy Absorption, 3. Dissociation, 4. Sleep Automatism, 5. Openness to Experience, 6. Devotion and Trust, 7. Autonomy-Skepticism, 8. Optimism-Placidity, 9. Aloofness-Reserve, 10. Caution vs Impulsiveness, 11. Relaxation.

Like other constructs, absorption differentiates between trait and state manifestation (Hall et al., 2016). Absorption as a state refers to actually being in a different state of mind, as subjectively experienced. This is similar to research that studies musical involvement (Nagy & Szabó, 2002, 2004), musical receptivity (George & Ilavarasu, 2021), and engagement (Vroegh, 2019) during music listening. Thus far, absorption in music has been mostly studied in as a trait (Garrido & Schubert, 2013; Kreutz et al., 2008; Sandstrom & Russo, 2013). In addition, Herbert (2012) argued that absorption is better conceptualized as a trait as compared to state. Therefore, the current study assumes the theoretical position of absorption as a trait.

Absorption as a General Trait

Current studies have reported several associations between absorption as a general trait and musical emotions. Absorption trait was found to be related to music's ability to influence an individual's mood, listening habits and musical preferences (Wild et al., 1995). Specifically, Wild et al. (1995) found positive correlations between TAS scores and the ability of music to influence individuals' feelings. Garrido and Schubert (2011) examined the effect of personality on liking music that induces sadness and found that absorption, music empathy and empathic concern positively correlated with liking music that induces sadness. This provides evidence that general absorption trait and music empathy are the two best predictors of liking music that induces sadness. Likewise, Kreutz et al. (2008) showed that absorption trait significantly correlated with emotional arousal ratings.

However, the TAS may not be the most ideal measure of absorption in music as several items appear strange to participants (e.g., Sometimes I feel as if my mind could envelope the whole world; If I wish I ca imagine that my body is so heavy that I could not move it even if I wanted to). In addition, only 4 out of 24 items specifically mentioned music. Subsequently, researchers wondered if they could better capture music-specific absorption. With that, Sandstrom and Russo (2013) developed the Absorption in Music Scale (AIMS), which measures "an individual's ability and willingness to allow music to draw them into an emotional experience". In AIMS, each item is related to music. In addition, the AIMS demonstrated high convergent validity with the TAS, and hence it should be a more appropriate measure when studying music specifically.

Absorption Specific to Musical Emotions

Using the AIMS, several studies have found absorption trait to be related to emotional responses evoked by music (e.g., Margulis, 2017; Sandstrom & Russo, 2013). In the study conducted by Sandstrom and Russo (2013), they found that emotional responses to music were correlated with the AIMS scale but not correlated with measures of empathy or music training, hence providing support for criterion validity of the AIMS. Specifically, they found that AIMS score was positively correlated with the difference score for valence, indicating that higher levels of absorption in music are associated with stronger responses to music along the valence dimension of emotion (i.e., greater polarization). Likewise, individuals with high absorption trait also tended to experience more narrative engagement with music (Margulis, 2017).

The moderating effects of absorption trait have also been documented in studies that examined different emotional states induced by music (e.g., Hogue et al., 2016; Loxton et al., 2016) as well as studies that investigated mindfulness meditation (e.g., Dvorak & Hernandez-Ruiz, 2019; Hernandez-Ruiz, Dvorak, et al., 2020). Loxton et al. (2016) found that the relationship between reward sensitivity and music involvement is uniquely mediated by greater absorption in music. Hogue et al. (2016) further demonstrated the moderating effect of absorption trait for music that induces happiness. In particular, a positive relationship between absorption in music and liking for music that induces happiness was observed only in men, and no relationship between absorption and liking was observed in women. In a study that compared the effectiveness and preference for different auditory stimuli in supporting mindfulness meditation, Dvorak and Hernandez-Ruiz (2019) found that levels of absorption in music may moderate participants' responses to auditory stimuli for mindfulness meditation.

These studies thus lay the groundwork for expecting an association between absorption trait and music-evoked emotions, regardless of conceptualizing absorption as a general trait or absorption specifically in music.

Current Study

Thus far, studies that investigated the relationship between absorption trait and emotional responses have looked at the effect on different types of emotional states (e.g., sadness and happiness). Relatively few studies have looked at its effects on music from different musical styles that vary in terms of level of familiarity. By investigating the role of absorption trait and effects of familiarity with musical styles on music-evoked emotions, I could examine if individuals who are high in absorption in music would allow themselves to become engaged in many sorts of music as compared to those who are less willing to be immersed in aesthetic experiences. This could thus help to further clarify the function of absorption trait in musical experiences.

In addition, current literature on the associations of absorption trait with music-evoked emotions has shown inconsistent findings. While most studies have reported a significant association (Hogue et al., 2016; Kreutz et al., 2008; Loxton et al., 2016; Sandstrom & Russo, 2013), some studies did not (e.g., Eerola et al., 2016). Eerola et al. (2016) found high trait empathy and emotional contagion to be related to feelings of sadness and being moved (also termed as *moving sadness*), but not with absorption trait or nostalgia-proneness.

Moreover, despite a growing number of studies showing an association between absorption trait and music-evoked emotions, a majority employed self-reported behavioral measures. Only a handful of studies incorporated other measures, such as microsaccade-rate (Lange et al., 2017). To the best of our knowledge, no study thus far has explored the relationship between absorption trait and neural activity. As such, the current study will conduct exploratory analyses of absorption trait and EEG activity during music listening to see if there are any brain-behavior associations.

The primary objective of Study 2c is to investigate how individual differences in absorption trait affect music-evoked emotions. As a contribution to this this field of research, I examined the relationship between absorption trait and music-evoked emotions with music of familiar and unfamiliar musical style. As in the previous chapter, familiar musical style is represented by JPN_Nostalgia while unfamiliar musical style is represented by GRK_Nostalgia. With that, the current study aims to address these two research questions: Firstly, what is the role of absorption trait in music-evoked emotions? Secondly, what are the electrophysiological correlates of absorption in music-evoked emotions?

For the first research question, the effect of absorption trait is hypothesized to be observed in the unfamiliar musical style (GRK_Nostalgia) and not familiar musical style (JPN_Nostalgia):

1) For the unfamiliar musical style, individuals with high absorption trait will show greater polarized emotional ratings as compared to individuals with low absorption trait. This is because individuals high in absorption trait are more likely to be immersed in a wider variety of musical experiences as compared to individuals low in absorption trait.

2) For the familiar musical style, no significant differences in emotional ratings between individuals with low and high absorption trait will be found. This is because familiar musical style evokes stronger emotional responses irrespective of absorption trait.

For the second research question, exploratory correlation analyses between absorption trait score and EEG power spectra are conducted given the paucity of existing literature on absorption in music and EEG.

6.2. Methods

Participants

Participants are the same as in Study 2A, with the following demographic background: Data from 49 participants (28M 21F; age: *M* = 23.94, *SD* = 3.46) were included in this study. 23 participants have formal musical training, and 26 does not have formal musical training. 20 participants were involved in music-related CCAs, and 29 were not involved in music-related CCAs. See Chapter 4 for more details of participant inclusion/exclusion criteria.

Music Stimuli

This chapter employed music of the high valence and low arousal quadrants of Japanese animation OSTs (JPN_Nostalgia) and Greek Laïkó music (GRK_Nostalgia). Each musical excerpt was normalized to ensure equal loudness across excerpts. The music condition JPN_Nostalgia consisted of 4 stimuli (duration: 45-seconds, inclusive of 1-second fade in and 1-second fade out). The music condition GRK_Nostalgia consisted of 3 stimuli (duration: 24- to 41-seconds, inclusive of 1-second fade in and 1-second fade-out).
For more details of the music stimuli, please refer to Appendices A-3 and A-4.

Materials

Participants completed the baseline mood measure (POMS; Grove & Prapavessis, 1992) and emotion rating questionnaire (Appendixes B-2 and B-3). After completing the music listening tasks, participants completed the Absorption in Music Scale (AIMS; Sandstrom & Russo, 2013).

Absorption in Music

To measure absorption trait, the current study employed the Absorption in Music Scale (AIMS; Sandstrom & Russo, 2013). The AIMS is a 34-item scale which "measures an individual's ability and willingness to allow music to pull them into an emotional experience". For each item, participants rated on a five-point Likert scale (1: Strongly disagree, 5: Strongly agree). Sample items include: "I sometimes feel like I am 'one' with the music", "It is sometimes possible for me to be completely immersed in music and to feel as if my whole state of consciousness has been temporarily altered", "Music sometimes helps me 'step outside' my usual self and experience an entirely different state of being". All items are worded positively. An average of the 34 items was calculated to obtain represent an individual's level of absorption. With this scoring method, the lowest possible score is 34 while the highest possible score is 170. Low scores represent individuals with low absorption trait; high scores represent individuals with high absorption (Appendix D-1).

The AIMS showed good internally consistency (Cronbach's α ranged between .92 and .94), demonstrated good test-retest reliability (r = .86). was strongly correlated with similar scales such as the TAS (r = .76). Therefore, there is sufficient reliability and validity of the AIMS to use in a study with familiar and unfamiliar musical styles. While the AIMS was originally developed in Canada (Sandstrom & Russo, 2013), a pilot study has been conducted in Singapore to establish its validity (Oh, 2019).

Procedure and EEG Recording

Full details of the experimental procedure were described in Chapter 4 (Study 2A). The current study is primarily concerned with procedures after the music listening task (Fig. 6-1).

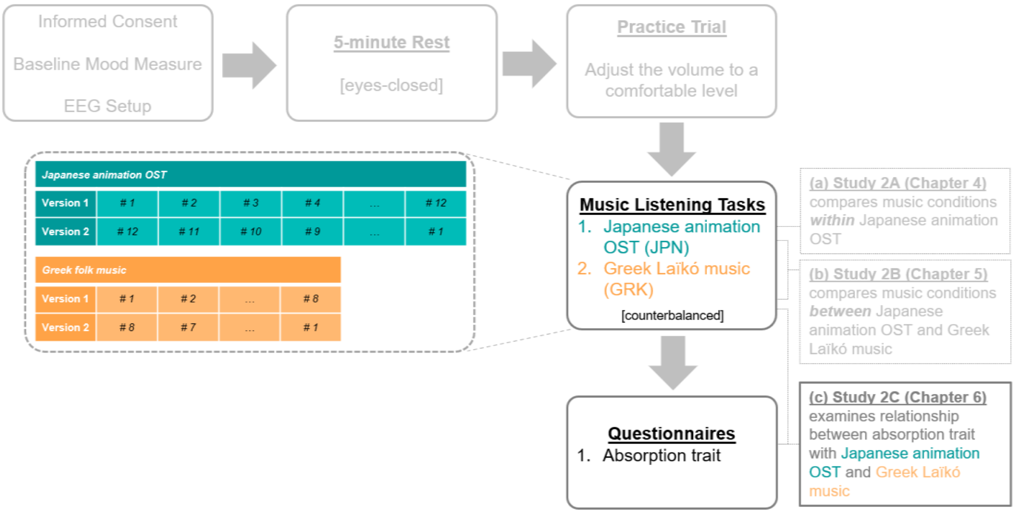


Fig. 6-1. Music conditions and questionnaire examined in Study 2C, extracted from the same EEG task paradigm as described in Chapter 4.

Behavioral Data Analysis

Descriptives of absorption score were first outlined. Non-parametric statistical analyses will be employed should the absorption score not be normally distributed. Next, correlations between absorption score with demographics (age, gender and formal music lessons) are conducted to examine if there are associations between absorption trait and the aforementioned demographic variables. Should any of the associations be significant, they were subsequently included in the regression analyses with emotional responses as outcome variables.

Thereafter, the relationship between absorption trait and emotional response (valence and arousal ratings) are examined by separate correlation analyses between absorption score with valence and arousal ratings of JPN_Nostalgia and GRK_Nostalgia.

To investigate if absorption moderates emotional response depending on familiarity with musical style, multiple regression analyses were conducted with music condition, absorption score and the interaction (music condition * absorption score) as predictors of outcome variables valence and arousal ratings.

Behavioral data analyses were conducted with SPSS Version 26 and R version 4.0.3. R package ggplot2 (Wickham, 2016) was employed for data visualization.

EEG Data Analysis

Pre-processing

Data was first pre-processed with EEGLAB (version 13.4.4b; Delorme & Makeig, 2004). The same pre-processing pipeline detailed in Chapter 4 is used (refer to Fig. 4-3).

Correlation Analysis

To investigate the relationship between absorption and neural activity during music-evoked emotions, separate correlations between absorption score and (1) EEG spectra power of individual scalp channels, (2) EEG spectra power of brain regions (frontal, parietal, temporal and occipital), and (3) asymmetry index (see Chapter 4 for computation of asymmetry index) were conducted for each music condition in each frequency band.

6.3. Results

Behavioral Results

Distribution of Absorption Scores

The current sample scored an average of 123.18 (*SD* = 18.55) on the AIMS, with a range of 74 to 159 (Fig. 6-2). Shapiro-Wilk test shows that the average score (consequently termed AIMS_total) is normally distributed (p =.52). Therefore, subsequent analyses employed parametric statistical tests.

Compared to the norms obtained in the original AIMS paper (Sandstrom and Russo, 2013), of which the mean was 113.5 (*SD* = 23.8), with a range of 46 to 164, the current sample has a relatively higher average absorption score and narrower range.

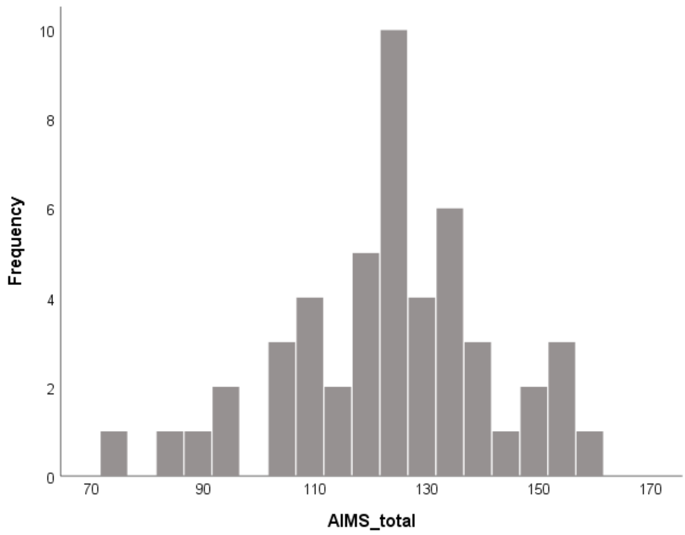


Fig. 6-2. Distribution of absorption score (AIMS_total).

Correlation between Absorption Score and Demographics

Pearson correlations showed that AIMS_total was not significantly correlated to gender ($r(47) = 0.12$, p =.42), age ($r(47) = - 0.27$, p =.059) or formal music lessons ($r(47) = 0.037$, $p = .80$). As such, these variables were not included in subsequent regression analyses.

Correlation between Absorption Score and Emotion Ratings

Given that not all valence and arousal ratings are normally distributed (Appendix D-2), spearman correlations between the AIMS_total and emotion ratings (i.e., valence and arousal ratings) of each music condition separately.

Spearman correlations only yielded significant positive correlations with arousal ratings of GRK_Nostalgia ($r_s(47) = .46$, $p < .001$) and not JPN_Nostalgia ($r_s(47) = .16$, $p = .28$), indicating that higher absorption scores are associated with higher arousal ratings for GRK_Nostalgia (Fig. 6-3). No significant correlations were obtained with valence ratings at $p < .05$.

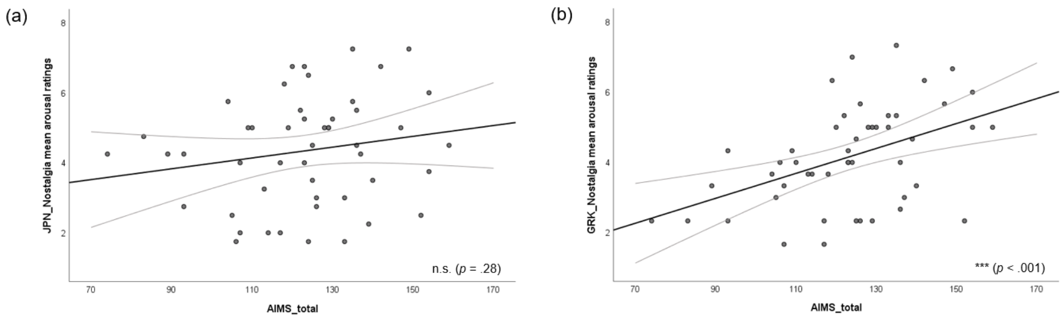


Fig. 6-3. Spearman correlations between AIMS_total and arousal ratings of (a) JPN_Nostalgia, (b) GRK_Nostalgia.

Regression Analyses on Valence Rating

Valence rating was not significantly predicted by music condition (β = 0.77, $t(44) = 1.19$, $p = .24$), AIMS_total ($\beta = 0.0044$, $t(44) = 0.55$, $p = .58$), or the interaction between music condition and AIMS_total ($\beta = -0.0045$, $t(44) = -0.84$, $p = .41$). In other words, there was no effect of musical style or absorption trait on valence ratings of JPN_Nostalgia and GRK_Nostalgia.

Regression Analyses on Arousal Rating

Arousal rating was significantly predicted by music condition ($\beta = 1.33$, $t(44) = 2.52$, $p = .013$), AIMS_total ($\beta = 0.025$, $t(44) = 3.07$, $p = .0028$), and the interaction between music condition and AIMS_total ($\beta = -0.010$, $t(44) = -2.41$, $p = .018$) (Fig. 6-4.).

Post-hoc analyses of simple effects were conducted following the significant interaction effect. Low absorption trait was represented by the 5th percentile (AIMS_total = 86) and high absorption trait represented by the 95th percentile (AIMS_total = 154).

For individuals with low absorption trait, there was no significant difference in arousal ratings of JPN_Nostalgia ($M = 3.77$) and GRK_Nostalgia ($M = 2.84$) ($t(94) = 1.88$, $p = .064$). Likewise, for individuals with high absorption score, there was no significant difference in arousal ratings of JPN_Nostalgia ($M = 4.82$) and GRK_Nostalgia ($M = 5.25$) ($t(94) = -0.78$, $p = 0.43$).

In the familiar musical style (JPN_Nostalgia), there was no significant difference in arousal ratings between individuals with low absorption trait and high absorption trait ($t(94) = -1.52$, $p = .13$). However, in the unfamiliar musical style (GRK_Nostalgia), arousal rating of individuals with low absorption trait ($M = 2.84$) was significantly lower as compared to individuals with high absorption trait ($M = 5.25$) ($t(94) = -4.33$, $p < .001$).

In sum, the effect of absorption was observed only in the arousal ratings of unfamiliar musical style (GRK_Nostalgia), with individuals low in absorption trait rating the music as significantly more passive as compared to individuals with high absorption trait.

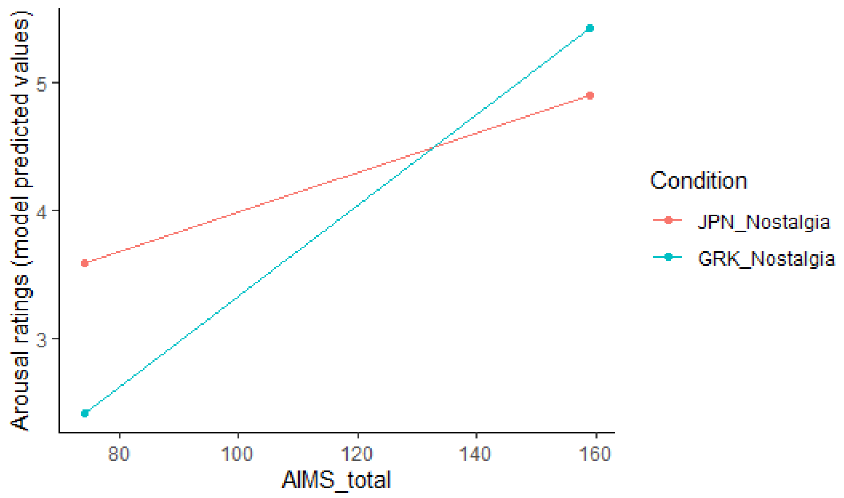


Fig. 6-4. Relationship between AIMS_total and arousal ratings in JPN_Nostalgia and GRK_Nostalgia.

EEG Results

Pearson Correlation between AIMS_Total, Scalp Channels, Brain Regions and Asymmetry Index (AI)

For all frequency bands, log EEG power from all scalp channels was not significantly correlated with AIMS_total at FDR-corrected $p < .05$. Likewise, AIMS_total was not significantly correlated to log EEG spectral power of any brain regions in alpha, beta and theta frequencies at FDR-corrected $p < .05$ (Appendix D-3; Table S6-1). Finally, AI was not significantly correlated with AIMS_total at Bonferroni-corrected $p < .05$ (Appendix D-3; Table S6-2).

6.4 Discussion

In the current study, the relationship between absorption trait and music-evoked emotions was examined by comparing the emotional responses of individuals with low and high absorption trait when they listen to music of familiar (JPN_Nostalgia) and unfamiliar (GRK_Nostalgia) musical styles.

Absorption Trait and Familiar Musical Style

In addition, the current study further showed that music of a familiar musical style elicited similar levels of arousal between individuals with low and high absorption trait. This supports our hypothesis that no significant differences in emotional response will be observed in familiar musical style, as music of the familiar musical style is theorized to be able to elicit emotions in listeners given that listeners would be familiar with the musical syntax of that style.

Absorption Trait and Unfamiliar Musical Style

In general, effects of absorption trait were mostly observed in arousal ratings and not valence ratings, thus providing partial support for our hypotheses. Specifically, the effect of absorption trait was only observed in the arousal (i.e., very passive – very active) ratings of unfamiliar musical style, such that individuals with low absorption trait showed lower arousal ratings for the unfamiliar musical style as compared to individuals with high absorption trait. In other words, individuals who are less likely to be immersed in a musical experience felt that the music of the unfamiliar musical style was significantly more passive as compared to individuals who are more willing to be immersed in the musical experience.

This result is of a reversed hypothesized direction, as I expected individuals with high absorption trait to be more likely to be immersed in a wider variety of musical experiences as compared to individuals with low absorption trait, thus showing greater polarized emotional responses (i.e., lower arousal rating). A plausible explanation for this discrepancy could be that the terms used to quantify emotional arousal in the current study (i.e., very passive *vs* very active) resulted in showing that individuals with high absorption trait felt that music that evokes Nostalgia were felt as more active, thus resulting in higher arousal scores. As such, a higher arousal rating does not necessarily reflect lesser emotional intensity.

While the significant associations between absorption trait and arousal ratings, but not valence ratings is consistent with previous work such as Kreutz et al. (2008), it should be noted that other studies have instead shown absorption trait to be associated with valence ratings, and not arousal ratings (e.g., Sandstrom & Russo, 2013). Thus, this could be an avenue for future research to investigate the relationship between absorption trait and different types of emotional states systematically. Despite the inconsistencies in the relationship between absorption trait and type of emotional responses (i.e., valence or arousal), results from our study and previous studies lend more support to the notion that absorption trait affects music-evoked emotions, as compared to studies that did not find this relationship (e.g., Eerola et al., 2016).

Absorption Trait, Demographics and EEG Activity

While the effect of absorption was observed in the behavioral arousal ratings of unfamiliar musical style (GRK_Nostalgia), absorption trait was neither significantly correlated with demographic variables (gender, age, or formal music lessons) nor EEG activity. The lack of associations between absorption trait and formal music lessons is consistent with Sandstrom and Russo (2013), indicating that absorption in music happens regardless of musical training.

I speculate that the lack of correlations between absorption trait and EEG activity may be that the current sample showed relatively higher average absorption score and a narrower range (current study: scores ranged between 74 to 159) as compared to Sandstrom and Russo (2013) (scores ranged between 46 to 164). Therefore, it may be possible that differences in EEG activity were not found as the current sample did not consist of individuals with a very low absorption trait.

Limitations

While this is a pioneering study in examining absorption trait and familiarity with musical style on music-evoked emotions, it is not without limitations. Firstly, as the experiment was conducted in a laboratory setting, it thus might not be a very accurate representation of immersion in musical experiences. Future studies could be conducted in more naturalistic settings that are conducive for musical immersion.

