

**INDIVIDUAL DIFFERENCES IN AFFECTIVE AND COGNITIVE
PROCESSING OF MUSICAL PITCH**

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Master's Thesis

Music, Mind, and Technology

13.8.2012

University of Jyväskylä

JYVÄSKYLÄN YLIOPISTO

Tiedekunta – Faculty Humanities	Laitos – Department Music
Tekijä – Author David Ellison	
Työn nimi – Title Individual differences in affective and cognitive processing of musical pitch	
Oppiaine – Subject Music, Mind, and Technology	Työn laji – Level Master’s thesis
Aika – Month and year August 2012	Sivumäärä – Number of pages 42
<p>Tiivistelmä – Abstract</p> <p>Musical pitch processing has been studied extensively, but rarely in the context of affective pitch processing, or of individual differences in pitch processing. In this study, participants answered surveys measuring personality and empathy dimensions. They then listened to tonal chord sequences to determine whether they sounded correct or incorrect, and whether they sounded happy or sad, while electroencephalogram (EEG) was recorded. The last chord of each sequence could be either incorrect (containing one note which is out of tune) or correct (containing no such mistuning), and affective content was varied by having sequences resolve in major and minor modes. Personality dimension <i>agreeableness</i> correlated positively with the frequency of musical emotion ratings that agree with music theory. A number of other individual difference variables correlated with EEG amplitudes. Early (300-500ms) electrical brain responses differentiated major-mode, correctly tuned target chords from other target chords. Later (600-800ms, 900-1100ms, 1600-1800ms) electrical brain responses differentiated correctly and incorrectly tuned target chords. This study lends moderate evidence for systematic individual differences in pitch processing. Also, it appears as though the mode of mistuned target chords can modulate brain responses to tuning violations through either sensory or affective processes.</p>	
Asiasanat – Keywords	
Säilytyspaikka – Depository	
Muita tietoja – Additional information	

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1 PROBLEM STATEMENT

Pitch is an important feature of music all over the world. Although not all music relies on it, music which uses pitch to generate melodies is very widespread throughout humanity. Melodic music systems employ a clear set of discrete pitch classes and rules which dictate how they relate to each other and how they may be used together (Harwood, 1976). For example, the pitches used in one musical performance usually need to have a ratio among their frequencies such that no pitch sounds “out of tune”. In Western tonal music, these pitch relations are determined by the chromatic equal tempered scale. If a pitch is out of tune, listeners can usually notice it immediately, even listeners with no formal musical training. Appropriately, much research on the perceptual and cognitive brain processes that give rise to the experience of hearing music has focused on pitch processing.

Brain response data has seen much use in research on the processing of pitch. Primarily it is used in research on the formation and violation of tonality. Tonality is a system governing the relationships between notes in a musical piece, according to which one note serves as a central reference point and the other notes have hierarchical roles relative to this central, or *tonic*, note. Brain processes related to tonality, such as the establishment of a tonic note or the violation of the tonal hierarchy, are examples of what we will call *cognitive* pitch processing. Recently, however, researchers have pointed out that other, non-cognitive forms of pitch processing, such as *affective* processes, can be studied using brain response data as well (Koelsch, Fritz, von Cramon, Müller, & Friederici, 2006; Brattico, Jacobsen, de Baene, Glerean, & Tervaniemi, 2010). The degree of variability of these brain responses across individuals, however, is an issue which has not been researched much. A number of studies have linked individual differences in people's music listening behaviour and music perception with individual differences in other areas – areas such as personality (see Rentfrow & McDonald, 2009, for a review) and cognitive style (Kreutz, Schubert, & Mitchell, 2008). It is therefore reasonable to suppose that: a) music-related brain responses vary across people; b) there exist traits (dimensions of personality along which individuals vary, and which are

consistent over one's lifetime (Nettle & Nettle, 2007)) that influence music processing; and c) variations in brain responses correlate with differences in some traits relevant to music processing. These are hypotheses which should be considered as we work toward a model of musical pitch processing. The present study shall verify these hypotheses using a modification of an experimental paradigm from Brattico et al. (2010) that is able to discern between cognitive and affective listening processes.