In addition, the current study only examined the pleasant/passive emotional state (felt as Nostalgia) in both familiar (Japanese animation OSTs) and unfamiliar (Greek Laïkó music) musical styles. Thus, results may be limited to pleasant and passive emotional states, or specifically the emotion Nostalgia, but may not be generalizable to other emotional states such as happiness.

Summary and Future Directions

In conclusion, the current study examined the moderating effects of absorption trait as individuals listened to music of a familiar and unfamiliar musical style. Results showed that individuals with low and high absorption trait experienced similar emotional intensity in the familiar musical style. However, in the unfamiliar musical style, individuals who are less likely to be immersed in a musical experience (i.e., low absorption trait) felt that the music was more passive as compared to individuals who are more willing to be immersed in a musical experience (i.e., high absorption trait).

Given that absorption has been shown to be related to the personality dimension of Openness to Experience, it would be interesting for future work to study how absorption and the difference dimensions of personality predict emotional responses, so as to clarify if absorption trait and Openness to Experience are theoretically different constructs or have different predictive power of emotional responses. Future studies could further examine the relationship between level of familiarity with musical style and music preference and alexithymia.

Lastly, with the ongoing debate of reliable electrophysiological markers of emotional arousal, future studies could employ other measures such as skin conductance, which are more robust in measuring physiological arousal, to investigate the relationship between absorption trait and potential changes in arousal state.

CHAPTER VII: GENERAL DISCUSSION

7.1. Summary of Background Information

One of the most intriguing aspects of music lies in its emotional qualities. Several research approaches have sought to elucidate the relationship between music and emotion. From the music analytic approach, researchers are primarily interested in the effects of various musical features and on emotion (e.g., Eerola et al., 2012; Jaquet et al., 2012; Thompson & Robitaille, 1992; Watson, 1942; Wedin, 1972). However, researchers from the psychological approach argue that simply mapping the relationship between musical features and emotions do not explain why and how music evokes emotion. Instead, it is necessary to discuss the underlying psychological mechanisms (Juslin & Västfjäll, 2008; Meyer, 1956) and to examine reciprocal feedback relationships between music, listener and the situation or context (Hargreaves et al., 2005). From the neurobiological approach, researchers employed neuroimaging methods such as EEG and fMRI to investigate the neural correlates of music listening and emotional processes (Altenmuller et al., 2002; Arjmand et al., 2017; Baumgartner et al., 2006; Chang et al., 2015; Daly et al., 2014; Daly et al., 2015; Daly et al., 2019; Li et al., 2014; Madsen et al., 2019; Mikutta et al., 2012; Sammler et al., 2007; Schmidt & Trainor, 2001; Trochidis & Bigand, 2013; Zhao et al., 2018), and explore feasibility of emotion-classification (e.g., Hadjidimitriou & Hadjileontiadis, 2013; Koelstra et al., 2012; Lin, Wang, et al., 2010; Shahabi & Moghimi, 2016).

Anchored in their respective disciplines, individual research approach has added valuable knowledge to the inquiry of why and how music evokes emotions. However, the field of music and emotion could benefit from having one research discipline informing another. For instance, while machine learning studies have shown feasibility in emotion-recognition based on EEG activity acquired during music listening tasks, they have often neglected the individual differences, of which studies investigating individual differences have documented cumulative evidence of the influence of individual differences (e.g., personality, music preference) on music-evoked emotions.

Therefore, this thesis adopted a multi-disciplinary approach to examine the electrophysiological correlates of music-evoked emotions, relate it to underlying psychological mechanisms, employ machine learning techniques to clarify the differences between unfamiliar and familiar musical style, and to examine the role of individual difference, particularly absorption trait, in music-evoked emotions (Fig. 7-1). This is addressed through a pilot behavioral experiment (Study 1) and an EEG experiment, of which three sub-studies (Studies 2A, 2B and 2C) are derived from it.

Study 1 developed music stimuli of familiar and unfamiliar musical styles. Musical styles that are age and culturally relevant to the sample recruited were selected, instead of using classical music, as the majority of existing studies have done so (Fig. 7-1, box in grey).

Next, Study 2A clarified the electrophysiological correlates of music-evoked emotions. A survey of existing literature showed that there is a lack of whole-brain approach studies in alpha, theta, beta frequency bands, and there are various reports of involvement of other brain regions and asymmetries relating to valence and arousal. By clarifying the electrophysiological correlates, I hoped to provide better understanding of emotions during music listening for future emotion-classification research (Fig. 7-1, boxes in pink).

Following which, Study 2B investigated the effects of familiarity with musical style on music-evoked emotions. I wanted to examine this effect as it is not fully known if familiarity with musical styles will have an effect on emotion and it is important to understand this so as to further inform research on emotion-classification (Fig. 7-1, boxes in pink).

Lastly, Study 2C examined the role of absorption trait in music-evoked emotions. While current literature has unanimously showed that individual differences shape emotional response to music, little is currently known about the role of absorption trait in music-evoked emotions (Fig. 7-1, box in green).

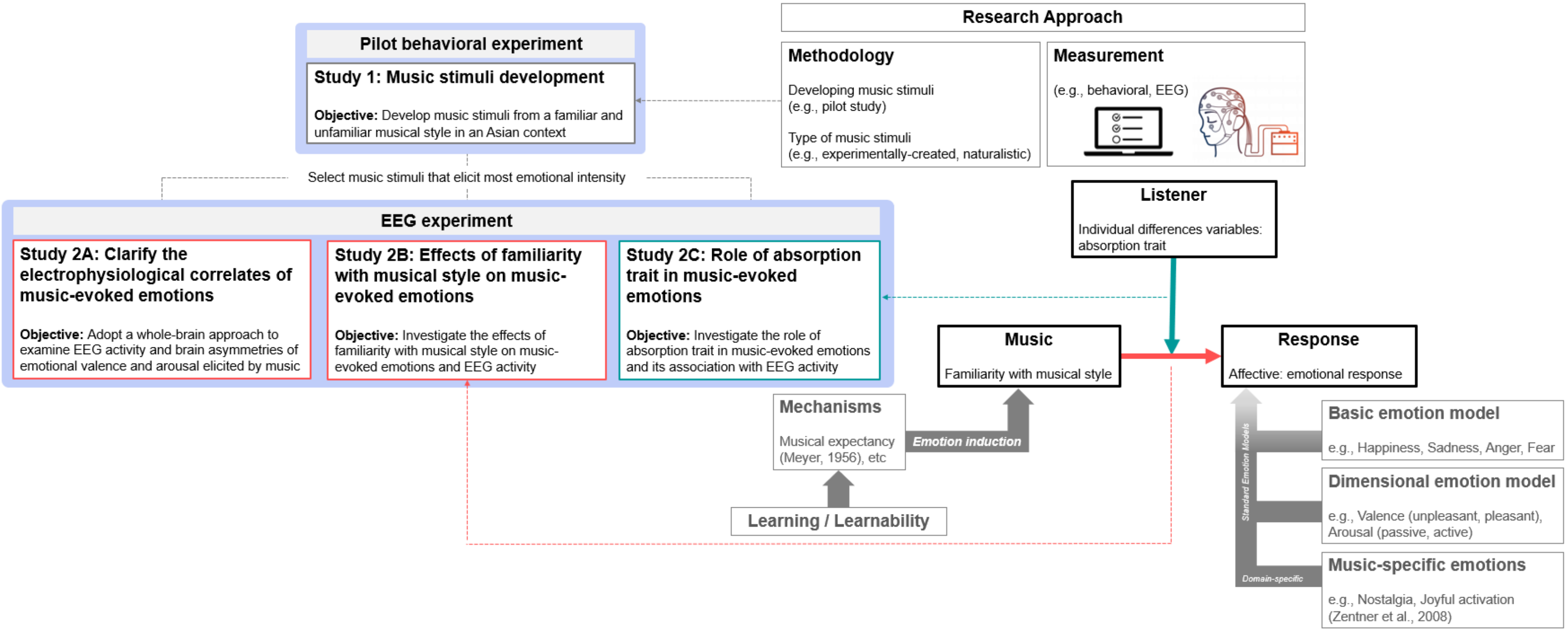


Figure 7-1. Overarching research framework organized according to music, listener and response. ***Study 1 (grey).*** Pilot behavioral experiment that develops music stimuli (naturalistic) of familiar and unfamiliar musical styles. ***Studies 2A (pink), 2B (pink) and 2C (green).*** EEG experiment that (A) systematically examined neural activity and asymmetries at each brain region across alpha, theta and beta frequency bands, (B) investigated the effects of familiarity with musical style on music-evoked emotions and (C) examined the role of absorption trait in music-evoked emotions. Literature reviewed (underlying mechanisms and emotion models) are in light grey. Bolded solid lines indicate directionality between variables. Dashed lines indicate the theoretical or methodological basis of each study.

7.2. Summary of Findings from This Thesis

Summary of findings for all studies (Fig. 7-2) are first presented before discussing its theoretical and methodological implications in the next section.

Study 1: Music Stimuli Development

In Study 1, I showed the feasibility of using Japanese animation OSTs and Greek Laïkó music to elicit emotions in a sample of Singaporean participants. Particularly, the author chose Japanese animation OSTs to represent familiar musical style and Greek Laïkó music to represent unfamiliar musical style. Collectively, music stimuli were distributed in three emotional states: low valence high arousal, high valence high arousal and high valence low arousal. These music stimuli were better represented with emotions from the music-specific model (Zentner et al., 2008) as compared to basic emotion model (Ekman, 1992a, 1992b). Music stimuli that elicited the highest intensity for each emotional state were subsequently chosen to be used in the EEG study.

Study 2A: Clarifying the Electrophysiological Correlates of Music-evoked Emotions

In Study 2A, I clarified the electrophysiological correlates of emotional valence (unpleasant – pleasant) and arousal (very passive – very active) by employing music of the familiar musical style (based on Study 1).
According to the hemispheric valence hypothesis Davidson (1984, 1988, 1992a), it was expected that pleasant music would elicit greater relative left frontal EEG activity while unpleasant music would elicit greater relative right frontal EEG activity. However, this hypothesis was not supported in the present study as the interaction between valence and hemisphere was not significant. I also hypothesized that frontal AI would be correlated with emotional valence.

Likewise, this hypothesis was not supported in the present study as there was no significant correlation between frontal asymmetry index and valence ratings.

Based on existing studies that documented an association between frontal midline theta power and pleasantness (Aftanas & Golocheikine, 2001; Sammler et al., 2007), I hypothesized that frontal midline theta would be higher in pleasant as compared to unpleasant music. However, frontal midline theta power was not significantly predicted by the type of music condition (pleasant or unpleasant), after controlling for arousal ratings.

For emotional arousal, absolute frontal alpha power was expected to be associated with arousal (Dawson, 1994) and that music of higher level of arousal would show greater right parietal activity (Heilman, 1997; Heller, 1993). However, support for these hypotheses was not found as the main effects of arousal in alpha band were not significant and the main effect of arousal in the parietal region was not significant in alpha, theta or beta frequency bands.

Instead, results from the study showed that music listening in general (regardless of type of emotional valence or arousal), tended to elicit higher beta power in right parietal region in all music conditions. Right-biased parieto-temporal and left-biased fronto-occipital asymmetries were also commonly observed in either alpha or theta frequency bands.

Study 2B: Effects of Familiarity with Musical Style on Music-evoked Emotions

In Study 2B, music of the familiar musical style is hypothesized to be felt as more pleasant than the unfamiliar musical style, as listeners would have a better understanding of the stylistic musical expectations of a familiar musical style (Meyer, 1956). I also hypothesized that there will not be significant difference between degree of emotional arousal in both musical styles as arousal is thought to be more related to basic acoustic cues. Support for both hypotheses were demonstrated as Wilcoxon-signed rank test showed significant differences in valence ratings (familiar musical style felt as more pleasant as compared to unfamiliar musical style) and not for arousal ratings.

For EEG activity, music of the unfamiliar musical style is expected to elicit greater overall whole-brain EEG activity as compared to familiar musical style, as current literature suggest higher attentional resources are required when listening to music of an unfamiliar musical style (Li et al., 2014; Nan et al., 2006). This hypothesis was partially supported as significant main effects of musical style were found in all brain regions in theta frequency band, frontal region in alpha frequency band, and fronto-temporo-occipital regions in beta frequency band, with unfamiliar musical style eliciting greater EEG activity as compared to familiar musical style.

Besides, I hypothesized that if frontal midline theta was more related to attention (given that findings from Study 2A did not find the expected association of frontal midline theta and pleasantness), unfamiliar musical style will elicit greater frontal midline theta power as compared to familiar musical style. This hypothesis was supported as paired *t*-test shows frontal midline theta power to be significantly higher in unfamiliar musical style as compared to familiar musical style.

Lastly, I hypothesized that unfamiliar and familiar musical style could be distinguished based on EEG brain activity. This hypothesis was supported as well as from results of binary classification accuracies between familiar and unfamiliar musical style, using spectral powers from alpha, beta and theta frequency bands as well as differential asymmetry, ranging between 89.39% to 94.49%.

Study 2C: Role of Absorption Trait in Music-evoked Emotions

In Study 2C, the effect of absorption trait was hypothesized to be observed in emotional responses to music of an unfamiliar musical style and not familiar musical style. Specifically, individuals with high absorption trait will show greater polarized emotional responses to music in the unfamiliar musical style, as they are more likely to be immersed in a wider variety of musical experiences as compared to individuals who are low in absorption trait (Sandstrom & Russo, 2013). In addition, no significant differences in emotional responses between individuals with low and high absorption trait were expected in the familiar musical style as the familiar musical style should evoke similar emotional intensity irrespective of absorption trait. Results showed partial support for the hypothesis, such that moderating effects of absorption trait was found only for emotional arousal and not valence. In particular, individuals with low absorption trait felt that music of unfamiliar musical style was significantly more passive as compared to individuals with high absorption trait. No significant differences of emotional responses between individuals with low and high absorption traits were found in the familiar musical style. Lastly, results did not show significant associations between absorption trait and EEG activity or demographic variables such as age, gender or musical training (as indexed by whether individuals attended formal music lessons).

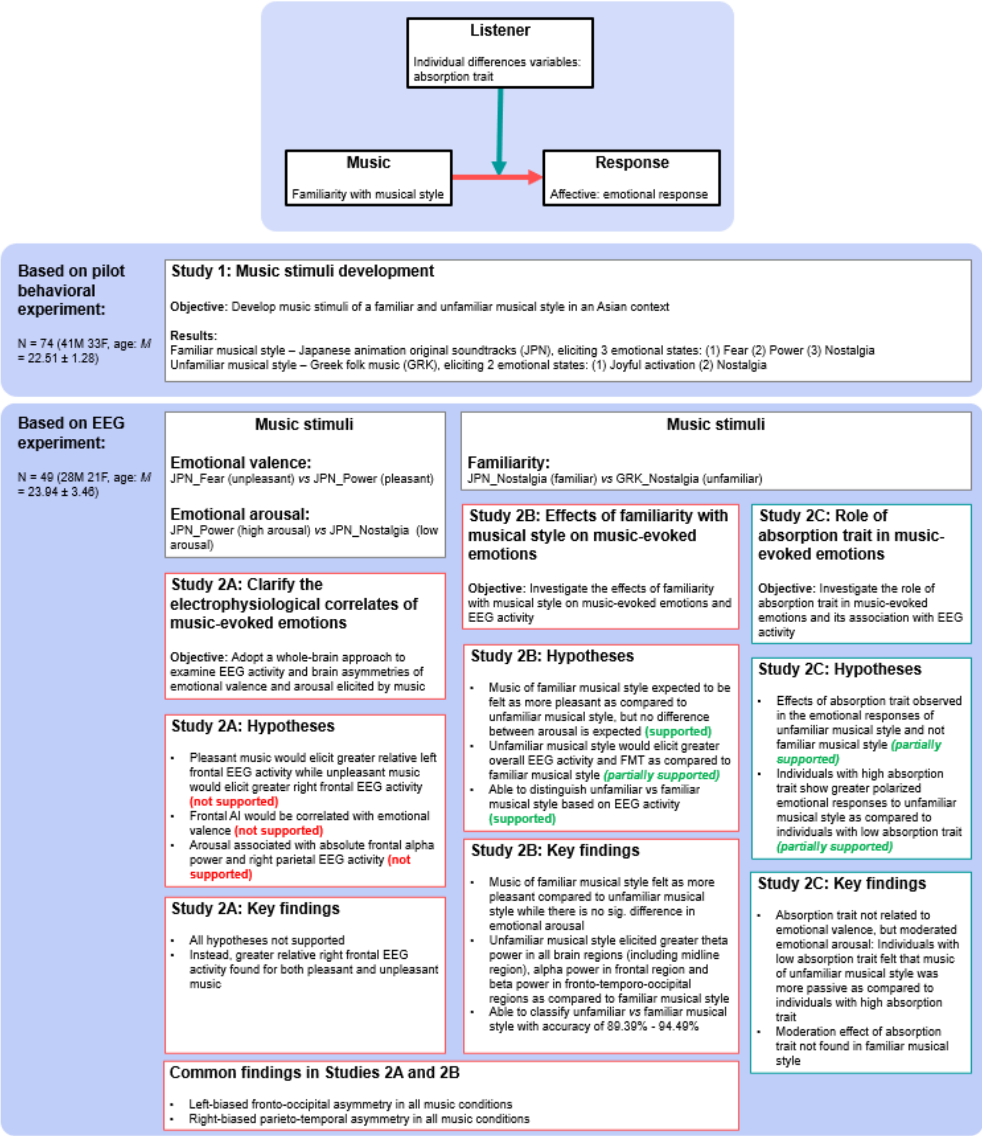


Fig. 7-2. Summary of findings in the thesis. Abbreviations: AI = Asymmetry Index. EEG = Electroencephalography.

7.3. Theoretical Implications

Music-evoked Emotions

Music is indeed able to elicit emotions, regardless of the musical style or genre used. This line of argument is the same as papers that adopted the stance of universality of music's expressive power (Argstatter, 2016; Brown & Jordania, 2011; Egermann et al., 2015; Fritz et al., 2009; Laukka et al., 2013). However, the pleasantness and arousal of emotion would depend on an individual's musical experience and exposure to musical styles. Music-specific emotion terms (from GEMS; Zentner et al., 2008) were more reflective of the emotion elicited in the music as compared to basic emotion terms.

In the music stimuli developed, there was a lack of unpleasant and passive music in Japanese animation OSTs and lack of unpleasant music in Greek Laïkó music. Therefore, while the music was experimenter-selected, it seems that different musical styles or genres have a tendency to elicit one emotional state more than the other. In addition, the challenge in developing music stimuli that is unpleasant and passive (usually denoted by the emotion *Sadness*), could be that sad music is sometimes experienced as pleasant (Droit-Volet et al., 2010; Gabrielsson, 2001).

The finding of differences in emotional valence and not arousal between familiar and unfamiliar musical style is in line with studies that suggest valence to be more culturally mediated and arousal to be more consistent across music of different cultures (Egermann et al., 2015) and genres (Eerola, 2011).

Brain Asymmetries

Frontal Alpha Asymmetry

While frontal alpha asymmetry has been widely and commonly employed as an index of emotional valence, I did not find the expected frontal alpha asymmetry to reflect emotional valence (refer to Study 2A). The lack of association between frontal alpha asymmetry and emotional valence was also reported in other existing studies. For instance, Daly et al. (2014) did not find alpha asymmetry to be related to valence, but instead found that asymmetry in the beta frequency was negatively correlated with valence. In addition, Sammler et al. (2007) did not find frontal alpha asymmetry when comparing pleasant and unpleasant emotions elicited by music, but instead found that frontal midline theta power was associated with increased valence. Likewise, Chang et al. (2015) found that parietal asymmetry was related to valence in a manner that larger asymmetry index in the parietal area was observed in response to positive emotion as compared to negative emotion. Moreover, Gold et al. (2013) also reached did not find clear support for the validity of frontal alpha asymmetry to be considered as a biomarker for depression and anxiety.

In this regard, I propose several considerations when discussing frontal alpha asymmetry: Firstly, it is unclear how pleasant or unpleasant does a stimulus need to be in order to elicit frontal alpha asymmetry.

Secondly, given that the frontal alpha asymmetry was thought to represent approach and withdrawal motivational processes (Davidson, 1995; Harmon-Jones, 2003; Heilman, 1997), it is unclear if positive and negative emotions elicited by music also draw upon these motivational processes which have been commonly associated with adaptive survival purposes (e.g., being able to perceive an angry facial expression). In other words, listening to scary music (JPN_Fear) may not necessarily result in withdrawal tendencies; and neither does listening to triumphant music (JPN_Power) create approach motivation. Considering the context of the emotion being elicited – i.e., listening to music in a laboratory setting – another perspective could be that the music listening task itself is one that evokes low motivational intensity. Consequently, underlying motivational directions should be interpreted in a framework of low motivational intensity positive and negative emotions, which may have different neural representations in frontal cortical activity (Gable & Harmon-Jones, 2010).

Thirdly, it is currently unclear if frontal alpha asymmetry is a reliable marker of emotional valence elicited by facial expressions (as originally conceptualized by Davidson et al., 1990), or more broadly in the visual modality as compared to the auditory modality. Thus, it would be useful for future studies to clarify the relationship between stimulus modality (visual *vs* auditory) and frontal alpha asymmetry.

Fronto-occipital vs Parieto-temporal Asymmetries

In addition, all music conditions showed left-biased fronto-occipital asymmetry in either alpha or theta frequency bands, and right-biased parieto-temporal asymmetry in alpha frequency band (refer to studies 2A and 2B). Therefore, these brain asymmetries are more reflective of music listening *per se*, rather than emotions elicited by music. An interesting finding is the asymmetry in occipital region, which was not expected participants listened to music with eyes closed. It is plausible that participants engaged in visual imagery during music listening, as suggested by previous studies (e.g., Juslin &

Västfjäll, 2008; Küssner & Eerola, 2019; Taruffi & Küssner, 2019), thus resulting in occipital asymmetries.

Frontal Midline Theta: Emotional or Attentional Functions?

Existing studies have reported that listening to music of an unfamiliar musical style engaged greater attentional resources as compared to a familiar musical style (Li et al., 2014; Madsen et al., 2019; Nan et al., 2006). This was supported by higher EEG activity in frontal, parietal, temporal and occipital regions during the unfamiliar musical style (GRK_Nostalgia) as compared to the familiar musical style (JPN_Nostalgia).

Likewise, higher theta power was observed in the frontal midline region during unfamiliar musical style as compared to familiar musical style although music of familiar musical style was felt as significantly more pleasant than unfamiliar musical style. Accordingly, if frontal midline theta power purely reflected emotional valence, the behavioral findings of our study would be incongruent with the EEG findings. Thus, a more likely explanation could be that frontal midline theta power might be more fundamentally associated with general attention and cognitive control. The notion that frontal midline theta is related to heightened mental effort and sustained attention has previously been documented (Inanaga, 1998; Schacter, 1977). In a more recent review by Cavanagh and Frank (2014), the authors reported that theta band activities over the midfrontal cortex appear to reflect a common computation used for realizing the need for cognitive control and communicating top-down control across broad networks. Specifically, they argue that frontal midline theta activities have largely been quantified as ERP components that reflect medial prefrontal cortex (mPFC)-related control processes elicited by novel information, conflicting stimulus-response requirements, punishing feedback, and the realization of errors, which all share a commonality of a need for increased cognitive control (Cohen & Cavanagh, 2011; Hanslmayr et al., 2008; Narayanan et al., 2013; Nigbur et al., 2012; van Driel et al., 2012). Therefore, frontal midline theta dynamics are thought to act as temporal templates for organizing midfrontal neuronal processes, which are then enhanced following events indicating a need for increased control (Cavanagh et al., 2012).

Individual Differences: Absorption Trait

In comparing emotional responses to music of familiar and unfamiliar musical styles (Study 2B), results showed that on average, participants felt that music of the familiar musical style (JPN_Nostalgia) was significantly more pleasant as compared to music of the unfamiliar musical style (GRK_Nostalgia). In addition, there was no significant difference in level of emotional arousal of both musical styles.

However, when the role of absorption trait in the study of effects of familiarity of musical style on music-evoked emotions is considered (Study 2C), results showed significant differences in emotional arousal between individuals with low and high absorption trait, but not valence ratings. This finding first extends the work of (Sandstrom & Russo, 2013), by examining absorption trait in the context of familiar and unfamiliar musical style. Secondly, it shows that incorporating individual difference variables provide a better understanding in the nuances between music, listener and the context/situation, a similar finding as Hogue et al. (2016). Thus, future studies should consider including a measure of absorption trait or other types of individual differences when investigating music-evoked emotions.

7.4. Methodological Implications

Self-Report Measurements of Emotional Response

Different emotion rating paradigms were employed for the pilot behavioral experiment and EEG experiment. In the pilot behavioral experiment (Study 1), the software for dual axis rating and media annotation (DARMA; Girard & Wright, 2018) was used to examine if music stimuli elicited stable emotional patterns over time (e.g., Appendix A-5). Participants were instructed to provide continuous felt-emotion ratings as they listened to the music. In the EEG experiment (Studies 2A, 2B and 2C), participants were instructed to close their eyes during the music and to experience how the music make them feel. In so doing, it is hoped that additional cognitive workload and motion artefact related to using the continuous rating paradigm would be reduced, so as to attain cleaner EEG data. As such, participants only provided their valence and arousal ratings on a 9-point Likert-scale after the music ended.

While several similarities in emotional ratings from the pilot behavioral experiment and the EEG experiment were observed, some other differences also emerged. In both experiments, music stimuli of the familiar and unfamiliar musical styles elicited the same emotion in terms of discrete emotions and the valence-arousal dimensions. Thus, this establishes a certain level of reliability of the music stimuli developed. However, JPN_Fear (low valence, high arousal) music was rated as less active (indicated by the lower arousal ratings) in the EEG experiment as compared to the pilot behavioral experiment (Study 1). In addition, JPN_Nostalgia (high valence, low arousal) were felt with lesser emotional intensity in the EEG experiment as compared to that of the pilot behavioral experiment. In addition, one of the music stimuli from

GRK_Nostalgia (musical excerpt "*4l*") differed in the level of arousal in the EEG experiment as compared to the pilot behavioral experiment (Fig. 7-3).

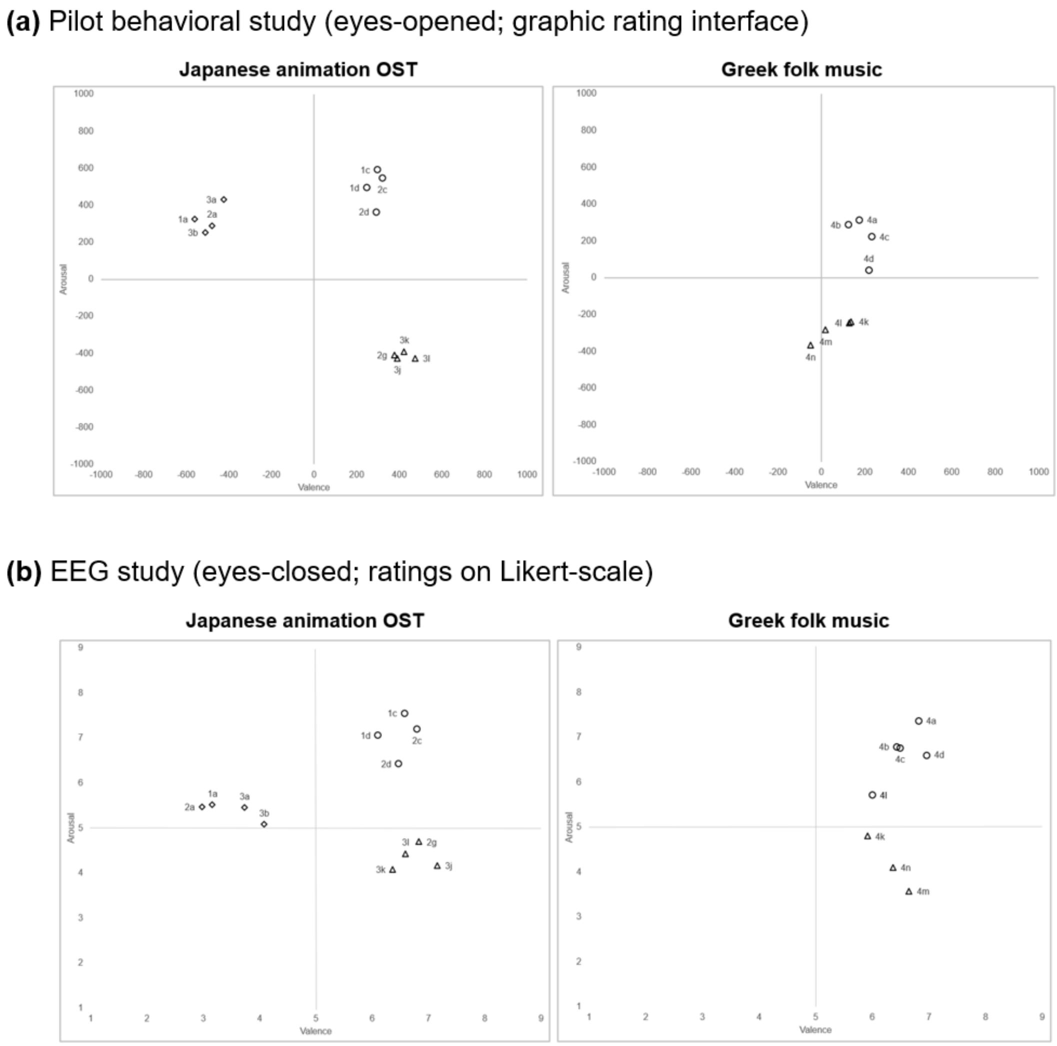


Fig. 7-3. Emotion ratings of music stimuli in pilot behavioral experiment (Study 1) and EEG experiment (Studies 2A, 2B, 2C). Each point in the valence-arousal space represents a music excerpt.

I suggest three plausible explanations for the differences in emotion ratings of music stimuli in the studies: (1) differences in eye-states during music listening, (2) continuous rating *vs* rating emotions after listening to music, (3) differences in self-report measurements.

Should the differences be due to eye-states, Chang et al. (2015) found that individuals tended to experience music as more pleasant in the eyes-opened as compared to eyes-closed state. However, this effect was not observed in the current thesis: JPN_Fear (low valence, high arousal) was felt as almost the same extent of unpleasantness in the pilot behavioral experiment (Study 1; eyes-opened) as compared to the EEG experiment (eyes-closed); and that for the valence ratings for pleasant music in both familiar and unfamiliar musical styles are quite comparable. Instead, the differences are observed more in the arousal levels elicited by the music, such that arousal ratings become more "centered" in the two-dimensional space (i.e., indicative of neutral affect) in the EEG experiment as compared to the pilot behavioral experiment. In addition, Lerner et al. (2009) suggested that during the eyes-closed state, unpleasant emotions and arousal level elicited by fear-inducing music may be enhanced. Support for this is evident by increased activation in the amygdala, anterior hippocampus, temporal pole and ventromedial prefrontal foci. However, the EEG experiment (eyes-closed) did not find increased negative emotion and arousal level in JPN_Fear as compared to the pilot behavioral experiment (eyes-opened).

Thus, a more plausible account of the emotion ratings differences observed in the current thesis is likely to be due to differences in self-report measurement paradigms, rather than differences in eye-states or cognitive load. Specifically, I postulate that a graphical representation of the two-dimensional valence-arousal space might allow participants to better indicate their felt emotions.

7.5. Limitations

There are several limitations with regards to the development of music stimuli employed in the current thesis. Firstly, there is an inherent selection bias of the list of music stimuli as they are selected by the experimenter. As such, future studies could instead adopt the methodology of first recruiting a pool of participants to list down songs and to refine selections based on this pool of music with the relevant criteria needed. Secondly, information on how participants felt about the characteristics of the music (e.g., melodic complexity, rhythmic complexity, timbre, etc) was not collected. Having this information would be useful in understanding how participants perceived the musical features and to correlate it with felt emotions.

While I attempted to increase ecological validity by choosing naturalistic music stimuli, the experimental setting still poses some constrains on the ecological context of the music listening situation. In real-world situations, individuals usually use music in a goal-directed manner (Moors et al., 2017; Moors & Fischer, 2019). However, in the experimental setting, the goal is already given to the individual (e.g., participating in the experiment), and this therefore places limits on what motivation the listener comes with.

Lastly, it should be noted that methods employed in the current EEG data analyses (i.e., averaging power spectra) does not take into account the temporal variation of the musical excerpts. In this instance, the primary objective of the EEG data analyses was to examine brain activity underlying an emotional state by using music that elicit a robust singular emotion across an extended period of time (which has been demonstrated in Study 1 where results showed that the valence/arousal ratings stayed in the same emotion quadrant continuously throughout the musical excerpt (Appendix A-6). Nonetheless, this is certainly an interesting and valuable direction for future studies to look at, so as have a better understanding of the temporal dynamics of emotional processing.

7.6. Future Directions and Potential Applications

Given the inherent trade-off between the experimental and naturalistic approaches in developing music stimuli (refer to Chapter 2 Lit Review for more details), future studies that employed naturalistic music could consider extracting acoustic features of music stimuli and doing some correlations or classification with the music itself to add another layer of understanding to the interactions between music and psychological processes in leading to emotional responses.

In addition, future studies examining effects of familiarity with musical style could also employ other types of EEG analyses such as EEG-based functional and effective connectivity indices or source localization, which has been shown to be able to appropriate in classifying (Lee & Hsieh, 2014; Shahabi & Moghimi, 2016) and examining different emotional states (Isotani et al., 2002). Employing these techniques could help to further elucidate the connectivity patterns between brain regions in listening to music of familiar and unfamiliar musical styles.

While our findings of moderation effect of absorption trait on emotional arousal is similar to Kreutz et al. (2008), other studies have instead found associations between absorption trait and emotional valence (Sandstrom & Russo, 2013). Future studies could thus seek to clarify this association by investigating a wider range of musical genres or styles and types of emotions.

In addition, it is also possible that music-evoked emotions are related to an individual's ability to translate internal emotional experiences into precise and explicit verbal forms, which is often reduced in those with alexithymia (Taruffi et al., 2017). Thus, future studies of individual differences could consider examining both absorption and alexithymia traits in addition to the widely studied variables of personality, music preference, musical expertise and empathy.

Several potential applications can be derived from this thesis. Firstly, Study 1 developed a novel set of musical stimuli from the genre Japanese animation OSTs, which are currently understudied in the field of music and emotion (Warrenburg, 2020). This set of musical stimuli could be a valuable resource for future studies which (1) may benefit from using culturally appropriate validated music in the study of musical emotions (e.g., Japan) or (2) which are interested in examining cross-cultural similarities or differences in emotional expression and experience (e.g., Europe, Canada, etc). In addition, Study 1 also provided evidence that both the familiar (Japanese animation OSTs) and unfamiliar (Greek Laïkó music) musical styles were able to elicit emotions, thus attesting to the notion that almost all types of music can access emotions in people. Therefore, music could for instance, function as a useful tool in conjunction with traditional therapies, such as cognitive behavioral therapy, in the treatment of anxiety disorders by helping to put an individual in a desired emotional state (Luce, 2001), regulate emotion and promote relaxation (Silverman, 2007).

Secondly, results from Study 2A further elucidate current understanding of brain processes underlying music-evoked emotions by emphasizing the involvement of other regions besides frontal cortex, such as parietal and temporal regions particularly. Given that music involves these brain regions, it could potentially be used as a tool for neuro-rehabilitation in cases where these regions are less efficient (see Paraskevopoulos et al., 2021).

Thirdly, Study 2B took into account the effects of familiarity with musical style and showed that it is important to consider the individual's musical taste, background and experiences, as it may have differential effects on musical emotions. From a clinical perspective, therapists should consider the musical profile of the client when choosing an appropriate selection of music, so as to achieve better treatment efficacy. In addition, Study 2B showed that the theta frequency band was more successful in differentiating familiar and unfamiliar musical styles. This is informative more future emotion-classification research or brain-computer interface (BCI) applications when considering feature selection.

Lastly, Study 2C accounted for the role of individual differences, particularly absorption trait, in musical emotions and showed that absorption trait is more related to emotional arousal. As such, absorption trait could be a useful measure to include at the pre-screening stage when deciding if the client could potentially benefit from music or creative arts related therapy. For instance, if the client scores low in absorption, he/she might not benefit from music-related programs as he/she is less likely to be immersed in an aesthetic experience and therefore may not show the desired kind of effect.

7.7. Conclusion

In sum, the current thesis examined the music-listener relationship and the role of listener characteristics in music-evoked emotions. First, the feasibility of using music of familiar and unfamiliar musical styles to study music-evoked emotions was demonstrated. Consistent with current literature, emotional valence was found to be more culturally mediated as compared to arousal. In addition, music of an unfamiliar musical style elicited greater theta power in all brain regions (including midline area), alpha power in frontal regions, and beta power in fronto-temporo-occipital regions as compared to familiar musical style. Frontal midline theta was thus postulated to be reflective of more general cognitive and attentional processes, which underlies pleasurable musical emotions. Lastly, absorption trait was found to moderate emotional arousal in the unfamiliar musical style. Specifically, individuals with low absorption trait felt that music of the unfamiliar musical style was more passive as compared to individuals with high absorption trait. Taken together, this thesis once again highlights the importance to consider the relationship between music and listener as well as the characteristics of the listener when examining music-evoked emotions.

References

Abeles, H., & Chung, J. W. (1996). Responses to music. In D. A. Hodges (Ed.), *Handbook of music psychology*. IMR Press.

Abolhasani, M., Oakes, S., & Oakes, H. (2017). Music in advertising and consumer identity: The search for Heideggerian authenticity. *Marketing Theory*, *17*(4), 473-490. https://doi.org/10.1177/1470593117692021

Aftanas, L. I., & Golocheikine, S. A. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. *Neurosci Lett*, *310*(1), 57-60. https://doi.org/10.1016/s0304-3940(01)02094-8

Aftanas, L. I., Koshkarov, V. I., Pokrovskaja, V. L., Lotova, N. V., & Mordvintsev, Y. (1996). Event-Related Desynchronization (ERD) Patterns to Emotion-Related Feedback Stimuli. *International Journal of Neuroscience*, *87*(3-4), 151-173. https://doi.org/10.3109/00207459609070834

Ali, S. O., & Peynircioğlu, Z. F. (2006). Songs and emotions: are lyrics and melodies equal partners? *Psychology of Music*, *34*(4), 511-534. https://doi.org/10.1177/0305735606067168

Altenmuller, E., Schurmann, K., Lim, V. K., & Parlitz, D. (2002). Hits to the left, flops to the right: different emotions during listening to music are reflected in cortical lateralisation patterns. *Neuropsychologia*, *40*(13), 2242-2256. https://doi.org/10.1016/s0028-3932(02)00107-0

Alves, N. T., Fukusima, S. S., & Aznar-Casanova, J. A. (2008). Models of brain asymmetry in emotional processing. *Psychology & Neuroscience*, *1*, 63-66. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1983-32882008000100010&nrm=iso

Ara, A., & Marco-Pallarés, J. (2020). Fronto-temporal theta phase-synchronization underlies music-evoked pleasantness. *Neuroimage*, *212*, 116665. https://doi.org/https://doi.org/10.1016/j.neuroimage.2020.116665

Argstatter, H. (2016). Perception of basic emotions in music: Culture-specific or multicultural? *Psychology of Music*, *44*(4), 674-690. https://doi.org/10.1177/0305735615589214

Arjmand, H.-A., Hohagen, J., Paton, B., & Rickard, N. S. (2017). Emotional Responses to Music: Shifts in Frontal Brain Asymmetry Mark Periods of Musical Change [Original Research]. *Frontiers in Psychology*, *8*(2044). https://doi.org/10.3389/fpsyg.2017.02044

Babinski, J. (1914). Contribution of cerebral hemispheric organization in the study of mental troubles. *Review Neurologique*, *27*, 845-848.

Bachner-Melman, R., Dina, C., Zohar, A. H., Constantini, N., Lerer, E., Hoch, S., Sella, S., Nemanov, L., Gritsenko, I., Lichtenberg, P., Granot, R., & Ebstein, R. P. (2005). AVPR1a and SLC6A4 Gene Polymorphisms Are Associated with Creative Dance Performance. *PLOS Genetics*, *1*(3), e42. https://doi.org/10.1371/journal.pgen.0010042

Baird, A., & Samson, S. (2015). Music and Dementia. *Prog Brain Res*, *217*, 207-235. https://doi.org/10.1016/bs.pbr.2014.11.028

Balasubramanian, G., Kanagasabai, A., Mohan, J., & Seshadri, N. P. G. (2018). Music induced emotion using wavelet packet decomposition—An EEG study. *Biomedical Signal Processing and Control*, *42*, 115-128. https://doi.org/https://doi.org/10.1016/j.bspc.2018.01.015

Balkwill, L.-L., & Thompson, W. F. (1999). A Cross-Cultural Investigation of the Perception of Emotion in Music: Psychophysical and Cultural Cues. *Music Perception*, *17*(1), 43-64. https://doi.org/10.2307/40285811

Barrett, F. S., & Janata, P. (2016). Neural responses to nostalgia-evoking music modeled by elements of dynamic musical structure and individual differences in affective traits. *Neuropsychologia*, *91*, 234-246. https://doi.org/10.1016/j.neuropsychologia.2016.08.012

Baumgartner, H. (1992). Remembrance of Things Past: Music, Autobiographical Memory, and Emotion. *ACR North American Advances*.

Baumgartner, T., Esslen, M., & Jancke, L. (2006). From emotion perception to emotion experience: emotions evoked by pictures and classical music. *Int J Psychophysiol*, *60*(1), 34-43. https://doi.org/10.1016/j.ijpsycho.2005.04.007

Bell, A. J., & Sejnowski, T. J. (1995). An information-maximization approach to blind separation and blind deconvolution. *Neural Comput*, *7*(6), 1129-1159. https://doi.org/10.1162/neco.1995.7.6.1129

Bell, C. (1914). *Art*. Chatto & Windus.

Bigand, E., & Poulin-Charronnat, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition*, *100*(1), 100-130. https://doi.org/10.1016/j.cognition.2005.11.007

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

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

Boisen, S., Crystal, M., Schwartz, R., Stone, R., & Weischedel, R. (2000). Annotating Resources for Information Extraction. LREC,

Borod, J. C., Andelman, F., Obler, L. K., Tweedy, J. R., & Wilkowitz, J. (1992). Right hemisphere specialization for the identification of emotional words and sentences: Evidence from stroke patients. *Neuropsychologia*, *30*(9), 827-844. https://doi.org/https://doi.org/10.1016/0028-3932(92)90086-2

Borod, J. C., Cicero, B. A., Obler, L. K., Welkowitz, J., Erhan, H. M., Santschi, C., Grunwald, I. S., Agosti, R. M., & Whalen, J. R. (1998). Right hemisphere emotional perception: evidence across multiple channels. *Neuropsychology*, *12*(3), 446-458. https://doi.org/10.1037//0894-4105.12.3.446

Brattico, E., Alluri, V., Bogert, B., Jacobsen, T., Vartiainen, N., Nieminen, S., & Tervaniemi, M. (2011). A Functional MRI Study of Happy and Sad Emotions in Music with and without Lyrics. *Front Psychol*, *2*, 308. https://doi.org/10.3389/fpsyg.2011.00308

Bresin, R., & Friberg, A. (2011). Emotion rendering in music: Range and characteristic values of seven musical variables. *Cortex*, *47*(9), 1068-1081. https://doi.org/https://doi.org/10.1016/j.cortex.2011.05.009

Brown, S., & Jordania, J. (2011). Universals in the world's musics. *Psychology of Music*, *41*(2), 229-248. https://doi.org/10.1177/0305735611425896

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

Carlsen, J. C. (1981). Some factors which influence melodic expectancy. *Psychomusicology: A Journal of Research in Music Cognition*, *1*(1), 12-29. https://doi.org/10.1037/h0094276

Cavanagh, J. F., & Frank, M. J. (2014). Frontal theta as a mechanism for cognitive control. *Trends Cogn Sci*, *18*(8), 414-421. https://doi.org/10.1016/j.tics.2014.04.012

Cavanagh, J. F., Zambrano-Vazquez, L., & Allen, J. J. (2012). Theta lingua franca: a common mid-frontal substrate for action monitoring processes. *Psychophysiology*, *49*(2), 220-238. https://doi.org/10.1111/j.1469-8986.2011.01293.x

Chamorro-Premuzic, T., Fagan, P., & Furnham, A. (2010). Personality and uses of music as predictors of preferences for music consensually classified as happy, sad, complex, and social. *Psychology of Aesthetics, Creativity, and the Arts*, *4*(4), 205-213. https://doi.org/10.1037/a0019210

Chang, C.-C., & Lin, C.-J. (2011). LIBSVM: A library for support vector machines. *ACM Trans. Intell. Syst. Technol.*, *2*(3), 1-27. https://doi.org/10.1145/1961189.1961199

Chang, Y.-H., Lee, Y.-Y., Liang, K.-C., Chen, I.-P., Tsai, C.-G., & Hsieh, S. (2015). Experiencing affective music in eyes-closed and eyes-open states: an electroencephalography study [Original Research]. *Frontiers in Psychology*, *6*(1160). https://doi.org/10.3389/fpsyg.2015.01160

Chin, N. H. (2016). *Music in mood regulation in adolescence: An initial exploration of the Singapore context*

Clayton, M., Sager, R., & Will, U. (2005). In time with the music: the concept of entrainment and its significance for ethnomusicology. European meetings in ethnomusicology.,

Coan, J. A., & Allen, J. J. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biol Psychol*, *67*(1-2), 7-49. https://doi.org/10.1016/j.biopsycho.2004.03.002

Cohen, M., & Cavanagh, J. F. (2011). Single-Trial Regression Elucidates the Role of Prefrontal Theta Oscillations in Response Conflict [Original Research]. *Frontiers in Psychology*, *2*(30). https://doi.org/10.3389/fpsyg.2011.00030

Combs, A. L., Black, J., O'Donnell, A., Pope, R., Buckner, J., Crow, L., Ray, K., & Vandermeer, J. A. (1988). Absorption and appreciation of visual art. *Perceptual and Motor Skills*, *67*(2), 453-454. https://doi.org/10.2466/pms.1988.67.2.453

Conard, N. J., Malina, M., & Münzel, S. C. (2009). New flutes document the earliest musical tradition in southwestern Germany. *Nature*, *460*(7256), 737-740. https://doi.org/10.1038/nature08169

Costa, T., Rognoni, E., & Galati, D. (2006). EEG phase synchronization during emotional response to positive and negative film stimuli. *Neurosci Lett*, *406*(3), 159-164. https://doi.org/10.1016/j.neulet.2006.06.039

Cross, I. (2001). Music, cognition, culture and evolution. In I. Peretz & R. J. Zatorre (Eds.), *The Cognitive Neuroscience of Music* (pp. 42-56). Oxford University Press.

Crowder, R. G. (1984). Perception of the major/minor distinction: I. Historical and theoretical foundations. *Psychomusicology: A Journal of Research in Music Cognition*, *4*(1-2), 3-12. https://doi.org/10.1037/h0094207

Cuddy, L. L., & Lunney, C. A. (1995). Expectancies generated by melodic intervals: Perceptual judgments of melodic continuity. *Perception & Psychophysics*, *57*(4), 451-462. https://doi.org/10.3758/BF03213071

Daltrozzo, J., Tillmann, B., Platel, H., & Schön, D. (2010). Temporal aspects of the feeling of familiarity for music and the emergence of conceptual processing. *J Cogn Neurosci*, *22*(8), 1754-1769. https://doi.org/10.1162/jocn.2009.21311

Daly, I., Malik, A., Hwang, F., Roesch, E., Weaver, J., Kirke, A., Williams, D., Miranda, E., & Nasuto, S. J. (2014). Neural correlates of emotional responses to music: an EEG study. *Neurosci Lett*, *573*, 52-57. https://doi.org/10.1016/j.neulet.2014.05.003

Daly, I., Malik, A., Weaver, J., Hwang, F., Nasuto, S. J., Williams, D., Kirke, A., & Miranda, E. (2015, 21-24 Sept. 2015). Identifying music-induced emotions from EEG for use in brain-computer music interfacing. 2015 International Conference on Affective Computing and Intelligent Interaction (ACII),

Daly, I., Williams, D., Hwang, F., Kirke, A., Miranda, E. R., & Nasuto, S. J. (2019). Electroencephalography reflects the activity of sub-cortical brain regions during approach-withdrawal behaviour while listening to music. *Sci Rep*, *9*(1), 9415. https://doi.org/10.1038/s41598-019-45105-2

Davidson, R. J. (1984). Affect, Cognition, and Hemispheric Specialization. In J. K. C. E. Izard, R. Zajonc (Ed.), *Emotion, Cognition, and Behavior* (pp. 320-365). Cambridge University Press.