Some researchers of differences in music listening have made the distinction between cognitive and affective modes of listening (Bharucha, Curtis, and Paroo, 2006; Chamorro-Premuzic and Furnham, 2007; Kreutz et al., 2008). The cognitive mode concerns such things as appreciating the structure or timbre of music, while the affective mode concerns using music for mood regulation or for empathizing with an artist. As stated earlier, these two listening modes have been investigated using brain response data, albeit very minimally in the case of the affective listening mode. Affective processing of nonmusical stimuli, has, however, been researched a fair amount (see section 2.1 or Brattico et al., 2010, for a review of brain imaging research on the cognitive and affective processing of stimuli). In any case, if we are to examine differences in brain processes among music listeners, a comparison of how people differ in cognitive versus affective processing would be an appropriate starting point.

The paradigm used in the present experiment had participants performing two types of listening task – one cognitive and one affective – while brain responses were recorded using electroencephalography (EEG). The present study employed this paradigm and a battery of individual difference questionnaires in order to investigate individual differences in cognitive and affective pitch processing. The goal was to observe whether processing differences correlate with established measures of individual difference. The following chapter will review background literature relevant to the topic at hand, the third chapter will describe and discuss the research methods used, the fourth chapter will state the results, and the fifth chapter will discuss the results.

2 LITERATURE REVIEW

2.1 Cognitive and affective modes of pitch processing

When people listen to music, there are various brain processes involved. These include processes that assess the temporal, tonal, timbral, and structural properties of the music – which we will call *cognitive* processing – as well as other processes, such as *affective* processing. Cognitive processing can, for example, allow us to implicitly notice when a note is out of key or out of rhythm – even in the absence of formal musical training – by building a musical context out of the incoming sound stream. In addition to this sort of grammatical understanding of the music, we make other types of assessment, such as evaluating its pleasantness. When we hear music, we know whether we like it or not, sometimes quite immediately. We can also perceive emotion in the music, and be affected emotionally by the music ourselves. These ways in which people feel and evaluate music are among the affective processes that occur during music listening. Affective processing will be contrasted with cognitive processing in this study.

The differences between cognitive and affective processing of stimuli have been described by some musical and non-musical research. Mandler and Shebo (1983) compared liking judgments of visually presented words and paintings to cognitive descriptive judgments. Participants' liking judgments of words were slower than judgments of whether the same words – or non-words – were real. Evaluation of paintings was also delayed relative to judgments of whether the participant had seen the painting before. Based on their findings, the authors argue that affective judgments require more complex processing of the same underlying representations as descriptive or recognition judgments. In the music domain, Gagnon and Peretz (2000) have found different brain lateralization effects associated with cognitive and affective appraisals of music, and Brattico et al. (2010) have associated different electrical brain responses with cognitive and affective listening modes and judgment strategies.

Some researchers have postulated theories of the music listening experience which make a distinction between cognitive and affective processing. To Bharucha, Curtis, and

Paroo (2006), for example, the concept of cognitive processing described in the present paper is analogous to the processing of what they call *structural domains*, while other brain processes related to music listening, including affective processes, deal with *non-structural domains*. The structural domains include knowledge of the sources of sound in the music – i.e., timbre and the information one can derive from it, such as what instrument is being played and how it is being played – and of structural features – pitch, time, and their derivative features, such as tonal centre and meter. The non-structural domains are higher-order features which are believed to depend on the processing of the structural domains. Although there could be others, Bharucha et al. (2006) name two non-structural domains: affect – i.e., emotions perceived in the music and emotions felt because of the music – and motion – e.g., whether and/or how the music inspires one to move (i.e., dance), or any abstract concepts of motion communicated by the music. The processing of these different domains gives rise to the conscious experience of hearing music and all it entails – enjoyment or distaste, a desire to dance or to change the station, etc. This theory has implications for the sources of individual differences in music listening, which will be discussed further in the next sub-chapter.