Davidson, R. J. (1988). EEG measures of cerebral asymmetry: conceptual and methodological issues. *Int J Neurosci*, *39*(1-2), 71-89. https://doi.org/10.3109/00207458808985694

Davidson, R. J. (1992a). Anterior cerebral asymmetry and the nature of emotion. *Brain Cogn*, *20*(1), 125-151. https://doi.org/https://doi.org/10.1016/0278-2626(92)90065-T

Davidson, R. J. (1992b). Emotion and Affective Style: Hemispheric Substrates. *Psychological Science*, *3*(1), 39-43. https://doi.org/10.1111/j.1467-9280.1992.tb00254.x

Davidson, R. J. (1995). Cerebral asymmetry, emotion, and affective style. In *Brain asymmetry.* (pp. 361-387). The MIT Press.

Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. A., & Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology. I. *J Pers Soc Psychol*, *58*(2), 330-341.

Davidson, R. J., & Hugdahl, K. (1996). Baseline asymmetries in brain electrical activity predict dichotic listening performance. *Neuropsychology*, *10*(2), 241-246. https://doi.org/10.1037/0894-4105.10.2.241

Davidson, R. J., Scherer, K. R., & Goldsmith, H. H. (2003). *Handbook of affective sciences*. Oxford University Press.

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

Davis, M. (1984). The mammalian startle response. In R. C. Eaton (Ed.), *Neural mechanisms of startle behaviro* (pp. 287-342). Plenum Press.

Dawson, G. (1994). Frontal electroencephalographic correlates of individual differences in emotion expression in infants: A brain systems perspective on emotion. *Monographs of the Society for Research in Child Development*, *59*(2-3), 135-151, 250-283. https://doi.org/10.2307/1166142

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J Neurosci Methods*, *134*(1), 9-21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Devinsky, O., Morrell, M. J., & Vogt, B. A. (1995). Contributions of anterior cingulate cortex to behaviour. *Brain, 118 (Pt 1)*, 279-306. https://doi.org/10.1093/brain/118.1.279

Droit-Volet, S., Bigand, E., Ramos, D., & Bueno, J. L. (2010). Time flies with music whatever its emotional valence. *Acta Psychol (Amst)*, *135*(2), 226-232. https://doi.org/10.1016/j.actpsy.2010.07.003

Dvorak, A. L., & Hernandez-Ruiz, E. (2019). Comparison of music stimuli to support mindfulness meditation. *Psychology of Music*, *0*(0), 0305735619878497. https://doi.org/10.1177/0305735619878497

Eerola, T. (2011). Are the Emotions Expressed in Music Genre-specific? An Audio-based Evaluation of Datasets Spanning Classical, Film, Pop and Mixed Genres. *Journal of New Music Research*, *40*(4), 349-366. https://doi.org/10.1080/09298215.2011.602195

Eerola, T., Ferrer, R., & Alluri, V. (2012). Timbre and affect dimensions: Evidence from affect and similarity ratings and acoustic correlates of isolated instrument sounds. *Music Perception*, *30*(1), 49-70. https://doi.org/10.1525/mp.2012.30.1.49

Eerola, T., & Vuoskoski, J. K. (2013). A review of music and emotion studies: Approaches, emotion models, and stimuli. *Music Perception*, *30*(3), 307-340. https://doi.org/10.1525/mp.2012.30.3.307

Eerola, T., Vuoskoski, J. K., & Kautiainen, H. (2016). Being Moved by Unfamiliar Sad Music Is Associated with High Empathy. *Frontiers in Psychology*, *7*, 1176-1176. https://doi.org/10.3389/fpsyg.2016.01176

Egermann, H., Fernando, N., Chuen, L., & McAdams, S. (2015). Music induces universal emotion-related psychophysiological responses: comparing Canadian listeners to Congolese Pygmies [Original Research]. *Frontiers in Psychology*, *5*(1341). https://doi.org/10.3389/fpsyg.2014.01341

Ekman, P. (1971). Universals and cultural differences in facial expressions of emotion. *Nebraska Symposium on Motivation*, *19*, 207-283.

Ekman, P. (1992a). Are there basic emotions? *Psychological Review*, *99*(3), 550-553. https://doi.org/10.1037/0033-295X.99.3.550

Ekman, P. (1992b). An argument for basic emotions. *Cognition and Emotion*, *6*(3-4), 169-200. https://doi.org/10.1080/02699939208411068

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

Fachner, J., & Stegemann, T. (2013). Electroencephalography and music therapy: On the same wavelength? *Music and Medicine*, *5*(4), 217-222. https://doi.org/10.1177/1943862113495062

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*, *39*(2), 175-191. https://doi.org/10.3758/bf03193146

Fritz, T., Jentschke, S., Gosselin, N., Sammler, D., Peretz, I., Turner, R., Friederici, A. D., & Koelsch, S. (2009). Universal recognition of three basic emotions in music. *Curr Biol*, *19*(7), 573-576. https://doi.org/10.1016/j.cub.2009.02.058

Frühholz, S., Trost, W., & Kotz, S. A. (2016). The sound of emotions-Towards a unifying neural network perspective of affective sound processing. *Neurosci Biobehav Rev*, *68*, 96-110. https://doi.org/10.1016/j.neubiorev.2016.05.002

Gable, P., & Harmon-Jones, E. (2010). The motivational dimensional model of affect: Implications for breadth of attention, memory, and cognitive categorisation. *Cognition and Emotion*, *24*(2), 322-337. https://doi.org/10.1080/02699930903378305

Gabrielsson, A. (2001). Emotion perceived and emotion felt: Same or different? *Musicae Scientiae*, *5*(1_suppl), 123-147. https://doi.org/10.1177/10298649020050s105

Gabrielsson, A. (2010). Strong experiences with music. In *Handbook of music and emotion: Theory, research, applications.* (pp. 547-574). Oxford University Press.

Gabrielsson, A., & Juslin, P. N. (2003). Emotional expression in music. In *Handbook of affective sciences.* (pp. 503-534). Oxford University Press.

Gabrielsson, A., & Lindström, E. (2010). The role of structure in the musical expression of emotions. In *Handbook of music and emotion: Theory, research, applications.* (pp. 367-400). Oxford University Press.

Garrido, S., & Schubert, E. (2011). Individual Differences in the Enjoyment of Negative Emotion in Music: A Literature Review and Experiment. *Music Perception*, *28*(3), 279-296. https://doi.org/10.1525/mp.2011.28.3.279

Garrido, S., & Schubert, E. (2013). Adaptive and maladaptive attraction to negative emotions in music. *Musicae Scientiae*, *17*(2), 147-166. https://doi.org/10.1177/1029864913478305

George, M., & Ilavarasu, J. (2021). Development and Psychometric Validation of the Music Receptivity Scale [Original Research]. *Frontiers in Psychology*, *11*(3662). https://doi.org/10.3389/fpsyg.2020.585891

Girard, J. M., & Wright, A. G. C. (2018). DARMA: Software for dual axis rating and media annotation. *Behavior Research Methods*, *50*(3), 902-909. https://doi.org/10.3758/s13428-017-0915-5

Glisky, M. L., Tataryn, D. J., Tobias, B. A., Kihlstrom, J. F., & McConkey, K. M. (1991). Absorption, openness to experience, and hypnotizability. *Journal of Personality and Social Psychology*, *60*(2), 263-272. https://doi.org/10.1037/0022-3514.60.2.263

Gold, C., Fachner, J., & Erkkilä, J. (2013). Validity and reliability of electroencephalographic frontal alpha asymmetry and frontal midline theta as biomarkers for depression. *Scand J Psychol*, *54*(2), 118-126. https://doi.org/10.1111/sjop.12022

Gold, C., Voracek, M., & Wigram, T. (2004). Effects of music therapy for children and adolescents with psychopathology: a meta-analysis. *J Child Psychol Psychiatry*, *45*(6), 1054-1063. https://doi.org/10.1111/j.1469-7610.2004.t01-1-00298.x

Griffiths, P. (2004). *New Penguin Dictionary of Music*. Penguin Books.

Grove, J. R., & Prapavessis, H. (1992). Preliminary evidence for the reliability and validity of an abbreviated Profile of Mood States. *International Journal of Sport Psychology*, *23*(2), 93-109.

Hadjidimitriou, S. K., & Hadjileontiadis, L. J. (2013). EEG-Based Classification of Music Appraisal Responses Using Time-Frequency Analysis and Familiarity Ratings. *IEEE Transactions on Affective Computing*, *4*(2), 161-172. https://doi.org/10.1109/T-AFFC.2013.6

Hall, S. E., Schubert, E., & Wilson, S. J. (2016). The role of trait and state absorption in the enjoyment of music. *PLoS One*, *11*(11). https://doi.org/10.1371/journal.pone.0164029

Handy, T. C. (2005). *Event-related Potentials: A Methods Handbook*. MIT Press.

Hanslmayr, S., Pastötter, B., Bäuml, K. H., Gruber, S., Wimber, M., & Klimesch, W. (2008). The electrophysiological dynamics of interference during the Stroop task. *J Cogn Neurosci*, *20*(2), 215-225. https://doi.org/10.1162/jocn.2008.20020

Hargreaves, D. J., Miell, D. E., & MacDonald, R. A. R. (2005). How do people communicate using music? In D. E. Miell, R. A. R. MacDonald, & D. J. Hargreaves (Eds.), *Musical communication* (pp. 1-25). Oxford University Press.

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

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

Harmon-Jones, E., & Allen, J. J. B. (1998). Anger and frontal brain activity: EEG asymmetry consistent with approach motivation despite negative affective valence. *Journal of Personality and Social Psychology, 74*(5), 1310-1316. https://doi.org/10.1037/0022-3514.74.5.1310

Heilman, K. M. (1997). The neurobiology of emotional experience. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *9*(3), 439-448. https://doi.org/10.1176/jnp.9.3.439

Heller, W. (1990). The neuropsychology of emotion: Developmental patterns and implications for psychopathology. In *Psychological and biological approaches to emotion.* (pp. 167-211). Lawrence Erlbaum Associates, Inc.

Heller, W. (1993). Neuropsychological mechanisms of individual differences in emotion, personality, and arousal. *Neuropsychology*, *7*(4), 476-489. https://doi.org/10.1037/0894-4105.7.4.476

Herbert, R. (2012). Musical and non-musical involvement in daily life: The case of absorption. *Musicae Scientiae*, *16*(1), 41-66. https://doi.org/10.1177/1029864911423161

Hernandez-Ruiz, E., Dvorak, A. L., & Weingarten, K. (2020). Music stimuli in mindfulness meditation: Comparison of musician and non-musician responses. *Psychology of Music*, *0*(0), 0305735620901338. https://doi.org/10.1177/0305735620901338

Hernandez-Ruiz, E., James, B., Noll, J., & Chrysikou, E. G. (2020). What makes music relaxing? An investigation into musical elements. *Psychology of Music*, *48*(3), 327-343. https://doi.org/10.1177/0305735618798027

Hevner, K. (1935). The affective character of the major and minor modes in music. *The American Journal of Psychology*, *47*, 103-118. https://doi.org/10.2307/1416710

Hevner, K. (1936). Experimental studies of the elements of expression in music. *The American Journal of Psychology*, *48*, 246-268. https://doi.org/10.2307/1415746

Hevner, K. (1937). The affective value of pitch and tempo in music. *The American Journal of Psychology*, *49*, 621-630. https://doi.org/10.2307/1416385

Hewig, J., Hagemann, D., Seifert, J., Naumann, E., & Bartussek, D. (2004). On the selective relation of frontal cortical asymmetry and anger-out versus anger-control. *J Pers Soc Psychol*, *87*(6), 926-939. https://doi.org/10.1037/0022-3514.87.6.926

Hogue, J. D., Crimmins, A. M., & Kahn, J. H. (2016). “So sad and slow, so why can’t I turn off the radio”: The effects of gender, depression, and absorption on liking music that induces sadness and music that induces happiness. *Psychology of Music*, *44*(4), 816-829. https://doi.org/10.1177/0305735615594489

Hu, X., Yu, J., Song, M., Yu, C., Wang, F., Sun, P., Wang, D., & Zhang, D. (2017). EEG Correlates of Ten Positive Emotions. *Frontiers in human neuroscience*, *11*, 26-26. https://doi.org/10.3389/fnhum.2017.00026

Hunter, P. G., Schellenberg, E. G., & Schimmack, U. (2008). Mixed affective responses to music with conflicting cues. *Cognition and Emotion*, *22*(2), 327-352. https://doi.org/10.1080/02699930701438145

Huron, D. (2006). *Sweet anticipation: Music and the psychology of expectation*. MIT Press.

Husain, G., Thompson, W. F., & Schellenberg, E. G. (2002). Effects of Musical Tempo and Mode on Arousal, Mood, and Spatial Abilities. *Music Perception: An Interdisciplinary Journal*, *20*(2), 151-171. https://doi.org/10.1525/mp.2002.20.2.151

Inanaga, K. (1998). Frontal midline theta rhythm and mental activity. *Psychiatry Clin Neurosci*, *52*(6), 555-566. https://doi.org/10.1046/j.1440-1819.1998.00452.x

Isotani, T., Lehmann, D., Pascual-Marqui, R. D., Fukushima, M., Saito, N., Yagyu, T., & Kinoshita, T. (2002). Source localization of brain electric activity during positive, neutral and negative emotional states. *International Congress Series*, *1232*, 165-173. https://doi.org/https://doi.org/10.1016/S0531-5131(02)00166-8

James, W. (1884). What is an Emotion? *Mind*, *9*(34), 188-205. http://www.jstor.org/stable/2246769

Janata, P., Tomic, S. T., & Rakowski, S. K. (2007). Characterisation of music-evoked autobiographical memories. *Memory*, *15*(8), 845-860. https://doi.org/10.1080/09658210701734593

Jaquet, L., Danuser, B., & Gomez, P. (2012). Music and felt emotions: How systematic pitch level variations affect the experience of pleasantness and arousal. *Psychology of Music*, *42*(1), 51-70. https://doi.org/10.1177/0305735612456583

Johnson-laird, P. N., & Oatley, K. (1992). Basic emotions, rationality, and folk theory. *Cognition and Emotion*, *6*(3-4), 201-223. https://doi.org/10.1080/02699939208411069

Jones, M. R. (1987). Dynamic pattern structure in music: Recent theory and research. *Perception & Psychophysics*, *41*(6), 621-634. https://doi.org/10.3758/BF03210494

Jones, M. R., & Boltz, M. (1989). Dynamic attending and responses to time. *Psychol Rev*, *96*(3), 459-491. https://doi.org/10.1037/0033-295x.96.3.459

Juslin, P. N. (2001). Communicating emotion in music performance: A review and a theoretical framework. In *Music and emotion: Theory and research.* (pp. 309-337). Oxford University Press.

Juslin, P. N. (2012). Are musical emotions invariant across cultures? *Emotion Review*, *4*(3), 283-284. https://doi.org/10.1177/1754073912439773

Juslin, P. N. (2013). From everyday emotions to aesthetic emotions: Towards a unified theory of musical emotions. *Physics of Life Reviews*, *10*(3), 235-266. https://doi.org/https://doi.org/10.1016/j.plrev.2013.05.008

Juslin, P. N., & Laukka, P. (2003). Communication of emotions in vocal expression and music performance: Different channels, same code? *Psychological Bulletin*, *129*(5), 770-814. https://doi.org/10.1037/0033-2909.129.5.770

Juslin, P. N., & Laukka, P. (2004). Expression, perception, and induction of musical emotions: A review and a questionnaire study of everyday listening. *Journal of New Music Research*, *33*(3), 217-238. https://doi.org/10.1080/0929821042000317813

Juslin, P. N., Liljeström, S., Västfjäll, D., Barradas, G., & Silva, A. (2008). An experience sampling study of emotional reactions to music: listener, music, and situation. *Emotion*, *8*(5), 668-683. https://doi.org/10.1037/a0013505

Juslin, P. N., & Lindström, E. (2010). Musical expression of emotions: Modelling listeners' judgements of composed and performed features. *Music Analysis*, *29*(1‐3), 334-364. https://doi.org/https://doi.org/10.1111/j.1468-2249.2011.00323.x

Juslin, P. N., & Scherer, K. R. (2005). Vocal expression of affect. In *The new handbook of methods in nonverbal behavior research.* (pp. 65-135). Oxford University Press.

Juslin, P. N., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behav Brain Sci*, *31*(5), 559-575; discussion 575-621. https://doi.org/10.1017/s0140525x08005293

Juslin, P. N., & Zentner, M. R. (2001). Current trends in the study of music and emotion: Overture. *Musicae Scientiae*, *5*(1_suppl), 3-21. https://doi.org/10.1177/10298649020050s101

Kaneshiro, B., Dmochowski, J., Norcia, A., & Berger, J. (2014). Toward an objective measure of listener engagement with natural music using inter-subject EEG correlation.

Kania, A. (2014). The Philosophy of Music. In E. N. Zalta (Ed.), *The Standard Encyclopedia of Philosophy*.

Khalfa, S., Isabelle, P., Jean-Pierre, B., & Manon, R. (2002). Event-related skin conductance responses to musical emotions in humans. *Neurosci Lett*, *328*(2), 145-149. https://doi.org/10.1016/s0304-3940(02)00462-7

Kivy, P. (1990). *Music alone. Philosophical reflections on the purely musical experience.* Cornell University Press.

Kleinginna, P. R., & Kleinginna, A. M. (1981). A categorized list of emotion definitions, with suggestions for a consensual definition. *Motivation and Emotion*, *5*(4), 345-379. https://doi.org/10.1007/BF00992553

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Res Brain Res Rev*, *29*(2-3), 169-195. https://doi.org/10.1016/s0165-0173(98)00056-3

Koelsch, S. (2013). *Brain & Music* (First ed.). John Wiley & Sons, Ltd.

Koelsch, S. (2014). Brain correlates of music-evoked emotions. *Nature Reviews Neuroscience*, *15*(3), 170-180. https://doi.org/10.1038/nrn3666

Koelsch, S., Fritz, T., DY, V. C., Müller, K., & Friederici, A. D. (2006). Investigating emotion with music: an fMRI study. *Hum Brain Mapp*, *27*(3), 239-250. https://doi.org/10.1002/hbm.20180

Koelstra, S., Muhl, C., Soleymani, M., Lee, J., Yazdani, A., Ebrahimi, T., Pun, T., Nijholt, A., & Patras, I. (2012). DEAP: A Database for Emotion Analysis ;Using Physiological Signals. *IEEE Transactions on Affective Computing*, *3*(1), 18-31. https://doi.org/10.1109/T-AFFC.2011.15

Koelstra, S., Yazdani, A., Soleymani, M., Mühl, C., Lee, J.-S., Nijholt, A., Pun, T., Ebrahimi, T., & Patras, I. (2010). *Single trial classification of EEG and peripheral physiological signals for recognition of emotions induced by music videos* Proceedings of the 2010 international conference on Brain informatics, Toronto, ON, Canada.

Kolb, B., & Taylor, L. (1981). Affective behavior in patients with localized cortical excisions: role of lesion site and side. *Science*, *214*(4516), 89-91. https://doi.org/10.1126/science.7280683

Koo, T., & Li, M. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of chiropractic medicine*, *15 2*, 155-163.

Kövecses, Z. (2000). *Metaphor and emotion: Language, culture, and body in human feeling*. Cambridge University Press.

Kreutz, G., Ott, U., Teichmann, D., Osawa, P., & Vaitl, D. (2008). Using music to induce emotions: Influences of musical preference and absorption. *Psychology of Music*, *36*(1), 101-126. https://doi.org/10.1177/0305735607082623

Krumhansl, C. L. (1995). Effects of musical context on similarity and expectancy. *Systematische Musikwissenschaft*, *3*(2), 211-250.

Krumhansl, C. L., Louhivuori, J., Toiviainen, P., Järvinen, T., & Eerola, T. (1999). Melodic expectation in Finnish spiritual folk hymns: Convergence of statistical, behavioral, and computational approaches. *Music Perception*, *17*(2), 151-195. https://doi.org/10.2307/40285890

Kumagai, Y., Arvaneh, M., & Tanaka, T. (2017). Familiarity Affects Entrainment of EEG in Music Listening. *Frontiers in human neuroscience*, *11*, 384-384. https://doi.org/10.3389/fnhum.2017.00384

Küssner, M. B., & Eerola, T. (2019). The content and functions of vivid and soothing visual imagery during music listening: Findings from a survey study. *Psychomusicology: Music, Mind, and Brain*, *29*(2-3), 90-99. https://doi.org/10.1037/pmu0000238

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago Press.

Lane, R. D. (2000). Neural correlates of conscious emotional experience. In *Cognitive neuroscience of emotion.* (pp. 345-370). Oxford University Press.

Lang, P. J. (1979). A Bio-Informational Theory of Emotional Imagery. *Psychophysiology*, *16*(6), 495-512. https://doi.org/https://doi.org/10.1111/j.1469-8986.1979.tb01511.x

Lange, E. B., Zweck, F., & Sinn, P. (2017). Microsaccade-rate indicates absorption by music listening. *Consciousness and Cognition*, *55*, 59-78. https://doi.org/https://doi.org/10.1016/j.concog.2017.07.009

Latha, G. C. P., & Hema, C. A Review on Classifiers for Emotion Studies.

Latha, G. C. P., & Hema, C. R. (2012). A review on classifiers for emotion studies. *Emerging Trends in Engineering Research*, 239-247.

Laufs, H., Kleinschmidt, A., Beyerle, A., Eger, E., Salek-Haddadi, A., Preibisch, C., & Krakow, K. (2003). EEG-correlated fMRI of human alpha activity. *Neuroimage*, *19*(4), 1463-1476. https://doi.org/10.1016/s1053-8119(03)00286-6

Laufs, H., Krakow, K., Sterzer, P., Eger, E., Beyerle, A., Salek-Haddadi, A., & Kleinschmidt, A. (2003). Electroencephalographic signatures of attentional and cognitive default modes in spontaneous brain activity fluctuations at rest. *Proceedings of the National Academy of Sciences*, *100*(19), 11053-11058. https://doi.org/10.1073/pnas.1831638100

Laukka, P., Eerola, T., Thingujam, N. S., Yamasaki, T., & Beller, G. (2013). Universal and culture-specific factors in the recognition and performance of musical affect expressions. *Emotion*, *13*(3), 434-449. https://doi.org/10.1037/a0031388

Lazarus, R. S. (1982). Thoughts on the relations between emotion and cognition. *American Psychologist*, *37*(9), 1019-1024. https://doi.org/10.1037/0003-066X.37.9.1019

Lee, Y.-Y., & Hsieh, S. (2014). Classifying Different Emotional States by Means of EEG-Based Functional Connectivity Patterns. *PLoS One*, *9*(4), e95415. https://doi.org/10.1371/journal.pone.0095415

Lerdahl, F., & Jackendoff, R. (1983). *A Generative Theory of Tonal Music*. MIT Press.

Lerner, Y., Papo, D., Zhdanov, A., Belozersky, L., & Hendler, T. (2009). Eyes Wide Shut: Amygdala Mediates Eyes-Closed Effect on Emotional Experience with Music. *PLoS One*, *4*(7), e6230. https://doi.org/10.1371/journal.pone.0006230

Levenson, R. W. (2003). Autonomic specificity and emotion. In *Handbook of affective sciences.* (pp. 212-224). Oxford University Press.

Levitin, D. J. (2006). *This is your brain on music: The science of a human obsession*. Penguin Group.