Cognitive processing of pitch has been studied by testing behavioural and brain responses to violations of musical pitch expectancies. The most often used example of the former would probably be Krumhansl's method of having participants rate the appropriateness of notes with respect to a preceding tonal context (1990). As for brain response data related to cognitive pitch processing, much of it has been gathered using the event-related potential (ERP) method. An ERP is an electrophysiological brain response to an event, such as the presentation of a stimulus. ERPs are measured using EEG, which measures electrical potential differences (or *voltages*) on the scalp over time. These voltage fluctuations are the result of ionic current flow within neurons. ERP studies aim to identify specific patterns of electrical activity – or *ERP components* – related to certain types of phenomena.

Research has converged in identifying two categories of ERP component elicited by musical rule violation: early negative potentials, and later, long-lasting, high-amplitude positive potentials. The known early responses to musical incongruity are the early right anterior negativity (ERAN) and the mismatch negativity (MMN). Both appear around 200 ms after the onset of a musical rule violation, and are highest in amplitude near the front of the scalp. The MMN occurs in response to a change in a repeating auditory stimulus (e.g., Näätänen, Gaillard, & Mäntysalo, 1978). The change can be simple, such as a sequence of

similar sounds being interrupted by a different sound, or more abstract, as in a sequence of notes creating a musical context which is then violated by a note which is not in key. When the MMN is elicited by violations of musical scale properties, it appears to originate mainly from the right auditory cortex (Brattico, 2006; Leino, Brattico, Tervaniemi, & Vuust, 2007). The ERAN, on the other hand, has been observed following chord successions which are unusual in the Western tonal harmony system (Koelsch, Gunter, Friederici, & Schröger, 2000). The ERAN is generated mainly in the prefrontal lobes. Some studies have shown a lateralization of the ERAN, but it seems to vary from right to bilateral in adults (Koelsch, Maess, Grossman, & Friederici, 2003), and bilateral to left in children (Koelsch, Grossman, Gunter, Hahne, Schröger, & Friederici, 2003).

Later positive potentials associated with musical incongruity are the P300 and the P600. These components are relatively long in duration and high in amplitude. The P300 peaks in parietal regions around 300 ms after the onset of a target tone in a discrimination task (e.g., Squires, Squires, & Hillyard, 1975), of an incongruous tone presented at the end of a melody (e.g., Verleger, 1990), or of an incongruous chord at the end of a cadence (Janata, 1995). The P600 is elicited primarily in occipital regions and has been observed in experiments involving active listening and context appropriateness evaluation (for a review, see Besson and Schön, 2003). It appears to represent the re-analysis of musical and linguistic sequences following an incongruity (Patel, Gibson, Ratner, Besson, & Holcomb, 1998).

Literature on the affective processing of pitch is quite scarce compared to cognitive processing. It mostly consists of studies comparing cognitive and affective processing of musical stimuli, as in the aforementioned research by Gagnon and Peretz (2000) and Brattico et al. (2010). Gagnon and Peretz conducted a monaural listening experiment in which participants rated the pleasantness and correctness of tonal and atonal melodies. By varying the listening ear and responding hand of the participants (right versus left) in order to test for left or right brain hemisphere advantages, the researchers found that rating the pleasantness of melodies involved predominantly the right hemisphere of the brain, whereas rating whether the same melodies sounded correct did not appear to demonstrate any brain lateralization. To this author's knowledge, the 2000 study of Gagnon and Peretz is the first to provide evidence for the dissociation of affective appreciation and cognitive judgment in music listening.

Similarly, Brattico et al. (2010) collected ERP data which differentiated cognitive and evaluative processes during music listening. Participants listened to five-chord cadences which ended with varying levels of congruity. One third of the cadences ended in a chord

which appropriately resolved the cadence according to Western music theory, one third ended in a chord which only mildly fit the tonal context, and one third ended in a chord which was very much out of key. Prior to the presentation of each cadence, participants were prompted to give either a liking rating or a correctness rating upon the termination of the cadence.