Levitin, D. J., & Tirovolas, A. K. (2009). Current advances in the cognitive neuroscience of music. *Ann N Y Acad Sci*, *1156*, 211-231. https://doi.org/10.1111/j.1749-6632.2009.04417.x

Li, Y., Rui, X., Li, S., & Pu, F. (2014). Investigation of global and local network properties of music perception with culturally different styles of music. *Computers in Biology and Medicine*, *54*, 37-43. https://doi.org/https://doi.org/10.1016/j.compbiomed.2014.08.017

Lin, Y. P., Duann, J. R., Chen, J. H., & Jung, T. P. (2010). Electroencephalographic dynamics of musical emotion perception revealed by independent spectral components. *Neuroreport*, *21*(6), 410-415. https://doi.org/10.1097/WNR.0b013e32833774de

Lin, Y. P., Wang, C. H., Jung, T. P., Wu, T. L., Jeng, S. K., Duann, J. R., & Chen, J. H. (2010). EEG-based emotion recognition in music listening. *IEEE Trans Biomed Eng*, *57*(7), 1798-1806. https://doi.org/10.1109/tbme.2010.2048568

Loxton, N. J., Mitchell, R., Dingle, G. A., & Sharman, L. S. (2016). How to tame your BAS: Reward sensitivity and music involvement. *Personality and Individual Differences*, *97*, 35-39. https://doi.org/https://doi.org/10.1016/j.paid.2016.03.018

Luce, D. W. (2001). Cognitive Therapy and Music Therapy. *Music Therapy Perspectives*, *19*(2), 96-103. https://doi.org/10.1093/mtp/19.2.96

Lundqvist, L.-O., Carlsson, F., Hilmersson, P., & Juslin, P. N. (2009). Emotional responses to music: Experience, expression, and physiology. *Psychology of Music*, *37*(1), 61-90. https://doi.org/10.1177/0305735607086048

Madsen, J., Margulis, E. H., Simchy-Gross, R., & Parra, L. C. (2019). Music synchronizes brainwaves across listeners with strong effects of repetition, familiarity and training. *Scientific Reports*, *9*(1), 3576. https://doi.org/10.1038/s41598-019-40254-w

Makris, D., Karydis, I., & Sioutas, S. (2015). The Greek Music Dataset. EANN '15,

Margulis, E. H. (2017). An Exploratory Study of Narrative Experiences of Music. *Music Perception*, *35*(2), 235-248. https://doi.org/10.1525/mp.2017.35.2.235

McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological Methods*, *1*(1), 30-46. https://doi.org/10.1037/1082-989X.1.1.30

McKinney, C. H., Antoni, M. H., Kumar, M., Tims, F. C., & McCabe, P. M. (1997). Effects of guided imagery and music (GIM) therapy on mood and cortisol in healthy adults. *Health Psychology*, *16*(4), 390-400. https://doi.org/10.1037/0278-6133.16.4.390

Meltzer, B., Reichenbach, C. S., Braiman, C., Schiff, N. D., Hudspeth, A. J., & Reichenbach, T. (2015). The steady-state response of the cerebral cortex to the beat of music reflects both the comprehension of music and attention [Original Research]. *Frontiers in human neuroscience*, *9*(436). https://doi.org/10.3389/fnhum.2015.00436

Meyer, L. B. (1956). *Emotion and meaning in music*. Chicago.

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

Mills, C. K. (1912). The cerebral mechanisms of emotional expression. *Transactions of the College of Physicians of Philadelphia*, *34*, 381-390.

Moore, K. S. (2013). A systematic review on the neural effects of music on emotion regulation: Implications for music therapy practice. *Journal of Music Therapy*, *50*(3), 198-242. https://doi.org/10.1093/jmt/50.3.198

Moors, A., Boddez, Y., & De Houwer, J. (2017). The power of goal-directed processes in the causation of emotional and other actions. *Emotion Review*, *9*(4), 310-318. https://doi.org/10.1177/1754073916669595

Moors, A., & Fischer, M. (2019). Demystifying the role of emotion in behaviour: toward a goal-directed account. *Cogn Emot*, *33*(1), 94-100. https://doi.org/10.1080/02699931.2018.1510381

Mueller, K., Mildner, T., Fritz, T., Lepsien, J., Schwarzbauer, C., Schroeter, M. L., & Möller, H. E. (2011). Investigating brain response to music: a comparison of different fMRI acquisition schemes. *Neuroimage*, *54*(1), 337-343. https://doi.org/10.1016/j.neuroimage.2010.08.029

Nagy, K., & Szabó, C. (2002). Individual differences in musical involvment. ICMPC7. Proceedings of the 7th International Conference on Music Perception & Cognition, Adelaide, Australia.

Nagy, K., & Szabó, C. (2004, August 3-7, 2004). Differences in phenomenological experiences of music listening: The influence of intensity of musical involvement and type of music on musical experiences. ICMPC8. Proceedings of the 8th International Conference on Music Perception & Cognition, Evanston, IL.

Nan, Y., Knösche, T. R., & Friederici, A. D. (2006). The perception of musical phrase structure: A cross-cultural ERP study. *Brain Res*, *1094*(1), 179-191. https://doi.org/https://doi.org/10.1016/j.brainres.2006.03.115

Narayanan, N. S., Cavanagh, J. F., Frank, M. J., & Laubach, M. (2013). Common medial frontal mechanisms of adaptive control in humans and rodents. *Nat Neurosci*, *16*(12), 1888-1895. https://doi.org/10.1038/nn.3549

Narmour, E. (1991). The top-down and bottom-up systems of musical implication: Building on Meyer's theory of emotional syntax. *Music Perception*, *9*(1), 1-26. https://doi.org/10.2307/40286156

Nater, U. M., Abbruzzese, E., Krebs, M., & Ehlert, U. (2006). Sex differences in emotional and psychophysiological responses to musical stimuli. *Int J*

Psychophysiol, *62*(2), 300-308. https://doi.org/10.1016/j.ijpsycho.2006.05.011

Nemati, S., Akrami, H., Salehi, S., Esteky, H., & Moghimi, S. (2019). Lost in music: Neural signature of pleasure and its role in modulating attentional resources. *Brain Res*, *1711*, 7-15. https://doi.org/https://doi.org/10.1016/j.brainres.2019.01.011

Niedermeyer, E. (1999). The normal EEG of the waking adult. In E. L. d. S. Niedermeyer, F. H. (Ed.), *Electroencephalography - Basic principles, clinical applications, and related fields* (4th ed., pp. 149-173). Williams & Wilkins.

Nielzén, S., & Cesarec, Z. (1982). Emotional experience of music as a function of musical structure. *Psychology of Music*, *10*(2), 7-17. https://doi.org/10.1177/0305735682102002

Nigbur, R., Cohen, M. X., Ridderinkhof, K. R., & Stürmer, B. (2012). Theta dynamics reveal domain-specific control over stimulus and response conflict. *J Cogn Neurosci*, *24*(5), 1264-1274. https://doi.org/10.1162/jocn_a_00128

Oakes, T. R., Pizzagalli, D. A., Hendrick, A. M., Horras, K. A., Larson, C. L., Abercrombie, H. C., Schaefer, S. M., Koger, J. V., & Davidson, R. J. (2004). Functional coupling of simultaneous electrical and metabolic activity in the human brain. *Human Brain Mapping*, *21*(4), 257-270. https://doi.org/https://doi.org/10.1002/hbm.20004

Oh, J. G. (2019). *Pictures at an exhibition: The effect of music on works of abstract art* [Undergraduate thesis, Nanyang Technological University]. Singapore.

Paraskevopoulos, E., Chalas, N., Karagiorgis, A., Karagianni, M., Styliadis, C., Papadelis, G., & Bamidis, P. (2021). Aging Effects on the Neuroplastic Attributes of Multisensory Cortical Networks as Triggered by a Computerized Music Reading Training Intervention. *Cereb Cortex*, *31*(1), 123-137. https://doi.org/10.1093/cercor/bhaa213

Pardo, J. V., Pardo, P. J., Janer, K. W., & Raichle, M. E. (1990). The anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm. *Proc Natl Acad Sci U S A*, *87*(1), 256-259. https://doi.org/10.1073/pnas.87.1.256

Parsons, L. M. (2001). Exploring the functional neuroanatomy of music performance, perception, and comprehension. *Ann N Y Acad Sci*, *930*, 211-231. https://doi.org/10.1111/j.1749-6632.2001.tb05735.x

Patel, A. D. (2003). Language, music, syntax and the brain. *Nat Neurosci*, *6*(7), 674-681. https://doi.org/10.1038/nn1082

Patel, A. D. (2008). *Music, language, and the brain*. Oxford University Press Inc.

Pearce, M. T. (2018). Statistical learning and probabilistic prediction in music cognition: mechanisms of stylistic enculturation. *Ann N Y Acad Sci*, *1423*(1), 378-395. https://doi.org/10.1111/nyas.13654

Pearce, M. T., & Wiggins, G. A. (2006). Expectation in Melody: The Influence of Context and Learning. *Music Perception: An Interdisciplinary Journal*, *23*(5), 377-405. https://doi.org/10.1525/mp.2006.23.5.377

Pereira, C. S., Teixeira, J., Figueiredo, P., Xavier, J., Castro, S. L., & Brattico, E. (2011). Music and emotions in the brain: familiarity matters. *PLoS One*, *6*(11), e27241. https://doi.org/10.1371/journal.pone.0027241

Peretz, I. (1990). Processing of local and global musical information by unilateral brain-damaged patients. *Brain*, *113 (Pt 4)*, 1185-1205. https://doi.org/10.1093/brain/113.4.1185

Peretz, I., Gagnon, L., & Bouchard, B. (1998). Music and emotion: perceptual determinants, immediacy, and isolation after brain damage. *Cognition*, *68*(2), 111-141. https://doi.org/10.1016/s0010-0277(98)00043-2

Platel, H., Price, C., Baron, J. C., Wise, R., Lambert, J., Frackowiak, R. S., Lechevalier, B., & Eustache, F. (1997). The structural components of music perception. A functional anatomical study. *Brain*, *120 (Pt 2)*, 229-243. https://doi.org/10.1093/brain/120.2.229

Posner, J., Russell, J. A., & Peterson, B. S. (2005). The circumplex model of affect: an integrative approach to affective neuroscience, cognitive development, and psychopathology. *Dev Psychopathol*, *17*(3), 715-734. https://doi.org/10.1017/s0954579405050340

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annu Rev Neurosci*, *13*, 25-42. https://doi.org/10.1146/annurev.ne.13.030190.000325

Razran, G. (1954). The conditioned evocation of attitudes (cognitive conditioning?). *Journal of Experimental Psychology*, *48*(4), 278-282. https://doi.org/10.1037/h0058778

Rentfrow, P. J., & Gosling, S. D. (2003). The do re mi's of everyday life: The structure and personality correlates of music preferences. *Journal of Personality and Social Psychology*, *84*(6), 1236-1256. https://doi.org/10.1037/0022-3514.84.6.1236

Rigg, M. G. (1939). What features of a musical phrase have emotional suggestiveness? *Bulletin. Oklahoma A & M College*, *36, 13*, 38-38.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annu Rev Neurosci*, *27*, 169-192. https://doi.org/10.1146/annurev.neuro.27.070203.144230

Rogenmoser, L., Zollinger, N., Elmer, S., & Jäncke, L. (2016). Independent component processes underlying emotions during natural music listening. *Soc Cogn Affect Neurosci*, *11*(9), 1428-1439. https://doi.org/10.1093/scan/nsw048

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161-1178. https://doi.org/10.1037/h0077714

Rybak, M., Crayton, J. W., Young, I. J., Herba, E., & Konopka, L. M. (2006). Frontal alpha power asymmetry in aggressive children and adolescents with mood and disruptive behavior disorders. *Clin EEG Neurosci*, *37*(1), 16-24. https://doi.org/10.1177/155005940603700105

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

Sandstrom, G. M., & Russo, F. A. (2013). Absorption in music: Development of a scale to identify individuals with strong emotional responses to music. *Psychology of Music*, *41*(2), 216-228. https://doi.org/10.1177/0305735611422508

Schacter, D. L. (1977). EEG theta waves and psychological phenomena: a review and analysis. *Biol Psychol*, *5*(1), 47-82. https://doi.org/10.1016/0301-0511(77)90028-x

Schäfer, T., & Sedlmeier, P. (2010). What makes us like music? Determinants of music preference. *Psychology of Aesthetics, Creativity, and the Arts*, *4*(4), 223-234. https://doi.org/10.1037/a0018374

Scherer, K. R. (2000). Psychological models of emotion. In *The neuropsychology of emotion.* (pp. 137-162). Oxford University Press.

Scherer, K. R., & Oshinsky, J. S. (1977). Cue Utilization in Emotion Attribution from Auditory Stimuli. *Motivation and Emotion*, *1*(4), 331-346. https://doi.org/10.1007/BF00992539

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

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

Schmuckler, M. A. (1989). Expectation in music: Investigation of melodic and harmonic processes. *Music Perception*, *7*(2), 109-149. https://doi.org/10.2307/40285454

Schomer, D. L., Lopes da Silva, F. H., Amzica, F., & Lopes da Silva, F. H. (2017). Niedermeyer's ElectroencephalographyBasic Principles, Clinical Applications, and Related Fields. In *Cellular Substrates of Brain Rhythms*. Oxford University Press. https://doi.org/10.1093/med/9780190228484.003.0002

Schubert, E. (1999). Measuring Emotion Continuously: Validity and Reliability of the Two-Dimensional Emotion-Space. *Australian Journal of Psychology*, *51*(3), 154-165. https://doi.org/10.1080/00049539908255353

Sergent, J., Zuck, E., Terriah, S., & MacDonald, B. (1992). Distributed neural network underlying musical sight-reading and keyboard performance. *Science*, *257*(5066), 106-109. https://doi.org/10.1126/science.1621084

Shahabi, H., & Moghimi, S. (2016). Toward automatic detection of brain responses to emotional music through analysis of EEG effective connectivity. *Computers in Human Behavior*, *58*, 231-239. https://doi.org/https://doi.org/10.1016/j.chb.2016.01.005

Silberman, E. K., & Weingartner, H. (1986). Hemispheric lateralization of functions related to emotion. *Brain Cogn*, *5*(3), 322-353. https://doi.org/10.1016/0278-2626(86)90035-7

Silverman, M. J. (2007). Evaluating current trends in psychiatric music therapy: a descriptive analysis. *J Music Ther*, *44*(4), 388-414. https://doi.org/10.1093/jmt/44.4.388

Silvia, P. J., Fayn, K., Nusbaum, E. C., & Beaty, R. E. (2015). Openness to experience and awe in response to nature and music: Personality and profound aesthetic experiences. *Psychology of Aesthetics, Creativity, and the Arts*, *9*(4), 376-384. https://doi.org/10.1037/aca0000028

Sloboda, J. A., & O'Neill, S. A. (2001). Emotions in everyday listening to music. In *Music and emotion: Theory and research.* (pp. 415-429). Oxford University Press.

Sluckin, W., Hargreaves, D. J., & Colman, A. M. (1983). Novelty and human aesthetic preferences. In J. Archer & L. Brirke (Eds.), *Exploration in animals and humans* (pp. 245-269). Van Nostrand Reinhold.

Spielberg, J. M., Stewart, J. L., Levin, R. L., Miller, G. A., & Heller, W. (2008). Prefrontal Cortex, Emotion, and Approach/Withdrawal Motivation. *Soc Personal Psychol Compass*, *2*(1), 135-153. https://doi.org/10.1111/j.1751-9004.2007.00064.x

Steinbeis, N., Koelsch, S., & Sloboda, J. A. (2006). The role of harmonic expectancy violations in musical emotions: evidence from subjective, physiological, and neural responses. *J Cogn Neurosci*, *18*(8), 1380-1393. https://doi.org/10.1162/jocn.2006.18.8.1380

Stevens, C. S. (2011). Touching the audience: Music and television advertising in Japan. *Japanese Studies*, *31*(1), 37-51. https://doi.org/10.1080/10371397.2011.560260

Taruffi, L., Allen, R., Downing, J., & Heaton, P. (2017). Individual differences in music-perceived emotions: The influence of externally oriented thinking. *Music Perception*, *34*(3), 253-266. https://doi.org/10.1525/mp.2017.34.3.253

Taruffi, L., & Küssner, M. B. (2019). A review of music-evoked visual mental imagery: Conceptual issues, relation to emotion, and functional outcome. *Psychomusicology: Music, Mind, and Brain*, *29*(2-3), 62-74. https://doi.org/10.1037/pmu0000226

Teipel, S., Bakardjian, H., Gonzalez-Escamilla, G., Cavedo, E., Weschke, S., Dyrba, M., Grothe, M. J., Potier, M.-C., Habert, M.-O., Dubois, B., Hampel, H., & group, I. N.-p. s. (2017). No association of cortical amyloid load and EEG connectivity in older people with subjective memory complaints. *NeuroImage. Clinical*, *17*, 435-443. https://doi.org/10.1016/j.nicl.2017.10.031

Tellegen, A. (1981). Practicing the two disciplines for relaxation and enlightenment: comment on "Role of the feedback signal in electromyograph biofeedback: the relevance of attention" by Qualls and Sheehan. *J Exp Psychol Gen*, *110*(2), 217-231.

Tellegen, A., & Atkinson, G. (1974). Openness to absorbing and self-altering experiences ("absorption"), a trait related to hypnotic susceptibility. *Journal of Abnormal Psychology*, *83*(3), 268-277. https://doi.org/10.1037/h0036681

Tellegen, A., Lykken, D. T., Bouchard, T. J., Wilcox, K. J., Segal, N. L., & Rich, S. (1988). Personality similarity in twins reared apart and together. *Journal of Personality and Social Psychology*, *54*(6), 1031-1039. https://doi.org/10.1037/0022-3514.54.6.1031

Temperley, D. (2001). *The Cognition of Basic Musical Structures*. MIT Press.

Thammasan, N., Moriyama, K., Fukui, K. I., & Numao, M. (2017). Familiarity effects in EEG-based emotion recognition. *Brain Inform*, *4*(1), 39-50. https://doi.org/10.1007/s40708-016-0051-5

Thayer, J. F., & Faith, M. L. (2001). A dynamic systems model of musically induced emotions. Physiological and self-report evidence. *Ann N Y Acad Sci*, *930*, 452-456. https://doi.org/10.1111/j.1749-6632.2001.tb05768.x

Thompson, W. F., & Robitaille, B. (1992). Can composers express emotions through music? *Empirical Studies of the Arts*, *10*(1), 79-89. https://doi.org/10.2190/NBNY-AKDK-GW58-MTEL

Tirovolas, A. K., & Levitin, D. J. (2011). Music perception and cognition Research from 1983 to 2010: A categorical and bibliometric analysis of empirical articles in Music Perception. *Music Perception*, *29*(1), 23-36. https://doi.org/10.1525/mp.2011.29.1.23

Tomkins, S. S. (1962). *Affect, imagery, consciousness: Vol. I. The positive affects*. Springer.

Trehub, S. E. (2003). The developmental origins of musicality. *Nat Neurosci*, *6*(7), 669-673. https://doi.org/10.1038/nn1084

Trochidis, K., & Bigand, E. (2012). EEG-based emotion perception during music listening. 12th International Conference on Music Perception and Cognition and the 8th Triennial Conference of the European Society for the Cognitive Sciences of Music, Thessaloniki, Greece.

Trochidis, K., & Bigand, E. (2013). Investigation of the effect of mode and tempo on emotional responses to music using EEG power asymmetry. *Journal of Psychophysiology*, *27*(3), 142-147. https://doi.org/10.1027/0269-8803/a000099

Trost, W., Ethofer, T., Zentner, M., & Vuilleumier, P. (2012). Mapping aesthetic musical emotions in the brain. *Cereb Cortex*, *22*(12), 2769-2783. https://doi.org/10.1093/cercor/bhr353

Tucker, D. M., & Williamson, P. A. (1984). Asymmetric neural control systems in human self-regulation. *Psychological Review*, *91*(2), 185-215. https://doi.org/10.1037/0033-295X.91.2.185

van den Bosch, I., Salimpoor, V. N., & Zatorre, R. J. (2013). Familiarity mediates the relationship between emotional arousal and pleasure during music listening. *Frontiers in human neuroscience*, *7*, 534-534. https://doi.org/10.3389/fnhum.2013.00534

van Driel, J., Ridderinkhof, K. R., & Cohen, M. X. (2012). Not All Errors Are Alike: Theta and Alpha EEG Dynamics Relate to Differences in Error-Processing Dynamics. *The Journal of Neuroscience*, *32*(47), 16795-16806. https://doi.org/10.1523/jneurosci.0802-12.2012

Västfjäll, D. (2002). Emotion induction through music: A review of the musical mood induction procedure. *Musicae Scientiae*, *5*(1_suppl), 173-211. https://doi.org/10.1177/10298649020050S107

Vella, E. J., & Mills, G. (2017). Personality, uses of music, and music preference: The influence of openness to experience and extraversion. *Psychology of Music*, *45*(3), 338-354. https://doi.org/10.1177/0305735616658957

Vroegh, T. (2019). Zoning-in or tuning-in? Identifying distinct absorption states in response to music. *Psychomusicology: Music, Mind, and Brain*, *29*(2-3), 156-170. https://doi.org/10.1037/pmu0000241

Vuoskoski, J. K., & Eerola, T. (2011). Measuring music-induced emotion: A comparison of emotion models, personality biases, and intensity of experiences. *Musicae Scientiae*, *15*(2), 159-173. https://doi.org/10.1177/1029864911403367

Wacker, J., Heldmann, M., & Stemmler, G. (2003). Separating emotion and motivational direction in fear and anger: effects on frontal asymmetry. *Emotion*, *3*(2), 167-193. https://doi.org/10.1037/1528-3542.3.2.167

Wang, C., Ulbert, I., Schomer, D. L., Marinkovic, K., & Halgren, E. (2005). Responses of Human Anterior Cingulate Cortex Microdomains to Error Detection, Conflict Monitoring, Stimulus-Response Mapping, Familiarity, and Orienting. *The Journal of Neuroscience*, *25*(3), 604-613. https://doi.org/10.1523/jneurosci.4151-04.2005

Warrenburg, L. A. (2020). Choosing the Right Tune: A Review of Music Stimuli Used in Emotion Research. *Music Perception*, *37*(3), 240-258. https://doi.org/10.1525/mp.2020.37.3.240

Watson, K. B. (1942). The nature and measurement of musical meanings. *Psychological Monographs*, *54*(2), i-43. https://doi.org/10.1037/h0093496

Wedin, L. (1972). A multidimensional study of perceptual-emotional qualities in music. *Scand J Psychol*, *13*(4), 241-257. https://doi.org/10.1111/j.1467-9450.1972.tb00072.x

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. http://ggplot2.org

Wieser, H. G. (2003). Music and the brain. Lessons from brain diseases and some reflections on the "emotional" brain. *Ann N Y Acad Sci*, *999*, 76-94. https://doi.org/10.1196/annals.1284.007

Wild, T. C., Kuiken, D., & Schopflocher, D. (1995). The role of absorption in experiential involvement. *Journal of Personality and Social Psychology*, *69*(3), 569-579. https://doi.org/10.1037/0022-3514.69.3.569

Winkler, I., Haufe, S., & Tangermann, M. (2011). Automatic classification of artifactual ICA-components for artifact removal in EEG signals. *Behav Brain Funct*, *7*, 30. https://doi.org/10.1186/1744-9081-7-30

Yoo, H., Kang, S., & Fung, V. (2018). Personality and world music preference of undergraduate non-music majors in South Korea and the United States. *Psychology of Music*, *46*(5), 611-625. https://doi.org/10.1177/0305735617716757

Zajonc, R. B. (1984). On the primacy of affect. *American Psychologist*, *39*(2), 117-123. https://doi.org/10.1037/0003-066X.39.2.117

Zeileis, A., Köll, S., & Graham, N. (2020). Various Versatile Variances: An Object-Oriented Implementation of Clustered Covariances in R [clustered data; covariance matrix estimator; object orientation; simulation; R]. *2020*, *95*(1), 36. https://doi.org/10.18637/jss.v095.i01

Zentner, M., Grandjean, D., & Scherer, K. R. (2008). Emotions evoked by the sound of music: characterization, classification, and measurement. *Emotion*, *8*(4), 494-521. https://doi.org/10.1037/1528-3542.8.4.494

Zhao, G., Zhang, Y., & Ge, Y. (2018). Frontal EEG Asymmetry and Middle Line Power Difference in Discrete Emotions. *Front Behav Neurosci*, *12*, 225. https://doi.org/10.3389/fnbeh.2018.00225

APPENDICES

Appendix A

MATERIALS FOR CHAPTER III

Study 1: Development of Music Stimuli of Familiar and Unfamiliar Musical Styles

Appendix A-1. NTU-IRB Research Study Approval

NANYANG TECHNOLOGICAL UNIVERSITY

Research Support Office

Reg. No. 200604393R

IRB-2015-09-012

18 September 2015

Associate Professor Chen Shen-Hsing Annabel
Cradle@NTU

NTU INSTITUTIONAL REVIEW BOARD APPROVAL
Project Title: Reducing arousal using a musical movement task: an EEG study

I refer to your application for ethics approval with respect to the above project.