ERP recordings showed signs of different preparation for the two tasks prior to cadence offset. Negative ERP responses to chords in the cadence prior to the final chord were enhanced during the correctness rating task. The researchers offer two interpretations. The negative enhancement could be the well-established early negative difference (early Nd; Hillyard, Hink, Schwent, & Picton, 1973; Luo and Wei, 1999) and thus indicate working memory operations in the auditory system (Singhal and Fowler, 2005); or, it could be a contingent negative variation (CNV; Birbaumer, Elbert, Canavan, & Rockstroh, 1990), which tends to be observed during tasks in which a pre-cue stimulus gives the subjects information about the upcoming stimulus to which they must react in a certain way. Should this be an example of a CNV, its presence only during the cognitive task could reflect additional preparation being required by the non-musically-trained participants in performing this music-theory-related task.

What appeared to be a P600 was elicited by stimuli receiving negative answers in both tasks, with no differentiation between the tasks. Later, approximately 1200 ms after the onset of the ending chord, electric potentials were elicited in both tasks preceding negative responses, but for the liking task they were positive and for the correctness task they were negative. The researchers pointed out that the late negative response to the correctness task could be a late posterior negative slow wave (LPN), which is often observed when participants are performing recognition tasks (Johansson and Mecklinger, 2003). The late positive response to the liking task, on the other hand, could be an example of the oft-reported *late positive potential* (LPP) component.

The LPP is one of the best-documented affect-related ERP components. It appears to be involved in the evaluation of various stimuli. Cacioppo, Crites, Gardner, and Berntson (1994) had participants rate the valence of visually displayed words denoting personality traits while EEG was recorded. Brain responses were recorded in response to mildly and highly positive and negative traits which were presented in a stream of highly positive traits. Generally, the more negative, and thus inconsistent, the stimulus is, the higher is the amplitude of a LPP which was evoked primarily over centroparietal regions. Lateralization differences have been observed in LPPs elicited by descriptive versus evaluative tasks. In a

later study, Crites and Cacioppo (1996) presented participants with visual words denoting different foods which could be described as either vegetable or non-vegetable. An LPP was elicited both when participants made a *semantic categorization* of the food – rating whether it is a vegetable or not – and when they made an *evaluative categorization* – rating whether it is good or bad. LPPs elicited by evaluative categorization were stronger over the right hemisphere than the left hemisphere when compared with LPPs elicited by semantic categorization.

In an experiment by Jacobsen and Höfel (2003), participants made judgments of the symmetry and aesthetic beauty of graphic patterns. LPPs were elicited during both tasks, but during the aesthetic evaluation task it exhibited a lateralization to the right. In a picture-viewing study, Schupp, Cuthbert, Bradley, and Cacioppo (2000) found evidence that the LPP is larger in response to more intense affective stimuli than it is to more neutral stimuli. This could explain why in Brattico et al. (2010), a LPP was observed only when participants rated the stimuli negatively. The stimuli eliciting positive liking ratings were probably not enjoyed very intensely by the participants, because they were only sequences of five chords played unemotionally by a computer. The disliked stimuli, on the other hand, might have evoked slightly more intense feelings, as some of the stimuli which ended in incongruous chords might have sounded very unpleasant.

Since almost as early as the invention of the EEG itself, scientists have been suggesting that individual differences in measured brain activity could reflect stable, trait-like differences in psychological functioning. For example, a line of research starting with Lemere (1936) examines the relationship between individual differences in EEG and personality traits (Stenberg, 1994). The remainder of chapter 2 will establish the possible existence of certain traits in music processing and behaviour, which shall be examined in relation to ERP differences in the experiment.

2.2 Individual differences in music listening

Charles S. Myers in 1922 became one of the first psychologists to publish a study of individual differences in music listening. Fifteen participants listened to orchestral recordings on a gramophone and then relayed their thoughts on the pieces to the researcher. Each participant heard four or five pieces out of a total of six which were used for the experiment. Pieces were typically around ten minutes long. Myers noticed that often individual

participants had a tendency toward commenting on one particular aspect of the music. One participant, A., wrote chiefly about emotions she felt while listening, or emotions which were being expressed by the music, making such comments as the following: “I imagine I am going to die, as if life were just ebbing out.” “A great feeling of happiness, followed by expansion inside, leading to great excitement and breathlessness for a moment.” “It tried to be lighthearted, but was all the time very sad.” Another participant, C., made many references to “patterns”: “It falls into a pattern.” “It is the sequence of sounds of different pitch that makes the pattern.” “Then the pattern changed.” “Then came a pattern of different type.” Although Myers’s sample size was too small to make generalizations – two professional musicians, three amateur musicians, five nonmusician artists, and five other nonmusicians – he reports observing first of all that technically trained musicians adopted a critical attitude toward the musical material in their comments, secondly that the musical participants tended to associate the music with imagery and events, and thirdly that the three participants deemed to be the most unmusical did not associate the music with imagery or events.

What Myers's research illustrates well is that the experience of listening to music is subjective. Different people notice different aspects of the same music when they listen to it. Sometimes it may even seem as though they are not hearing the same thing. A theory of the processing of music should take into account the fact that different people can experience music differently, and it should be able to explain why they have different experiences.

More modern studies and theories have also dealt with the different ways people experience music when listening to it. As mentioned in the previous sub-chapter, Bharucha, Curtis, and Paroo (2006) divide music processing into two broad categories of processes: structural domain processing and non-structural domain processing. What they also suggest is that these domains can be processed either implicitly or explicitly, and this gives rise to two broad varieties of conscious musical experience: If the brain processes structural domains *explicitly* and other domains *implicitly*, the individual is listening to the music cognitively and is, for example, experiencing its structural features. If the brain processes structural domains *implicitly* and other domains *explicitly*, then the individual could be experiencing the affective content of the music, or its feeling of movement. This trade-off between implicit and explicit processing leads to the varieties of musical experiences people may have.

Whereas Bharucha et al. (2006) refer to varieties of musical experience, Chamorro-Premuzic and Furnham (2007) refer to *uses* of music. In a questionnaire study, they posited and found evidence for three general uses which music can serve when people listen to it –

music as emotion regulation, cognitive/rational music listening, and music as a background for other activities (such as social events or work). By cognitive/rational uses, the researchers denote listening to music in an intellectual way, such as evaluating a particular performance, analyzing the song structure, or examining the roles of different instruments. The authors point out, however, that there could be other uses of music than these. These are merely the uses which seemed plausible according to the pilot study, and which were then supported by principal component analysis of the questionnaire results. The pilot study involved interviewing 43 participants about when and why they listen to music. Neither the pilot nor study samples were representative of the world population, so these three reasons people listen to music do not necessarily encompass all the reasons anyone listens to music. The primary purpose of this study, however, was to determine whether different people are prone to different ways of using music, and whether these tendencies are related to other individual differences – namely general intelligence, tendency to pursue intellectual activities, and personality. The results will be detailed in the following sub-chapter, after an overview of personality research – both in general and in relation to music listening – has been given.

2.3 Personality and music listening

Personality has been studied scientifically since at least the early twentieth century, during the era of lexical theory (e.g. Allport & Odbert, 1936). Most modern theories of personality, however, have used a factor analysis approach to arrive at a set of independent dimensions, or factors, along which people's personalities can vary. Factor analysis has been used to study personality since at least the 1930's (Thurstone, 1934) but it was not until the 1990's that the psychological community reached some manner of consensus on a framework for describing and assessing personality. Now known as the Five-Factor Model (FFM) or the Big Five, the most reliable measure of personality was born out of hundreds of thousands of trait ratings made by about as many participants (for a review, see John & Srivastava, 1999). First postulated in 1961 (Tupes & Christal), the FFM has since undergone many revisions in order to evolve into what is regarded today as a very reliable scientific framework.

The FFM is a hierarchical model of personality which divides all traits that describe individual differences in people's personality into five broad categories. These categories are operationalized as bipolar dimensions such as extraversion versus introversion. These dimensions subsume a hierarchy of more specific facets like *sociability* and traits like

talkative or *outgoing*. The five personality dimensions are – if we refer to them by the name of one of the poles only – extraversion, agreeableness, conscientiousness, neuroticism, and openness to experience:

1. *Extraversion* is a tendency to experience positive emotions and be energetic when in the company of others. Sometimes referred to by its opposite pole, *introversion*.
2. *Agreeableness* is a tendency to be compassionate and cooperative
3. *Conscientiousness* is a tendency toward self-discipline, diligence, and desire for achievement
4. *Neuroticism* is a tendency to experience anger, anxiety, depression, or other unpleasant emotions. Sometimes referred to by its opposite pole, *emotional stability*.
5. *Openness to experience* – sometimes simply called *openness* – is a tendency to be open to and appreciate new experiences, emotion, adventure, creativity, and curiosity.