The Board has deliberated on your application and noted from your application that your research involves collecting behavioral data from participants through auditory computerized tasks.

You have also confirmed that informed consent will be obtained from the participants and you have guaranteed the confidentiality of your participants' biodata obtained from them.

The documents reviewed are:

a) NTU IRB application form dated **02 September 2015**
b) Participant information sheet and consent form: version 1 dated **02 September 2015**
c) Data collection form: version 1 dated **02 September 2015**

The Board is therefore satisfied with the bioethical consideration for the project and approves the ethics application under **Expedited** review. The approval period is from **18 September 2015** to **30 December 2016**. The NTU IRB reference number for this study is **IRB-2015-09-012**. Please use this reference number for all future correspondence.

The following protocol and compliances are to be observed upon NTU IRB approval

1. All research involving procedures greater than minimal risk on minors (individuals who are less than the legal age of 21 years old) requires IRB approved written Parental Consent and assent from the participant to be obtained before any research protocols can be administered. Minimal risk refers to an anticipated level of harm and discomfort that is no greater than that ordinarily encountered in daily life, or during the performance of routine educational, physical, or psychological examination.

2. Only the approved Participants Information Sheet and Consent Form should be used. It must be signed by each subject prior to initiation of any protocol procedures. In addition, each subject should be given a copy of the signed consent form.

Blk N2.1, B4-01, 76 Nanyang Drive, Singapore 637331 Nanyang Avenue, Singapore 639798
Tel : +65 6791 9857, Fax: 6793 2019
www.ntu.edu.sg

3. Consent forms are important documents therefore they should be stored in the strictest arrangement. Loss of consent form would result in disciplinary action.

4. No deviation from, or changes of, the protocol should be initiated without prior written NTU IRB approval of an appropriate amendment.

5. The Principal Investigator should report promptly to NTU IRB regarding:
    a. Deviation from, or changes to the protocol.
    b. Changes increasing the risk to the subjects and/or affecting significantly the conduct of the trial
    c. All serious adverse events (SAEs) which are both serious and unexpected.
    d. New information that may affect adversely the safety of the subjects of the conduct of the trial.
    e. Completion of the study.

6. Continuing Review Request/ Notice of Study completion form should be submitted to NTU IRB for the following:
    a. Annual review: Status of the study should be reported to the NTU IRB at least annually using the Continuing Review Request/ Notice of Study completion form.
    b. Study completion or termination: Continuing Review Request/ Notice of Study completion form is to be submitted within 4 to 6 weeks of study completion or termination.

7. All Principal Investigators should comply with existing legislation that would have an impact on the domain of their research.

Professor Lee Sing Kong,
Chair, NTU Institutional Review Board
encl.

cc Director, Cradle@NTU
Members, NTU Institutional Review Board

Appendix A-2. Informed Consent Form used in Study 1 (pilot behavioral experiment)

NANYANG TECHNOLOGICAL UNIVERSITY

PARTICIPATION INFORMATION SHEET

Please read this consent agreement carefully.

1. **Study Information**

Protocol Title:
Investigating the EEG signatures underlying music listening: Behavioral study

Principal Investigator & Contact Details:
Overall Principal Investigator
Prof S. H. Annabel CHEN
Professor
Psychology, Nanyang Technological University
14 Nanyang Drive, HSS-04-19
Singapore 637332
Tel: +65 6316 8836/ Fax: +65 6795 5797

Co-Investigator
Dr. Dilip Kumar PRASAD
Research Fellow
Rolls-Royce@NTU Corporate Lab,
Nanyang Technological University
65 Nanyang Drive
Singapore 637460

Co-Investigator
J. Gladys HENG
Graduate Student
Psychology, Nanyang
Technological University
14 Nanyang Drive
Singapore 637332

Study Sponsor:
Nanyang Technological University

2. **Purpose of the research**

The purpose of this research is to understand how the brain processes emotions during music listening, which will contribute to developments of music and technology applications.

You are invited to participate in this research study. This information sheet provides you with information about this research. It is important to us that you first take time to read through and understand the information provided in this

sheet. Nevertheless, before you take part in this research study, the study will be explained to you and you will be given the chance to ask questions. After you are properly satisfied that you understand this study, and that you wish to take part in the study, you must sign this informed consent form. You will be given a copy of this consent form to take home with you.
You are eligible for this study if you are healthy and aged between 21 – 40 years old. Approximately 80 subjects will be involved in this study. Your participation in this study is entirely voluntary. Your decision whether or not to participate will not prejudice you or your status at NTU. If you decide to participate, you are free to withdraw your consent, including your authorization regarding the use and disclosure of your health information and to discontinue participation at any time without prejudice to you or effect on your medical care.

3. What procedures will be followed in this study

If you decide to participate, you will be asked to complete the following tasks:

1. An online demographics questionnaire about your background and music experience
2. **A music judgment task.** You will listen to several musical excerpts and be required to decide if they are the similar or different. This task is expected to take about 15 to 20 minutes.
3. **A music listening task.** In this task, you will be asked to provide emotion ratings as you listen to musical pieces presented both with and without visuals. This task is expected to take 1 hour and 15 minutes.
4. **A recognition task.** In this task, you will listen to various short musical excerpts and be required to indicate if you recognize these musical excerpts. This task is expected to take approximately 15 minutes.

Your participation in this session will be approximately 2 hours.

4. Possible Risks and Side Effects

You will not be subjected to any risks beyond what you may experience in everyday life. If you wish, you may withdraw your participation from the study at any point without penalty.

5. Possible Benefits from Participating in the Study

There is no direct benefit to you in participating in this study. However, knowledge gained as a result of your participation will facilitate further research in the field that has the potential for intervention methodologies designed to improve learning by emotion regulation.

6. Confidentiality of Study

Information collected for this study will be kept confidential. Any data that may be published in scientific journals will not reveal the identity of the subjects. Only the principal investigator and members of the research team will have access to your identifying information (e.g. names, contact numbers, addresses and email addresses) and this will not be released to any other person. All your identifiable health information and research data will be coded (i.e. only identified with a code number) at the earliest possible stage of the research. All data collected will be kept indefinitely in a coded form, without personal identifying information (your name, DOB, etc). Personal identifying information will be stored separately in locked files. The personal identifying information will be destroyed at the completion of the study, unless you agree that we may keep it so that we may re-contact you for future studies. The Institutional Review Board for Nanyang Technological University, for example, may inspect research records and learn your identity if this study falls within its jurisdiction.

7. Costs & Payments if Participating in the Study

As compensation for your time and inconvenience, you will receive *either*

- ☐ Up to 4 credits for research participation, *or*
- ☐ $25 cash payment

upon completion of the study. If you do not complete the study for any reason, credits or cash payment will not be made to you.

8. Voluntary Participation

Your participation in the study is completely voluntary. Participants who are obtaining course credits have the alternative not to participate by completing an assignment provided by your course instructor. If you do decide to participate, it is important that you complete the tasks to the best of your ability. At any time, during the study, if you no longer wish to participate, you may withdraw by informing the experimenter. Your decision to participate, decline, or withdraw from the study will have no consequence on your status or relationship with NTU. At the discretion of the Principal Investigator, subjects may be taken out of this study due to unanticipated circumstances. This might occur, for example, if you are unable to perform the task, or if your EEG signal contains artifacts due to motion or other causes.

9. Who to Contact if You Have Questions

If you have questions about this research study, you may contact the Overall Principal Investigator, Prof S. H. Annabel Chen, Tel (direct line): 6316-8836, Email: annabelchen@ntu.edu.sg.

If you have any concerns about this study or your rights as a participant, you may contact the Institutional Review Board (IRB) at NTU at 65-65922495. Email: irb@ntu.edu.sg .

CONSENT FORM

Protocol Title:
Investigating the EEG signatures underlying music listening: Behavioral study

Principal Investigator & Contact Details:
Overall Principal Investigator
Prof S. H. Annabel CHEN
Professor
Psychology, Nanyang Technological University
14 Nanyang Drive, HSS-04-19
Singapore 637332
Tel: +65 6316 8836/ Fax: +65 6795 5797

Co-Investigator
Dr. Dilip Kumar PRASAD
Research Fellow
Rolls-Royce@NTU Corporate Lab,
Nanyang Technological University
65 Nanyang Drive
Singapore 637460

Co-Investigator
J. Gladys HENG
Graduate Student
Psychology, Nanyang
Technological University
14 Nanyang Drive
Singapore 637332

I voluntarily consent to take part in this research study. I have fully discussed and understood the purpose and procedures of this study. This study has been explained to me in a language that I understand. I have been given enough time to ask any questions that I have about the study, and all my questions have been answered to my satisfaction. I can withdraw from the research at any point of time by informing the Principal Investigator and all my data collected will be discarded.

I **agree / do not agree*** that the experimenter may re-contact me to invite me to return for additional research studies relating to today's study.

I **agree / do not agree*** that the experimenter may re-contact me to invite me to participate in other future studies, maintaining a locked copy of my personally-identifying information. I note that future research using the data collected will be related to this research and will be subject to the approval of an Institutional Review Board.

I **agree / do not agree*** for my personal information (which will be coded) to be kept indefinitely by the principal investigator.

* please encircle as appropriate

_______________________ _____________________________ _________________

Name of Participant

Signature

Date

Investigator Statement

I, the undersigned, certify that I explained the study to the participant and to the best of my knowledge the participant signing this informed consent form clearly understands the nature, risks and benefits of her participation in the study.

_______________________ _____________________________ _________________

Name of Investigator

Signature

Date

Position: _____________________________________

Appendix A-3. List of Japanese animation Original Soundtracks (OSTs)

No	Musical Excerpt ID	Composer	Track Name	Album Name	Track No.	Min:Sec	Youtube Link	Date of release
Low valence, High arousal								
1	1a	Akira Senju	Pride	Fullmetal Alchemist Brotherhood OST 2	3	0:11 - 0:56	https://www.youtube.com/watch?v=oMLl29K33fk	2010
2	2a	Yuki Hayashi	Aku no shinri (Evil Of Psychology)	My Hero Academia OST	27	0:00 - 0:45	https://www.youtube.com/watch?v=uHf69Vt2Z4Y&t=50s	2016
3	3a	Shiro Sagisu	Crumbling Idee Fixe	Berserk Original Soundtrack	6	0:00 - 0:45	https://www.youtube.com/watch?v=MKa5xLoy2BE	2016
4	3b	Yutaka Yamada	Transplantation	Tokyo Ghoul Original Soundtrack	5	1:05 - 1:50	https://www.youtube.com/watch?v=FhKCS6n9lgE	2015
5	1b	Takanashi Yasuharu	Memento Mori	Shiki Original Soundtrack Mini Album "Noir"	2	1:19 - 2:04	https://www.youtube.com/watch?v=5RdGNBrUTgM	2011
6	2b	Yuki Hayashi	Hirogaru fuan (Spread Anxiety)	My Hero Academia OST	28	0:12 - 0:57	https://www.youtube.com/watch?v=H6vebWDGwoY	2016
7	3c	Naoki Sato	Final Battle In Tokyo	Blood-C: The Last Dark Original Soundtrack	1	1:52 - 2:37	https://www.youtube.com/watch?v=4vBnBZJ5Yu4&list=PLEC001DBF90C8EEBA	2012
8	3d	Kaoru Wada	Scheme	D.Gray-Man Hallow Original Soundtrack	5	0:26 - 1:11	https://www.youtube.com/watch?v=nckL_FZisLY	2016
9	3e	Hitoshi Sakimoto	An Uncomfortable Room	Chaos Dragon Original Soundtrack	5	0:00 - 0:45	https://www.youtube.com/watch?v=mgd-yksiGvc	2015
10	3f	Hitoshi Sakimoto	Lou's Theme	Chaos Dragon Original Soundtrack	11	0:32 - 1:17	https://www.youtube.com/watch?v=mgd-yksiGvc	2015
Low valence, Low arousal								
1	3g	Kow Otani	Track 10	Another Original Soundtrack	10	0:30 - 1:15	https://www.youtube.com/watch?v=uBolNvfq6OE&list=PLd2KLqwPHc2vr7XtOa59EE7BLZDZHY80v&index=10	2012

Appendix A-3 (cont'd). List of Japanese animation Original Soundtracks (OSTs)

No	Musical Excerpt ID	Composer	Track Name	Album Name	Track No.	Min:Sec	Youtube Link	Date of release
High valence, High arousal								
1	1c	Tatsuya Kato	Shokugeki Start!	Shokugeki no soma OST 1	30	1:54 - 2:39	https://www.youtube.com/watch?v=iZd99_wxiOA	2015
2	1d	Hiroyuki Sawano	Exorcist Concerto Second Movement: X	Blue Exorcist OST 1	2	2:53 - 3:38	https://www.youtube.com/watch?v=0tIAO8LZc0Q	2011
3	2c	Yasuharu Takanashi	Fairy Tail Main Theme	Fairy Tail OST 1	1	1:15 - 2:00	https://www.youtube.com/watch?v=cjnl3lfaoEo	2010
4	2d	Yuki Hayashi	Plus Ultra	My Hero Academia OST	18	0:00 - 0:45	https://www.youtube.com/watch?v=FvPWLLzHrSA	2016
5	2e	Hijiri Anze	Welcome! To Emerald Editing Group	Sekai-ichi Hatsukoi OST 1	8	0:30 - 1:17	https://www.youtube.com/watch?v=EmbauT11Pic&t=8s	2011
6	2f	Yuki Hayashi	Akaruku genki ni (Bright and Cheerfully)	My Hero Academia OST	19	0:00 - 0:45	https://www.youtube.com/watch?v=Tdcm9KL9ZTg	2016
7	3h	Masaru Yokoyama	Isla	Plastic Memories Original Soundtrack Vol. 1	6	1:00 - 1:45	https://www.youtube.com/watch?v=4XjejmAVUEE	2015
8	3i	Yasuharu Takanashi	"Log Horizon" Main Theme	LogHorizon	1	1:46 - 2:35	https://www.youtube.com/watch?v=czuVPFUc5Ns	2014

Appendix A-3 (cont'd). List of Japanese animation Original Soundtracks (OSTs)

No	Musical Excerpt ID	Composer	Track Name	Album Name	Track No.	Min:Sec	Youtube Link	Date of release
High valence, Low arousal								
1	2g	Yukari Hashimoto	After school without a plan	Gekkan Shojo Nozaki Kun Vol. 4	1	0:53 - 1:39	https://www.youtube.com/watch?v=XgSAn658Lyo	2014
2	3j	Masaru Yokoyama	Bye	Plastic Memories Original Soundtrack Vol. 1	8	0:45 - 1:30	https://www.youtube.com/watch?v=4XjejmAVUEE	2015
3	3k	REMEDIOS	Dynamic Sunset	Anohana: The Flower We Saw That Day	3	2:02 - 2:47	https://www.youtube.com/watch?v=bUz3n90O04E	2011
4	3l	S.E.N.S. Project	Story of Mind	Ore Monogatari (My Love Story) Original Soundtrack	7	1:03 - 1:48	https://www.youtube.com/watch?v=OcEorer4yx4	2015
5	1e	Yuki Hayashi	Shousha to Haisha (The Victors and The Defeated)	Haikyuu!! OST 2	10	1:13 - 1:58	https://www.youtube.com/watch?v=rhp4MbnjH9Y	2014
6	1f	Hijiri Anse	Hitori Ja Nai (Not alone)	Hybrid Child OST	30	0:24 - 1:19	https://www.youtube.com/watch?v=ICyqxGCr2ek	2015
7	1g	Hasegawa Tomoki	Kizutstuite mo (In spite of the wound)	NANA 707 Soundtracks	28	0:38 - 1:23	https://www.youtube.com/watch?v=tMqdZyWfTlU&t=23s	2006
8	1h	Hasegawa Tomoki	Kotayaka na Asa (A peaceful morning)	NANA 707 Soundtracks	5	0:12 - 0:57	https://www.youtube.com/watch?v=kBQgxzLJb38	2006
9	3m	Masaru Yokoyama	Memories	Plastic Memories Original Soundtrack Vol. 1	1	1:01 - 1:54	https://www.youtube.com/watch?v=4XjejmAVUEE	2015
10	3n	Yasuharu Takanashi	Shukumei	Fairy Tail Original Soundtrack Vol. 1	14	0:03 - 0:48	https://www.youtube.com/watch?v=KjlTmJQsceY	2012

Notes. Final selection of musical excerpts is highlighted in blue.

Appendix A-4. List of Greek folk songs selected from the Greek Music Dataset (Makris et al., 2015)

No.	Musical Excerpt ID	Composer	Track Name	Min:Sec	Youtube Link
High arousal					
1	4a	Tolhs Voskopoulos	H valitsa	0:00 - 0:22	http://www.youtube.com/watch?v=Jez0DQRaxWk
2	4b	Giwrgos Ntalaras	Alla mou len ta matia sou	0:00 - 0:23	http://www.youtube.com/watch?v=PVibsgTbKKI
3	4c	Tolhs Voskopoulos	Edw kai kamposo kairo	0:00 - 0:30	http://www.youtube.com/watch?v=RLTC8Q8veUc
4	4d	Mixalhs Violarhs	Zakynthinia mou komissa	0:03 - 0:23	http://www.youtube.com/watch?v=vKxrdPo6ayo
5	4e	Pasxalhs Terzhs	Egw ton theo mou	0:00 - 0:19	http://www.youtube.com/watch?v=UOYX5xVTqyI
6	4f	Xaris Aleksiou	Ax tha mazepsw dynamh	2:41 - 3:19	http://www.youtube.com/watch?v=KaKNZ15RxuI
7	4g	Nikos Ksylourhs	Egw thn eixa thn kardia	0:00 - 0:15	http://www.youtube.com/watch?v=qCCmLVEJPdQ
8	4h	Nikos Papazoglou	Andora-Korsikh-Xania	0:00 - 0:27	http://www.youtube.com/watch?v=lsaGwXv1EzA
9	4i	Giwrgos Ntalaras	As pan, sthn eyxh ta palia	0:00 - 0:26	http://www.youtube.com/watch?v=K3cUR9XvaCM
10	4j	Stamaths Kokotas	Me ti kardia na arnithw	1:44 - 2:29	http://www.youtube.com/watch?v=hcnYIWipiz0
Low arousal					
1	4k	Anna Vissi	Sagapw	0:02 - 0:35	http://www.youtube.com/watch?v=e_m-qFxuCDs
2	4l	Pantelhs Thalassinos	Ta smyrneika tragoudia	0:34 - 1:13	http://www.youtube.com/watch?v=9IbN9NKHTLM
3	4m	Margarita Zorbala	Margarita Magiopoula	0:00 - 0:24	http://www.youtube.com/watch?v=3rPaehCyhWU
4	4n	Maria Dhmhtriadh	To treno feugei stis 8	0:00 - 0:41	http://www.youtube.com/watch?v=CbVJ4tMB8Bw
5	4o	Giwrgos Ntalaras	Giorth zeimpekidwn	0:00 - 0:29	http://www.youtube.com/watch?v=Ov_-0rODj8o
6	4p	Melina Kana	Alkoolika stixakia	0:00 - 0:38	http://www.youtube.com/watch?v=IjJEHXHUjSQ
7	4q	Vicky Mosxoliou	Harami	0:00 - 0:20	http://www.youtube.com/watch?v=Aq368WxaYho
8	4r	Giwrgos Ntalaras	To prwto peristeri	0:00 - 0:23	http://www.youtube.com/watch?v=hxxcJQJ7AKw

Notes. Final selection of musical excerpts is highlighted in blue.

Appendix A-5. Dual Axis Rating and Media Annotation (DARMA)

DARMA is a computer software that can be used for continuous measurement of responses (Girard & Wright, 2018). Continuous ratings may be provided in response to media synchronized with the software. These ratings are provided along two dimensions that can be changed according to the study (Fig. 1). In the current study, participants provided continuous emotion ratings for music along the dimensions of emotional arousal and valence.

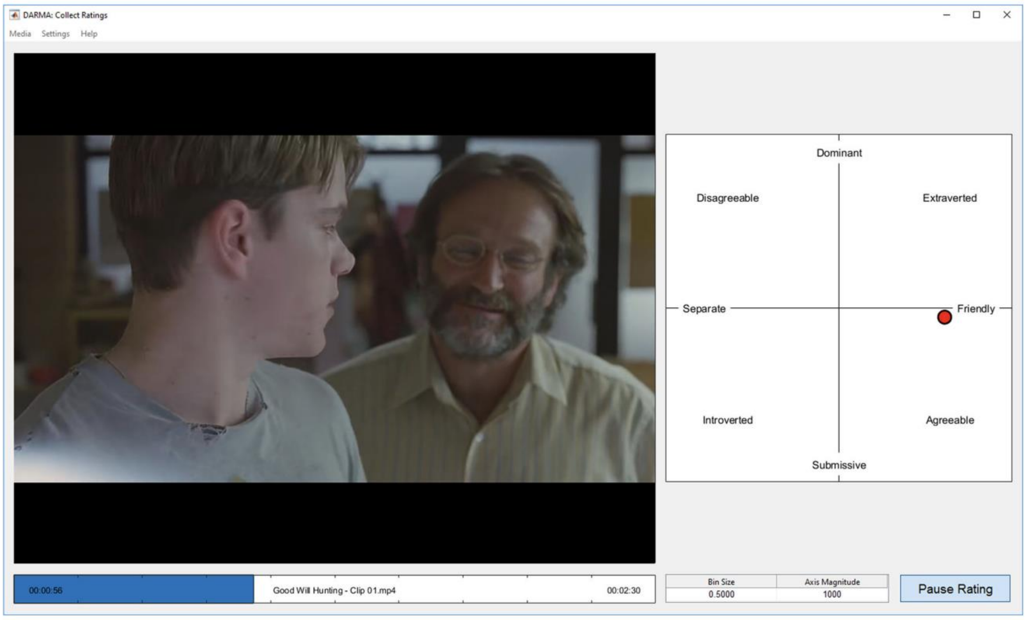
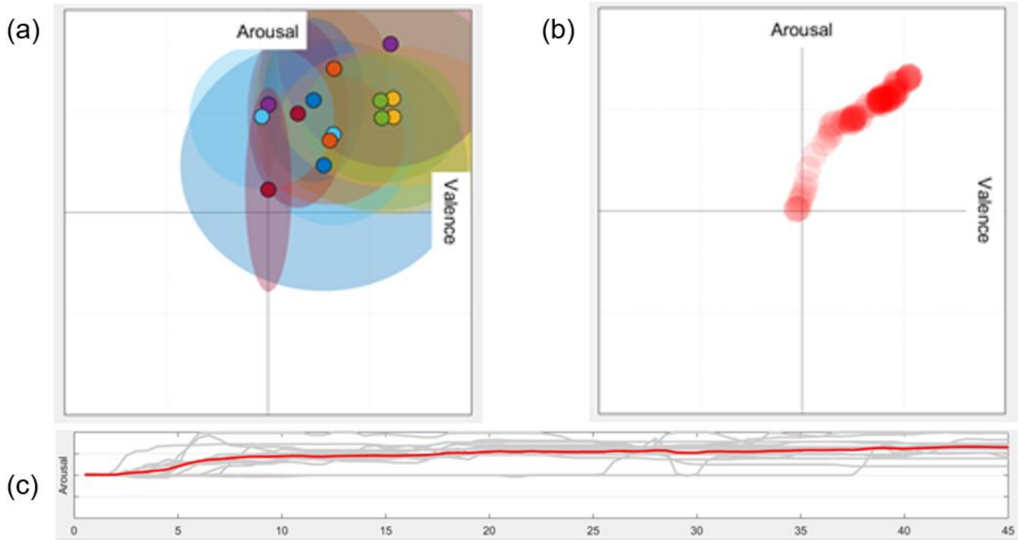


Fig. 1. DARMA window during continuous rating in response to synchronized video file. The x-axis and y-axis represent the two dimensions along which the continuous ratings are provided. *Adapted* from Girard & Wright (2018).