Recent studies have tended to use a revision of the Big Five from 1992 called the Neuroticism-Extraversion-Openness Personality Inventory, Revised (NEO-PI-R; Costa & McCrae) or a variation thereof. The NEO-PI-R can take forty-five minutes for a participant to complete. Although well-suited for endeavours in which personality assessment is the main aim, it is for this reason difficult to integrate it into a study involving other tasks and/or inventories that demand the participant's time as well. Shorter personality inventories using the Big Five framework have therefore been developed. Costa and McCrae themselves published a shortened version of the NEO-PI-R – the NEO Five Factor Inventory – in the same article as the original (1992). The NEO-FFI requires between ten and fifteen minutes to complete. Other tests can take as little as five minutes (44-item Big-Five Inventory (BFI); Benet-Martínez & John, 1998; John & Srivastava, 1999), or in the case of the Ten-Item Personality Inventory (TIPI; Gosling, Rentfrow, & Swann, 2003), even one minute.

The TIPI was created for use in tests in which there is not enough time for longer personality inventories, and their heightened accuracy is not required. The TIPI was based on Goldberg's (1992) list of unipolar and bipolar Big-Five markers, adjectives from the BFI, and John and Srivastava's (1999) Adjective Checklist Big-Five markers. It consists of just ten

items, each answerable by a seven-point Likert scale. Each item represents one pole of one of the five personality dimensions. There are thus two items per dimension. The items are pairs of adjectives describing the trait, which are separated by a comma and preceded by “I see myself as”. The TIPI essentially asks people directly about their personality in terms of the Big-Five trait dimensions. Although direct enquiry tends to be psychometrically weaker than longer, less direct measures, in the case of TIPI it has proven to be satisfactory. Gosling et al. (2003) demonstrated a sufficient convergence both between self- and observer ratings on the TIPI, as well as between the TIPI and other widely-used measures of the Big-Five framework according to self-, observer, and peer reports. The TIPI exhibits an adequate level of test-retest reliability. Patterns of external correlates of the TIPI are similar to those of the well-established and widely used BFI. Although these properties are slightly inferior to those of most widely-used Big-Five inventories, the researchers recommend the TIPI for situations where a brief measure is needed, personality is not the main aim, or the somewhat lesser psychometric properties of short measures can be tolerated.

Research on personality and music listening has concentrated on the link between the personality and the music preferences of the listener. This line of research has existed ever since Cattell theorized that music preferences could reveal unconscious aspects of personality which personality tests overlook (e.g., Cattell and Saunders, 1954). Since the 1990s, work in this area has mostly focused on the Big-Five personality dimensions and a wide range of musical styles. According to Rawlings and Ciancarelli (1997), people scoring high on *openness to experience* like a wide variety of music and extraverts tend to like “popular music”, a variable constructed via factor analysis which includes soundtrack music, top-40 dance music, and rap. McCown, Keiser, Mulhearn, and Williamson (1997) have found an association between high extraversion and psychoticism scores and music with exaggerated bass frequencies. Rentfrow and Gosling (2003) analyzed the music preferences of over 3500 people to establish four music preference dimensions: Reflective and Complex, Intense and Rebellious, Upbeat and Conventional, and Energetic and Rhythmic. Preference for Upbeat and Conventional music was positively related to extraversion and a conservative self-view. Reflective and Complex music was preferred by people who were more open to new experiences and who had higher IQ. Participants who possessed an athletic self-view preferred Intense and Rebellious music.