Appendix A-6. Example Emotion Rating of a Musical Excerpt using DARMA



(a) Each dot represents an individual's rating on the two-dimensional valence-arousal space. The shaded space represents the variation of the individual's rating for this musical excerpt. (b) Averaged rating of all participants. (c) Graphical representation of arousal ratings for the whole music excerpt (0 to 45 seconds). Red line represents the averaged arousal rating. Grey lines represent individual ratings.

Appendix A-7. Emotion Rating Questionnaire in Study 1 (pilot behavioral study)

1. How did this music make you **feel**?

Please rate the intensity with which you felt each of the following feelings on a scale ranging from 1 (not at all) to 5 (very much)

	1	2	3	4	5
Happy	○	○	○	○	○
Fear	○	○	○	○	○
Anger	○	○	○	○	○
Surprise	○	○	○	○	○
Disgust	○	○	○	○	○
Sadness (Depressed, sorrowful)	○	○	○	○	○
Amazement (Feeling of wonder and happiness)	○	○	○	○	○
Solemn (Feeling of transcendence, inspiration)	○	○	○	○	○
Tenderness (Sensuality, affect, feeling of love)	○	○	○	○	○
Nostalgia (Dreamy, melancholic, sentimental feelings)	○	○	○	○	○
Calmness (Relaxation, serenity, meditativeness)	○	○	○	○	○
Power (Feeling strong, heroic, triumphant, energetic)	○	○	○	○	○
Joyful activation (Feels like dancing, bouncy feeling, animated, amused)	○	○	○	○	○
Tension (Nervous, impatient, irritated)	○	○	○	○	○

2. Have you heard this tune before?

◯ Definitely Not	◯ Probably Not	◯ Not sure	◯ Probably Yes	◯ Definitely Yes

3. Please indicate which of the following genre **best** fits the music.

◯ Blues	◯ Classical	◯ Dance/Electronic
◯ Folk	◯ Hip Hop/Rap	◯ Inspirational (including Religious)
◯ Metal	◯ Jazz	◯ Oldies
◯ Pop (including K-pop, J-pop)	◯ Rock	◯ Soundtrack/Theme songs (e.g. soundtracks of movies, TV series or animations)

◯ Others ______________________________________

4. Are you able to anticipate what is coming next in the music?

◯ Definitely Not	◯ Probably Not	◯ Not Sure	◯ Probably Yes	◯ Definitely Yes

5. Please rate how much you like this music on a scale of 1 (not at all) to 9 (very much).

	1	2	3	4	5	6	7	8	9
Level of liking	◯	◯	◯	◯	◯	◯	◯	◯	◯

Appendix A-8. Demographics Questionnaire

Welcome Message

Thank you for participating in this study.

This survey will be asking about your personal background, music background as well as cultural identity. It would take approximately 7 minutes to complete. Should you have any questions, please do not hesitate to ask the researcher.

[IRB approval no.: IRB-2015-09-012-6]

Personal Information

Please enter your 3 digit participant code

The experimenter may re-contact me to invite me to return for additional research studies relating to today's study.

- I DO give consent
- I DO NOT give consent

Please provide your email address. For students in their final year, preferably a non-NTU email.

The experimenter may re-contact me to invite me to participate in other future studies, maintaining a locked copy of my personally-identifying information. I note that future research using the data collected will be related to this research and will be subjected to the approval of an Institutional Review Board.

- I DO give consent
- I DO NOT give consent

Please provide your email address. For students in their final year, preferably a non-NTU email.

This next set of questions are to collect information about your music background. Please answer the questions as accurately as possible.

Music Background

Have you received formal musical training besides music lessons in primary and secondary schools?

*Formal musical training: attended private music lessons

- ◯ Yes
- ◯ No

Please state the musical instrument(s) which you play. If you only play one instrument, please leave the fields for Instrument No. 2 and No. 3 empty.

	Instrument No. 1	Instrument No. 2	Instrument No. 3
Name of Instrument			
Age of commencement			
Highest certification obtained			
Are you still playing this instrument?			
If **Yes**, please state the amount of time spent playing this instrument (hours/week)			
If **No**, please state the age at which you stopped playing this instrument			

Do you play any musical instruments (e.g. guitar, piano) through informal training (e.g. self-taught, learnt from a friend etc.)?

- ◯ Yes
- ◯ No

Please indicate the instrument which you play and the corresponding level of proficiency.

	Level of Proficiency		
	Basic	Intermediate	Advanced
Name of Instrument ______	○	○	○
Name of Instrument ______	○	○	○

Have you participated in music-related co-ciricular activities (CCA), such as playing in a band, orchestra or sung in a choir? If **YES**, please further elaborate if you are still currently active or have stopped participating in the stated activity.

	Yes / No		How many years were you involved in this activity?	Are you currently active in this activity?	
	Yes	No	Please indicate your response in years.	Yes	No
Band (Eg, Jam Band, Harmonica Band, Band Ensemble, Guitar Ensemble etc.)	☐	☐	______	☐	☐
Choir	☐	☐	______	☐	☐
Others (Please specify) ______	☐	☐	______	☐	☐

Do you have perfect/absolute pitch? (an ability of a person to identify or recreate a musical note without the benefit of an external reference)?

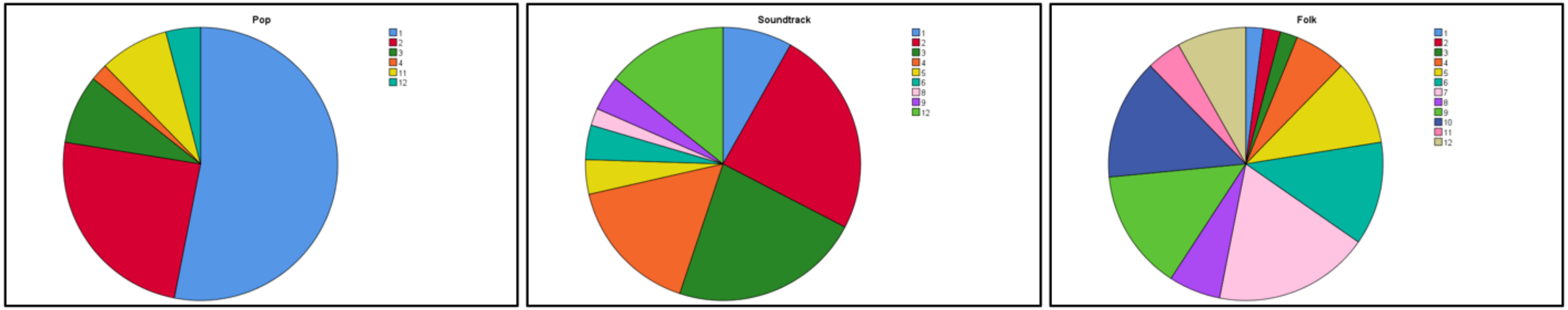
- ○ Definitely Yes
- ○ Probably Yes
- ○ Not sure
- ○ Probably No
- ○ Definitely No

Appendix B

MATERIALS FOR CHAPTER IV

Study 2A: Clarifying the Electrophysiological Correlates of Music-evoked Emotions

Appendix B-1. Listening Trends Among Participants in EEG Experiment



Notes. Participants ranked the music genre they most frequently listened to (*n* = 49). Depicted in the figure are for music genres related to the current dissertation: Pop, Soundtrack, Folk music. ***Left: Pop music.*** A majority of participants ranked Pop music as the most frequently listened to music genre. ***Middle: Soundtrack.*** A majority of participants ranked Soundtrack as the third or fourth most frequently listened to genre out of a list of 12 music genres. ***Right: Folk music.*** A majority of participants ranked Folk music as the sixth or seventh most frequently listened to genre out of a list of 12 music genres.

Appendix B-2. Baseline Mood Measure: Abbreviated Profile of Mood States (POMS)

Abbreviated POMS (Revised Version)

Name: ______________________________ Date:

Below is a list of words that describe feelings people have. Please **CIRCLE THE NUMBER THAT BEST DESCRIBES HOW YOU FEEL RIGHT NOW**.

	Not At All	A Little	Moderately	Quite a lot	Extremely
Tense	0	1	2	3	4
Angry	0	1	2	3	4
Worn Out	0	1	2	3	4
Unhappy	0	1	2	3	4
Proud	0	1	2	3	4
Lively	0	1	2	3	4
Confused	0	1	2	3	4
Sad	0	1	2	3	4
Active	0	1	2	3	4
On-edge	0	1	2	3	4
Grouchy	0	1	2	3	4
Ashamed	0	1	2	3	4
Energetic	0	1	2	3	4
Hopeless	0	1	2	3	4
Uneasy	0	1	2	3	4
Restless	0	1	2	3	4
Unable to concentrate	0	1	2	3	4
Fatigued	0	1	2	3	4
Competent	0	1	2	3	4
Annoyed	0	1	2	3	4
Discouraged	0	1	2	3	4
Resentful	0	1	2	3	4
Nervous	0	1	2	3	4
Miserable	0	1	2	3	4

PLEASE CONTINUE WITH THE ITEMS ON THE NEXT PAGE

	Not At All	A Little	Moderately	Quite a lot	Extremely
Confident	0	1	2	3	4
Bitter	0	1	2	3	4
Exhausted	0	1	2	3	4
Anxious	0	1	2	3	4
Helpless	0	1	2	3	4
Weary	0	1	2	3	4
Satisfied	0	1	2	3	4
Bewildered	0	1	2	3	4
Furious	0	1	2	3	4
Full of Pep	0	1	2	3	4
Worthless	0	1	2	3	4
Forgetful	0	1	2	3	4
Vigorous	0	1	2	3	4
Uncertain about things	0	1	2	3	4
Bushed	0	1	2	3	4
Embarrassed	0	1	2	3	4

THANK YOU FOR YOUR COOPERATION

PLEASE BE SURE YOU HAVE ANSWERED EVERY ITEM

Appendix B-3. Emotion Rating Questionnaire Used in EEG Experiment

INTRODUCTION

Participant ID

Welcome to the experiment.

You will be listening to a series of music clips. As you listen, you will be using this system to provide ratings of how the music makes you ***feel***.

Do not describe the music (e.g. the music is happy) or what the music may be expressing (e.g. this music expresses happiness).

Keep in mind that a music can be happy or can sound happy without making you feel happy.

How did this music make you **feel**?

Please rate the intensity with which you felt each of the following feelings on a scale ranging from 1 to 9.

Unpleasant				Neutral				Pleasant
1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

How did this music make you **feel**?

Please rate the intensity with which you felt each of the following feelings on a scale ranging from 1 to 9.

Very Passive				Neutral				Very Active
1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

How did this music make you ***feel***?

Please rate the intensity with which you felt each of the following feelings on a scale ranging from 1 (not at all) to 5 (very much).

	Not at all				Very much
	1	2	3	4	5
Happy	○	○	○	○	○
Fear	○	○	○	○	○
Anger	○	○	○	○	○
Surprise	○	○	○	○	○
Disgust	○	○	○	○	○
Sadness (Depressed, sorrowful)	○	○	○	○	○
Amazement (Feeling of wonder and happiness)	○	○	○	○	○
Solemn (Feeling of transcendence, inspiration)	○	○	○	○	○
Tenderness (Sensuality, affect, feeling of love)	○	○	○	○	○
Nostalgia (Dreamy, melancholic, sentimental feelings)	○	○	○	○	○
Calmness (Relaxation, serenity, meditativeness)	○	○	○	○	○
Power (Feeling strong, heroic, triumphant, energetic)	○	○	○	○	○
Joyful activation (Feels like dancing, bouncy feeling, animated, amused)	○	○	○	○	○
Tension (Nervous, impatient, irritated)	○	○	○	○	○

Have you heard this tune before?

- Definitely Not
- Probably Not
- Not sure
- Probably Yes
- Definitely Yes

Are you able to anticipate what is coming next in the music?

- Definitely Not
- Probably Not
- Not Sure
- Probably Yes
- Definitely Yes

Please rate how much you like this music on a scale of 1 (not at all) to 9 (very much).

	Not at all								Very much
	1	2	3	4	5	6	7	8	9
Level of liking	O	O	O	O	O	O	O	O	O

Please rest for a while.

Appendix B-4. Informed Consent Form used in EEG Experiment

Study Information sheet

Name of PI: Professor S. H. Annabel CHEN

Institution and contact details:
Psychology, Nanyang Technological University
14 Nanyang Drive, HSS-04-19
Singapore 637332
Tel: +65 6316 8836 / Fax: +65 6795 5797

IRB reference number: IRB-2015-09-012

Title of Study: Investigating the EEG signatures underlying music listening

Objective: The purpose of this research is to understand how the brain processes emotions during music listening, which will contribute to developments of music and technology applications. Approximately 110 participants, aged between 21 – 40 years old, will be recruited for this study.

Procedures: If you decide to participate, you will be asked to undergo **one** EEG session at Wee Kim Wee School of Communication and Information, NTU. Your participation in the EEG session will be approximately 2.5 hours.

Electroencephalography (EEG) and Electrodermal (EDA) Recording
To prepare you for the EEG recording, the experimenter will place electrodes on your head. These electrodes will be filled with an electrolyte gel. The experimenter will clean the corresponding surface position on the scalp with skin preparation gel before placing the electrodes on your head. These electrodes are made of small metal disks and do not penetrate the skin. In addition to the electrodes in the cap, up to 10 individual electrodes may be attached directly to the skin (nose tip, above and below one eye, the left and right temple, left and right mastoid, palms, forearms) using double sided electrode tape. The electrodes are used to measure the electrical activity of your brain during the experimental condition. Positioning of the electrodes will take about 30 minutes, but in some cases may take longer.

To prepare you for the EDA recording, you will wear a wristband (which is identical to a digital watch) on your wrist. This device passes a very small electric current through the skin and measures how it is conducted in the skin. This electric charge is too small to produce noticeable changes or affect your body in any way.

Thereafter, you will be asked to perform auditory listening tasks while EEG and EDA measurements are being recorded. There will be regular breaks between the tasks.

Auditory Cognitive Tasks and Questionnaires

After the EEG and EDA recordings, you will complete auditory computerized tasks that measure musical preferences and music perception skills, as well as questionnaires on musical background/experience and personality.

Right to Refuse or Withdraw: Your participation in the study is completely voluntary. If you do decide to participate, it is important that you complete the tasks to the best of your ability. At any time, during the study, if you no longer wish to participate, you may withdraw by informing the experimenter. Your decision to participate, decline, or withdraw from the study will have no consequence on your status or relationship with NTU. At the discretion of the Principal Investigator, participants may be taken out of this study due to unanticipated circumstances. This might occur, for example, if you are unable to perform the task, or if your EEG signal contains artifacts due to motion or other causes.

Risks and Discomforts: The EEG neuroimaging technique is commonly used in cognitive experiments to understand neural functions and this technique is non-invasive. The measurement of electrodermal activity is a technique commonly used to measure peripheral arousal in behavioral experiments, and the technique is non-invasive. Techniques used to attach EEG and the measurement of electrodermal activity have been used at numerous research institutions for many years with no significantly negative side effects reported.

However, it should be noted that the application of electrolyte gel in the discs is sometimes sticky and the discs may scratch a little. There is a remote possibility of skin irritation from the gel application when cleaning the surface of the scalp and attaching the electrodes. If this occurs with discomfort, we will discontinue the experiment and the gel will be washed off immediately. Another potential discomfort during the experiment is the stress related to performing some mental task under time constraints. However, this stress is not more intensive than what is experienced during a pen-and-paper test of mental abilities.

Benefits: There is no direct benefit to you in participating in this study. However, knowledge gained as a result of your participation will facilitate further research in the field that has the potential for intervention methodologies designed to improve learning by emotion regulation.

Alternatives: Participants who are obtaining course credits have the alternative not to participate by completing an assignment provided by their course instructors.

Compensation: As compensation for your time and inconvenience, you will receive *either*

- ☐ Up to 5 credits for research participation, *or*
- ☐ $25 cash payment

upon completion of the study. If you do not complete the study for any reason, credits or cash payment will not be made to you.

Anonymous and Confidential Data Collection: Information collected for this study will be kept confidential.

Confidentiality of records: Information collected for this study will be kept confidential. Any data that may be published in scientific journals will not reveal the identity of the subjects. Only the principal investigator and members of the research team will have access to your identifying information (e.g. names, contact numbers, addresses and email addresses) and this will not be released to any other person. All your identifiable health information and research data will be coded (i.e. only identified with a code number) at the earliest possible stage of the research. All data collected will be kept indefinitely in a coded form, without personal identifying information (your name, DOB, etc). Personal identifying information will be stored separately in locked files. The personal identifying information will be destroyed at the completion of the study, unless you agree that we may keep it so that we may re-contact you for future studies. The Institutional Review Board for Nanyang Technological University, for example, may inspect research records and learn your identity if this study falls within its jurisdiction.

Personal Data:

By signing the Consent Form attached, you (*or your legally acceptable representative, if relevant*) are authorizing (i) collection, access to, use and storage of your "Personal Data", and (ii) disclosure to, and use and storage by, authorised service providers and relevant third parties, whether located in Singapore or overseas, for the purposes of the study.

"**Personal Data**" means data about you which makes you identifiable: (i) from such data; or (ii) from that data and other information which an organization has or likely to have access. Research arising in the future, based on this "Personal Data", will be subject to review by the relevant institutional review board. Data collected are the property of Nanyang Technological University. In the event of any publication regarding this study, your identity will remain confidential.

Who to contact with questions: If you have questions about this research study, you may contact the Overall Principal Investigator, Prof. S. H. Annabel Chen at:

Tel (direct line): 6316-8836, Email: annabelchen@ntu.edu.sg.

Should you have questions on participants' rights in the study, please contact:

NTU-Institutional Review Board
Research Integrity and Ethics Office
50 Nanyang Avenue, North Spine
NS4-05-92A
Singapore 639798
Email: irb@ntu.edu.sg

Consent Form

I have read, discussed and understand the information and procedures in the study information sheet attached to this consent form. My questions concerning the study have been answered to my satisfaction, and I acknowledge that I am participating in this study of my own free will. I understand that I may refuse to participate or stop participating at any time.

Consent to participate in the research

☐ Yes, I agree to participate in this research.

☐ No, I do not agree to participate in this research.

I **agree / do not agree*** that the data collected from today's study could be used for future related research.

I **agree / do not agree*** that the experimenter may re-contact me to invite me to participate in other future studies, maintaining a locked copy of my personally-identifying information. I note that future research using the data collected will be related to this research and will be subject to the approval of an Institutional Review Board.

* please encircle as appropriate

________________________ ______________________________

Name of Participant Signature Date

Appendix B-5. Summary of EEG Findings for Emotional Valence

Table S4-1: Music condition as predictor [JPN_Fear (unpleasant) vs JPN_Power (pleasant)]

	β	S.E.	*t*-statistic	*p*-value
(a) Theta band				
Frontal	0.059	0.034	1.75	.08
Parietal	0.06	0.037	1.63	.10
Temporal	0.068	0.037	1.84	.07
Occipital	0.074	0.043	1.73	.09
(b) Alpha band				
Frontal ^	0.13	0.063	2.04	.04
Parietal	0.11	0.063	1.77	.08
Temporal ^	0.14	0.057	2.4	.02
Occipital ^	0.16	0.072	2.17	.03
(c) Beta band				
Frontal	0.061	0.035	1.73	.09
Parietal	0.048	0.032	1.47	.14
Temporal	0.0056	0.034	0.16	.87
Occipital	0.045	0.038	1.18	.24

Notes. ^ $p < .05$. No regression analyses are significant at Bonferroni-corrected $\alpha = .0125$.

Table S4-2: Hemisphere as predictor [left vs right]

	β	S.E.	*t*-statistic	*p*-value
(a) Theta band				
Frontal	-0.018	0.009	-1.86	.07
Parietal *	0.069	0.015	4.75	.001
Temporal	0.019	0.022	0.85	.40
Occipital *	-0.045	0.013	-3.47	.001
(b) Alpha band				
Frontal *	-0.032	0.012	-2.65	.009
Parietal *	0.15	0.023	6.54	.001
Temporal *	0.13	0.029	4.46	.001
Occipital	-0.03	0.020	-1.51	.13
(c) Beta band				
Frontal	0.012	0.020	0.62	.53
Parietal *	0.046	0.015	3.10	.002
Temporal	0.0033	0.033	0.01	.92
Occipital	-0.023	0.021	-1.11	.27

Notes. * $p < .01$. These effects remain statistically significant at Bonferroni-corrected $\alpha = .0125$.

Appendix B-5 (cont'd). Summary of EEG Findings for Emotional Valence

Table S4-3: Interaction effects (music condition x hemisphere)

	β	S.E.	*t*-statistic	*p*-value
(a) Theta band				
Frontal	-0.0008	0.0055	-0.15	.88
Parietal	-0.0022	0.0043	-0.52	.60
Temporal	-0.0078	0.0096	-0.81	.42
Occipital	-0.0014	0.0074	-0.19	.85
(b) Alpha band				
Frontal	-0.0055	0.0049	-1.13	.26
Parietal	-0.0041	0.0066	-0.62	.54
Temporal	0.01	0.0067	-1.52	.13
Occipital	-0.013	0.0073	-1.85	.07
(c) Beta band				
Frontal	0.002	0.010	0.21	.83
Parietal	-0.0078	0.009	-0.89	.38
Temporal	-0.0049	0.013	-0.39	.70
Occipital	-0.0033	0.006	-0.54	.59

Notes. No significant interaction effects at Bonferroni-corrected $\alpha = .0125$.

Table S4-4: Summary of EEG findings for Emotional Valence

Contrast: JPN_Power (pleasant) > JPN_Fear (unpleasant)								
	Brain Region				**Hemispheric Asymmetry**			
Frequency band	Frontal	Temporal	Parietal	Occipital	Frontal	Temporal	Parietal	Occipital
Alpha	(+ve) > (-ve) ^	(+ve) > (-ve) ^	(n.s.)	(+ve) > (-ve) ^	L > R *	R > L *	R > L *	(n.s.)
Beta	(n.s.)	(n.s.)	(n.s.)	(n.s.)	(n.s.)	(n.s.)	R > L *	(n.s.)
Theta	(n.s.)	(n.s.)	(n.s.)	(n.s.)	(n.s.)	(n.s.)	R > L *	L > R *
Frontal midline theta	(n.s.)							

Notes. ^ p < .05 , * p <.01

Appendix B-6. Comparisons of Asymmetry Index (AI) for Emotional Valence

Table S4-5: Paired *t*-tests of Asymmetry Index (AI) for music conditions JPN_Power (pleasant) and JPN_Fear (unpleasant)

	t-statistic	*p*-value	Mean difference	95% Confidence Interval	
				Lower	Upper
(a) Alpha band					
Frontal	1.5	.14	0.016	-0.006	0.038
Parietal	0.69	.50	0.009	-0.178	0.036
Temporal	1.54	.13	0.022	-0.007	0.050
Occipital	1.92	.06	0.031	-0.002	0.064
(b) Theta band					
Frontal	0.12	.91	0.001	-0.023	0.025
Parietal	0.57	.58	0.005	-0.013	0.023
Temporal	0.79	.44	0.017	-0.026	0.060
Occipital	0.32	.75	0.005	-0.028	0.038
(c) Beta band					
Frontal	0.4	.70	-0.008	-0.051	0.034
Parietal	0.88	.38	0.017	-0.022	0.057
Temporal	0.51	.61	0.013	-0.040	0.067
Occipital	0.74	.46	0.001	-0.017	0.036

Notes. Paired *t*-tests were not significant at Bonferroni-corrected $\alpha = .0125$.

Table S4-6: Main effects of music condition [JPN_Power (high arousal; active) vs JPN_Nostalgia (low arousal; passive)]

	F-value	*p*-value	partial eta-squared	Mean difference	95% Confidence Interval	
					Lower	Upper
(a) Theta band						
Frontal	1.02	.32	.021	0.008	-0.008	0.024
Parietal	0.65	.42	.013	-0.005	-0.018	0.008
Temporal	2.94	.09	.058	-0.012	-0.026	0.002
Occipital	1.89	.18	.038	-0.010	-0.024	0.004
(b) Alpha band						
Frontal	0.91	.35	.019	-0.011	-0.034	0.012
Parietal	3.72	.06	.072	-0.018	-0.036	0.001
Temporal	3.22	.08	.063	-0.016	-0.034	0.002
Occipital	2.47	.12	.049	-0.015	-0.004	0.035
(c) Beta band						
Frontal ^	4.09	.049	.079	0.031	0.000	0.062
Parietal	2.88	.96	.057	0.015	-0.003	0.033
Temporal	3.71	.06	.072	0.025	-0.001	0.051
Occipital	1.09	.30	.022	0.008	-0.007	0.023

Notes. ^ $p < .05$. This effect did not remain statistically significant at Bonferroni-corrected $\alpha = .0125$

Table S4-7: Main effects of hemisphere in music conditions JPN_Power and JPN_Nostalgia.