In addition to music preference, other aspects of music listening have been studied in conjunction with personality. According to a study by Vuoskoski and Eerola (2009),

personality traits appear to moderate the perception of emotions expressed by music. Participants who scored high on neuroticism on average rated musical excerpts as being sadder and tenser, while extraverted participants rated musical excerpts as being more positive. The previously mentioned study conducted by Chamorro-Premuzic and Furnham (2007) linked personality factors with differences in music listening behaviour. Participants (241 female, 100 male) completed a battery of self-report tests, including measures of general intelligence, personality factors, and one's preference for and tendency to engage in intellectual activities, as well as the Uses of Music Inventory designed for the study. Questionnaire data showed that respondents who were more open to new experiences, more intellectually engaged, or higher in IQ tended to use music in a cognitive way. When combined with the findings of Rentfrow and Gosling (2003) regarding the music preferences of individuals who score high on openness to experience and IQ, these results could suggest a link between cognitive music use and music which is complex and reflective. Respondents of Chamorro-Premuzic and Furnham (2007) who used music emotionally, on the other hand, were more likely to be more neurotic, more introverted, or less conscientious. There were no significant gender or age differences in any of the three uses of music, nor were there significant personality–gender or personality–age interactions. The lack of gender differences is surprising when one considers some of the literature which will be reviewed in section 2.4.

2.4 Gender, cognitive style, empathy, and music

In addition to personality, another topic that is often addressed in the psychological literature on individual differences is that of gender or psychological sex differences. Males and females seem to differ psychologically in a number of ways, be it due to nature or to nurture (for a review, see Baron-Cohen, 2003), and when a psychological phenomenon is being researched, often scientists endeavour to discover whether it differs between men and women. Music processing is one such phenomenon.

Two papers from the Max Planck Institute of Cognitive Neuroscience point toward differences between males and females in the processing of the structural domains of music. In the first (Koelsch, Maess, et al., 2003), the researchers re-analyzed ERP data from three previous experiments in which harmonic violations in third or fifth position of a five-chord sequence elicited ERAN brain responses. The data originated from 62 participants (31 male). Sex differences were found which consisted of the predominant appearance of the ERAN in

the right hemisphere in the brains of male participants, as opposed to its even distribution between both hemispheres in the brains of female participants. This different hemispheric weighting is similar to the gender difference found in the activation of language functions in the inferior frontolateral cortex, which is where the ERAN is suggested to be generated (Maess, Koelsch, Gunter, & Friederici, 2001). Language functions in this area are more bilaterally distributed in women while they tend to be more lateralized in men (Kansaku, Yamaura, & Kitazawa, 2000); however, with language this lateralization is toward the left side of the brain, whereas with musical harmony violation, the lateralization is toward the right.

In the latter of the two studies (Koelsch, Grossmann, et al., 2003), the authors found that there are sex differences in harmony processing even in children as young as age five. The researchers measured ERPs elicited in five- ($n = 14$, 7 boys) and nine-year-old ($n = 14$, 7 boys) children by musical chord sequences similar to the ones used in the aforementioned study by Koelsch, Maess, et al. (2003). In line with said research on adults, girls' brains elicited an early bilateral-anterior negativity in response to the inappropriate chords, but whereas an early right-anterior negativity has been observed in adult males, in boys this component was elicited predominantly by the left side of the brain. These responses also only occurred when the inappropriate harmony was in the final, fifth position of the sequence, and not when it was in third position. In conclusion, not only are there sex differences in the hemispheric weighting of cognitive music processing in children and adults, there are also age-related, or developmental stage, differences. Interestingly, the lateralization of the ERAN in children is similar to the regions involved in language processing in children and adults. The authors interpret this to possibly mean that language and music could be processed more similarly in childhood. This finding has implications for the hypotheses of a common evolutionary origin of language and music, and the role music plays in language acquisition.

What such observations about sex differences in brain function distribution mean with respect to the subjective experience of listening to music is a complicated issue that remains to be seen, but some unrelated research into the differences in music listening behaviour between males and females could begin to illuminate this topic. Saarikallio (2006) conducted a survey of 1515 Finnish adolescents which reported that girls used music for mood regulation more than boys. This finding is moderately supported by Wells and Hakanen (1991), who found that adolescent girls were somewhat more likely than adolescent boys to associate emotions with music and to use music for emotional regulation. Saarikallio (2006)

also found a positive correlation between greater use of music in mood regulation and the variables of musical background activity level, attention to one's feelings, and ability to reappraise one's emotional experiences. Older adolescents were also more likely to use music as mood regulation than were younger adolescents. These findings somewhat contradict those of Chamorro-Premuzic and Furnham (2007), who also studied the use of music as emotional regulation. They found no effect of gender on tendency toward a certain way of using music; however, these two studies used different inventories for assessing one's use of music for mood regulation, and they studied different populations.