	F-value	*p*-value	partial eta-squared	Mean difference	95% Confidence Interval	
					Lower	Upper
(a) Theta band						
Frontal ^	5.97	.02	.11	0.022	0.004	0.041
Parietal *	19.39	.001	.29	-0.068	-0.098	-0.037
Temporal	0.49	.49	.01	-0.016	-0.063	0.030
Occipital *	12.49	.001	.21	0.046	0.020	0.710
(b) Alpha band						
Frontal *	8.89	.004	.16	0.037	0.012	0.062
Parietal *	46.21	.001	.49	-0.144	-0.187	-0.102
Temporal *	19.13	.001	.29	-0.119	-0.174	-0.065
Occipital ^	6.67	.01	.12	0.046	-0.100	0.082
(c) Beta band						
Frontal	0.65	.43	.01	-0.015	-0.052	0.022
Parietal *	9.61	.003	.17	0.015	-0.003	0.033
Temporal	0.03	.87	.001	-0.005	-0.069	0.059
Occipital	2.1	.15	.04	0.029	-0.011	0.069

Notes. ^ $p < .05$, * $p < .01$

Table S4-8: Interaction effects (music condition x hemisphere)

	F-value	*p*-value	partial eta-squared
(a) Theta band			
Frontal	2.62	.11	.052
Parietal	0.12	.74	.002
Temporal	2.65	.11	.052
Occipital	0.054	.82	.001
(b) Alpha band			
Frontal	0.64	.64	.005
Parietal	0.13	.72	.003
Temporal	0.037	.85	.001
Occipital	0.6	.44	.012
(c) Beta band			
Frontal	0.022	.88	.001
Parietal	1.37	.25	.028
Temporal	1.89	.18	.038
Occipital	0.29	.59	.006

Notes. No significant interaction effects at Bonferroni-corrected $\alpha = .0125$.

Table S4-9: Summary of EEG findings for Emotional Arousal

Contrast: JPN_Power (high arousal; active) > JPN_Nostalgia (low arousal; passive)								
	Brain Region				**Hemispheric Asymmetry**			
Frequency band	Frontal	Temporal	Parietal	Occipital	Frontal	Temporal	Parietal	Occipital
Alpha	(n.s.)	(n.s.)	(n.s.)	(n.s.)	L > R *	R > L *	R > L *	L > R ^
Beta	High > Low ^	(n.s.)	(n.s.)	(n.s.)	(n.s.)	(n.s.)	R > L *	(n.s.)
Theta	(n.s.)	(n.s.)	(n.s.)	(n.s.)	L > R ^	(n.s.)	R > L *	L > R *

Notes. ^ $p < .05$, * $p < .01$

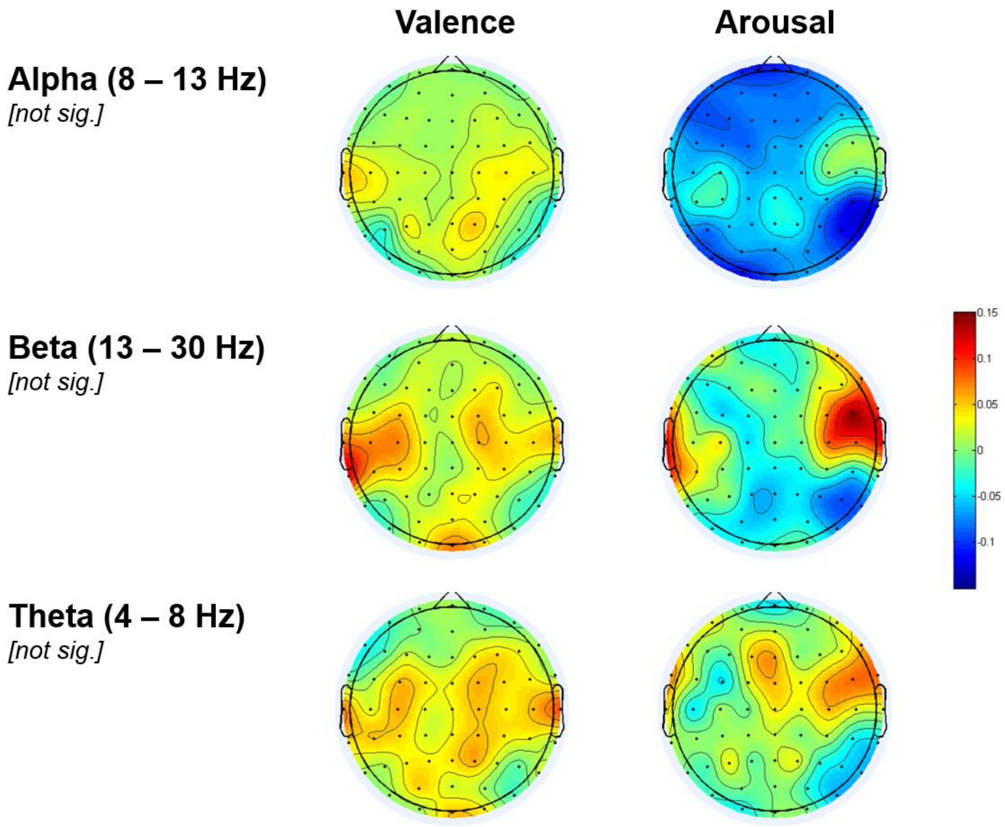
Appendix B-8. Comparisons of Asymmetry Index (AI) for Emotional Arousal

Table S4-10: Paired *t*-tests of Asymmetry Index (AI) for music conditions JPN_Power (active; high arousal) and JPN_Nostalgia (passive; low arousal)

	t-statistic	*p*-value	Mean difference	95% Confidence Interval	
				Lower	Upper
(a) Alpha band					
Frontal	-0.74	.46	-0.008	-0.029	0.013
Parietal	0.094	.93	0.001	-0.021	0.023
Temporal	-0.31	.76	-0.003	-0.026	0.019
Occipital	0.85	.40	0.015	-0.021	0.051
(b) Theta band					
Frontal	1.61	.11	0.018	-0.005	0.041
Parietal	-0.44	.66	-0.005	-0.025	0.016
Temporal	-1.59	.12	-0.023	-0.051	0.006
Occipital	-0.35	.73	-0.005	-0.036	0.025
(c) Beta band					
Frontal	0.013	.99	-0.0002	-0.031	0.031
Parietal	-1.31	.20	-0.025	-0.064	0.014
Temporal	-1.64	.11	-0.035	-0.079	0.008
Occipital	0.51	.61	0.010	-0.030	0.050

Notes. Paired t-tests were not significant at Bonferroni-corrected $\alpha = .0125$.

Appendix B-9. Topographic Maps of Spearman Correlations between Power Spectra from Each Frequency Band and Emotion Ratings



Topographic plots of Spearman correlations with valence and arousal ratings. For all frequency bands, log EEG power from all scalp channels was not significantly correlated with valence or arousal ratings with false discovery rate (FDR) corrected $p < .05$.

Appendix B-10. Spearman Correlations of Emotion Rating with log EEG Spectral Power and Asymmetry Index of Each Brain Region

Table S4-10: Spearman correlations between log EEG spectral power of brain regions and emotion rating

		Valence		**Arousal**	
		Correlation Coefficient	*p*-adj	Correlation Coefficient	*p*-adj
(a) Alpha band					
Frontal	Left	.007	1.00	-.087	.70
	Right	.012	1.00	-.067	.46
	Total	.005	1.00	-.079	.68
Parietal	Left	.004	1.00	-.059	.48
	Right	.020	1.00	-.077	.53
	Total	.013	1.00	-.074	.50
Occipital	Left	.000	.99	-.100	1.00
	Right	.009	1.00	-.078	.60
	Total	.007	1.00	-.090	.83
Temporal	Left	.009	1.00	-.069	.49
	Right	-.017	1.00	-.092	1.00
	Total	.001	1.00	-.094	1.00
(b) Beta band					
Frontal	Left	.036	1.00	-.017	1.00
	Right	.032	1.00	.066	1.00
	Total	.039	1.00	.054	0.78
Parietal	Left	.040	1.00	.004	.96
	Right	.032	1.00	-.027	.99
	Total	.035	1.00	-.011	.98
Occipital	Left	.020	.81	-.056	1.00
	Right	.027	.82	-.056	.86
	Total	.030	.86	-.057	1.00
Temporal	Left	.048	1.00	.128	1.00
	Right	.032	.93	.076	1.00
	Total	.045	1.00	.114	1.00

Notes. p-values are FDR-corrected at $\alpha < .05$ according to the Benjamini-Hochberg (1995) method: $P_{BH} = P_i \cdot (\frac{N}{rank_i})$

Table S4-10 (cont'd): Spearman correlations between log EEG spectral power of brain regions and emotion rating

		Valence		**Arousal**	
		Correlation Coefficient	*p*-adj	Correlation Coefficient	*p*-adj
(c) Theta band					
Frontal	Left	.010	.91	.005	1.00
	Right	.036	1.00	.027	1.00
	FMT	.020	.95	.048	1.00
	Total	.025	.99	.011	1.00
Parietal	Left	.041	1.00	.001	.99
	Right	.030	1.00	-.010	1.00
	Total	.042	1.00	-.009	1.00
Occipital	Left	.029	1.00	-.026	1.00
	Right	.013	.95	-.024	1.00
	Total	.027	1.00	-.017	1.00
Temporal	Left	.033	1.00	.021	1.00
	Right	.034	1.00	-.039	1.00
	Total	.048	1.00	-.019	1.00

Notes. FMT = Frontal midline theta. *p*-values are FDR-corrected at $\alpha < .05$ according to the Benjamini-Hochberg (1995) method: $P_{BH} = P_i \cdot (\frac{N}{rank_i})$

Appendix B-10 (cont'd). Spearman Correlations of Emotion Rating with log EEG Spectral Power and Asymmetry Index of Each Brain Region

Table S4-11: Spearman correlations between Asymmetry Index (AI) of each brain region and emotion rating

	Valence		**Arousal**	
	Correlation Coefficient	*p*-value	Correlation Coefficient	*p*-value
(a) Alpha band				
Frontal AI	.068	.41	.147	.08
Parietal AI	.007	.93	-.108	.20
Occipital AI	.004	.97	.049	.56
Temporal AI	-.058	.49	-.052	.54
(b) Beta band				
Frontal AI	.080	.34	.130	.12
Parietal AI	-.030	.72	-.090	.28
Occipital AI	-.005	.95	-.016	.85
Temporal AI	-.047	.57	-.016	.85
(c) Theta band				
Frontal AI	.104	.21	.044	.60
Parietal AI	.024	.77	-.048	.56
Occipital AI	-.024	.77	-.019	.82
Temporal AI	.006	.94	-.084	.31

Notes. No correlations are significant at Bonferroni-corrected $\alpha = .0125$.

Appendix C

MATERIALS FOR CHAPTER V

Study 2B: Effects of Familiarity with Musical Style on Music-evoked Emotions

Table S5-1: Main effects of music condition [JPN_Nostalgia (familiar) vs GRK_Nostalgia (unfamiliar)]

	F-value	*p*-value	partial eta-squared	Mean difference	95% Confidence Interval	
					Lower	Upper
(a) Theta band						
Frontal *	36.64	.001	0.43	-0.15	-0.19	-0.10
Parietal *	17.01	.001	0.26	-0.08	-0.11	-0.04
Temporal *	16.28	.001	0.25	-0.09	-0.14	-0.05
Occipital *	21.485	.001	0.31	-0.07	-0.09	-0.04
(b) Alpha band						
Frontal *	8.98	.004	0.16	-0.07	-0.11	-0.02
Parietal ^	4.65	.04	0.09	-0.04	-0.08	-0.003
Temporal ^	4.42	.04	0.09	-0.05	-0.09	-0.002
Occipital ^	5.83	.02	0.11	-0.04	-0.08	-0.007
(c) Beta band						
Frontal *	8.56	.01	0.15	-0.09	-0.15	-0.03
Parietal ^	5.2	.03	0.098	-0.05	-0.09	-0.005
Temporal *	7.82	.01	0.14	-0.08	-0.14	-0.02
Occipital *	7.27	.01	0.13	-0.04	-0.06	-0.01

Notes. ^ $p < .05$, * $p < .01$

Table S5-2: Main effects of hemisphere [left vs right]

	F-value	*p*-value	partial eta-squared	Mean difference	95% Confidence Interval	
					Lower	Upper
(a) Theta band						
Frontal *	12.24	.001	0.20	0.03	0.01	0.04
Parietal *	29.42	.001	0.38	-0.07	-0.10	-0.04
Temporal	0.074	.79	0.002	-0.005	-0.05	0.03
Occipital *	18.84	.001	0.28	0.05	0.03	0.07
(b) Alpha band						
Frontal *	11.85	.001	0.20	0.04	0.02	0.06
Parietal *	59.12	.001	0.55	-0.15	-0.19	-0.11
Temporal *	19.99	.001	0.29	-0.12	-0.17	-0.06
Occipital *	7.9	.007	0.14	0.05	0.014	0.08
(c) Beta band						
Frontal	0.56	.46	0.01	-0.01	-0.04	0.02
Parietal *	15.03	.001	0.24	-0.05	-0.07	-0.02
Temporal	0.069	.80	0.001	-0.007	-0.06	0.05
Occipital	2.81	.10	0.06	0.03	-0.006	0.07

Notes. * $p < .01$

Table S5-3: Interaction effects (music condition x hemisphere)

	F-value	*p*-value	partial eta-squared
(a) Theta band			
Frontal	0.12	.73	.003
Parietal	0.12	.73	.003
Temporal	1.91	.17	.038
Occipital	0.94	.34	.019
(b) Alpha band			
Frontal	.001	.98	.001
Parietal	0.84	.36	.020
Temporal	0.35	.56	.010
Occipital	0.03	.86	.001
(c) Beta band			
Frontal	0.32	.57	.007
Parietal	0.13	.73	.003
Temporal	0.18	.67	.004
Occipital	0.01	.92	.001

Notes. No significant interaction effects at Bonferroni-corrected $\alpha = .0125$.

Table S5-4: Summary of EEG findings for familiarity with musical style

Contrast: JPN_Nostalgia (familiar) > GRK_Nostalgia (unfamiliar)								
	Brain Region				**Hemispheric Asymmetry**			
Frequency band	Frontal	Temporal	Parietal	Occipital	Frontal	Temporal	Parietal	Occipital
Alpha	Unfamiliar > Familiar *	Unfamiliar > Familiar *	Unfamiliar > Familiar *	Unfamiliar > Familiar *	L > R **	R > L ***	R > L ***	L > R *
Beta	Unfamiliar > Familiar **	Unfamiliar > Familiar **	Unfamiliar > Familiar *	Unfamiliar > Familiar **	(n.s.)	(n.s.)	R > L ***	(n.s.)
Theta	Unfamiliar > Familiar ***	Unfamiliar > Familiar ***	Unfamiliar > Familiar ***	Unfamiliar > Familiar ***	L > R **	(n.s.)	R > L ***	L > R ***
Frontal midline theta	Unfamiliar > Familiar ***							

Notes. * $p < .05$, ** $p < .01$, *** $p < .001$

Appendix C-2. Comparisons of Asymmetry Index for Familiarity with Musical Style.

Table S5-5: Paired t-tests of Asymmetry Index (AI) for music conditions JPN_Nostalgia (familiar musical style) and GRK_Nostalgia (unfamiliar musical style)

	t-statistic	*p*-value	Mean difference	95% Confidence Interval	
				Lower	Upper
(a) Alpha band					
Frontal	-0.02	.98	-0.0004	-0.042	0.041
Parietal	-0.86	.40	-0.019	-0.063	0.025
Temporal	0.52	.61	0.019	-0.054	0.091
Occipital	-0.18	.86	-0.004	-0.051	0.042
(b) Theta band					
Frontal	-0.46	.65	-0.009	-0.051	0.032
Parietal	-0.30	.77	-0.008	-0.059	0.044
Temporal	1.45	.15	0.071	-0.027	0.170
Occipital	0.98	.33	0.023	-0.024	0.070
(c) Beta band					
Frontal	0.39	.70	0.013	-0.054	0.079
Parietal	0.38	.71	0.011	-0.049	0.071
Temporal	0.52	.60	0.027	-0.077	0.131
Occipital	-0.12	.91	-0.003	-0.056	0.050

Notes. Paired t-tests were not significant at Bonferroni-corrected $\alpha = .0125$.

Appendix D

MATERIALS FOR CHAPTER VI

Study 2C: Role of Absorption Trait in Music-evoked Emotions

Appendix D-1. Absorption in Music Scale (AIMS)

ABSORPTION IN MUSIC SCALE

Name:
Sex:

Date of Birth:
Date:

The following questions are about your experiences with music.

1. I will sometimes move my hand as if I were 'conducting' music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

2. When listening to music, I sometimes temporarily forget where I am

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

3. I sometimes feel like I am 'one' with the music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

4. When I listen to music I can get so caught up in it that I don't notice anything

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

5. When I feel that nobody understands me, I often turn on some music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

6. I will stop everything that I'm doing in order to listen to a special song/piece of music that is playing

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

7. I can imagine a song/piece of music so vividly that it holds my attention as if I were hearing it live

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

8. When I hear good music I tend to lose my train of thought and forget what I was thinking about

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

9. Sometimes when listening to music I feel as if my mind can understand the whole world

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

10. I sometimes feel that I understand the songwriter/composer's intentions completely

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

11. I can change almost any sound into music by the way I listen to it

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

12. I have stopped walking to listen to music that I came across on my path

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

13. While listening to music, I may become so involved that I may forget about myself and my surroundings

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

14. If I want to feel creative, I will turn on some music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

15. It is sometimes possible for me to be completely immersed in music and to feel as if my whole state of consciousness has been temporarily altered

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

16. I know what people mean when they talk about mind-altering musical experiences

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

17. At times when listening to music, I feel more connected with other people

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

18. I find that different sounds have different colors (e.g., red, blue)

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

19. I spend as much time as I can every day listening to music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

20. Sometimes music makes me feel and experience things as I did when I was a child

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

21. Sometimes I almost feel as if a song was written especially for/about me

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

22. I sometimes make my movements/actions (opening doors, pushing buttons, stepping of curbs) coincide with the music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

23. I like to find patterns in everyday sounds

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

24. When listening to music I can lose all sense of time

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

25. Before I do an activity (e.g., exercise, study), I usually carefully consider what music to play along with it

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

26. The sound of a speaking voice can be so fascinating to me that I can just go on listening to it

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

27. Music sometimes helps me 'step outside' my usual self and experience an entirely different state of being

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

28. When listening to music, I often imagine the musicians playing the songs

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

29. When listening to great music I sometimes feel as if I am being lifted into the air

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

30. When I am listening to music, I can tune out everything else

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

31. I sometimes see vivid images in my head when I listen to music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

32. I sometimes close my eyes so I can focus on the music I am listening to

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

33. There are times when I will do nothing except listen to music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

34. I sometimes feel like I'm part of something bigger than myself when I listen to music

1	2	3	4	5
Strongly Disagree	Somewhat Disagree	Neutral (Neither Agree nor Disagree)	Somewhat Agree	Strongly Agree

www.smartlaboratory.org/aims

Appendix D-2. Summary of Valence and Arousal Ratings for Each Music Condition in EEG Study

Music Condition	**Valence ratings** M (*SD*)	**Arousal ratings** M (*SD*)
JPN_Fear	3.49 (*2.03*) ^	5.38 (*1.72*) ^
JPN_Power	6.48 (*0.93*)	7.06 (*0.93*)
JPN_Nostalgia	6.74 (*1.52*) ^	4.34 (*1.56*)
GRK_Joy	6.54 (*0.87*)	6.65 (*0.96*)
GRK_Nostalgia	6.31 (*0.89*)	4.16 (*1.43*)

Notes. ^ variable is not normally distributed (p < .05 on Shapiro-Wilk test)

Appendix D-3. Pearson Correlations of Absorption Score with log EEG Spectral Power and Asymmetry Index of Each Brain Region

Table S6-1: Pearson correlation between log EEG spectral power of brain regions and absorption score (AIMS_total)

Music Condition: JPN_Nostalgia				**Music Condition: GRK_Nostalgia**	
		AIMS_total		AIMS_total	
		Correlation Coefficient	*p*-adj	Correlation Coefficient	*p*-adj
(a) Alpha band					
Frontal	Left	-.047	.89	-.091	1.00
	Right	-.046	.82	-.078	.79
	Total	-.049	.99	-.086	.96
Parietal	Left	-.086	1.00	-.089	1.00
	Right	-.033	.82	-.065	.72
	Total	-.052	1.00	-.076	.73
Occipital	Left	-.071	1.00	-.100	1.00
	Right	-.053	1.00	-.054	.71
	Total	-.064	1.00	-.082	.86
Temporal	Left	-.066	1.00	-.098	1.00
	Right	-.099	1.00	-.114	1.00
	Total	-.086	1.00	-.103	1.00
(b) Beta band					
Frontal	Left	-.100	1.00	-.135	1.00
	Right	-.014	.93	-.051	.97
	Total	-.058	.83	-.095	.89
Parietal	Left	-.115	1.00	-.113	1.00
	Right	-.092	1.00	-.203	1.00
	Total	-.103	1.00	-.165	1.00
Occipital	Left	-.064	.89	-.086	.84
	Right	-.119	1.00	-.118	1.00
	Total	-.094	1.00	-.099	.99
Temporal	Left	-.057	.76	-.015	.92
	Right	-.072	.93	-.036	.97
	Total	-.077	1.00	-.022	.96

Notes. p-values are FDR-corrected at $\alpha < .05$ according to the Benjamini-Hochberg (1995) method: $P_{BH} = P_i \cdot (\frac{N}{rank_i})$

Table S6-1 (cont'd): Pearson correlation between log EEG spectral power of brain regions and absorption score (AIMS_total)

Music Condition: JPN_Nostalgia				**Music Condition: GRK_Nostalgia**	
		AIMS_total		AIMS_total	
		Correlation Coefficient	*p*-adj	Correlation Coefficient	*p*-adj
(c) Theta band					
Frontal	Left	-.116	.79	-.195	1.00
	Right	-.089	.72	-.094	.68
	FMT	-.172	1.00	-.133	.52
	Total	-.104	.69	-.151	.65
Parietal	Left	-.152	1.00	-.139	.63
	Right	-.110	.73	-.160	.89
	Total	-.124	1.00	-.155	.75
Occipital	Left	-.072	.62	-.044	.91
	Right	-.074	.66	-.038	.79
	Total	-.076	.72	-.041	.85
Temporal	Left	-.151	1.00	-.135	.58
	Right	-.118	.91	-.180	1.00
	Total	-.149	.99	-.163	1.00

Notes. FMT = Frontal midline theta. *p*-values are FDR-corrected at $\alpha < .05$ according to the Benjamini-Hochberg (1995) method: $P_{BH} = P_i \cdot (\frac{N}{rank_i})$

Appendix D-3. Pearson Correlations of Absorption Score with log EEG Spectral Power and Asymmetry Index of Each Brain Region

Table S6-2: Pearson correlations between Asymmetry Index (AI) of each brain region and absorption score (AIMS_total)

Music Condition: JPN_Nostalgia			**Music Condition: GRK_Nostalgia**	
	AIMS_total		AIMS_total	
	Correlation Coefficient	*p*-value	Correlation Coefficient	*p*-value
(a) Alpha band				
Frontal AI	.009	.95	.067	.65
Parietal AI	.159	.28	.074	.61
Occipital AI	.091	.53	.178	.22
Temporal AI	-.100	.50	-.054	.71
(b) Beta band				
Frontal AI	.197	.17	.207	.16
Parietal AI	.036	.81	-.302	.04
Occipital AI	-.146	.32	-.082	.58
Temporal AI	-.016	.91	-.021	.88
(c) Theta band				
Frontal AI	.100	.49	.305	.03
Parietal AI	.056	.71	-.142	.33
Occipital AI	-.014	.93	.022	.88
Temporal AI	.066	.65	-.057	.70

Notes. No correlations are significant at Bonferroni-corrected α = .0125.