The above studies have found relationships between gender and either music listening behaviour or brain responses to musical stimuli; however, it would be short-sighted to view these differences as the direct product of biological sex. Instead we should pose the question of whether such differences in music processing are the product of differences in cognitive style which correlate with biological sex. To shed some light on the general links between music, gender, cognitive style, brain morphology, and subjective experience, we will for a moment turn to the line of research on psychological sex differences introduced by Baron-Cohen (2003). The idea that males and females are psychologically different is a controversial one, but Baron-Cohen points out that a great deal of contemporary research has made it difficult to ignore the fact that there are, on average, significant differences between the ways males and females of our species think and behave, and that these differences are not exclusively due to socialization (2003). That is not to say, however, that all men have one cognitive style and all women have another, but rather that males and females, on average, may differ on some traits.

According to empathizer-systemizer (E-S) theory (Baron-Cohen, 2002; 2003), there exists a two-dimensional spectrum of cognitive styles with one dimension called empathizing and the other dimension called systemizing. Individuals with a cognitive style high on the empathizing dimension (empathizers) are good at understanding the mental or emotional states of other people and, from there, predicting their behaviour. People with a cognitive style high on the systemizing dimension (systemizers), on the other hand, are good at understanding and predicting *systems* rather than people, a system being anything that is governed by rules in a clear and relatively reliable way, and which follows the underlying process of "input → operation → output". Females tend to be empathizers and males tend to be systemizers. One's cognitive style is an innate trait determined by brain morphology. E-S theory is an expansion of Baron-Cohen's extreme male brain theory of autism (Baron-Cohen,

2002), according to which the autistic brain is an extreme form of the male brain. In other words, that which makes the typical male brain different from the typical female brain (more systemizing and less empathizing) is even more prominent in the brains of people with autism. A deficiency in empathy has long been recognized as one of the principal symptoms of autism.

Nettle (2007) tested whether empathizing and systemizing could explain reported sex differences in interests and social behaviour, such as greater interest in technology among males and greater interest in aesthetic domains – such as literature, theatre, and music – among females (Twenge, 1999). Nettle replicated these findings, but not when using scores on measures of empathizing (EQ) and systemizing (SQ) as variables instead of gender. While SQ was found to entirely account for sex differences in interest in technology, neither the female advantage on EQ nor the male advantage on SQ could explain women's greater interest in aesthetic domains. Nettle believes this indicates that empathizing and systemizing are not the only factors having a role in some psychological sex differences.

In response, Kreutz, Schubert, and Mitchell (2008) suggest that perhaps both empathizers and systemizers are equally attracted to aesthetic domains, but for different reasons. They hypothesise that systemizers (and thus the average male) attribute higher significance to music, art, and literature if technical aspects are considered, while empathizers (and thus the average female) attribute higher significance to such matters if emotional aspects are considered. The researchers thus postulated two independent dimensions of music processing based on the empathizer and systemizer traits: music empathizing (ME) and music systemizing (MS). ME individuals may see music as a means of communicating one's mental state and thus they tend to focus on and be affected by emotional aspects of music. They empathize with the composer or performer. MS individuals, on the other hand, would see music as part of a system (e.g., the systems of music theory or playing technique) and thus they tend to focus on its structural and mathematical aspects. One need look no further than the previously mentioned Myers (1922) study for examples of these cognitive styles of music listening. Participant A. made many references to perceived and felt emotions, while participant C. would often allude to patterns. Another participant, G., was preoccupied with the sound quality of the gramophone and wanted to "pick out the instruments of the orchestra".

Kreutz et al. (2008) demonstrated the presence of ME and MS with two survey studies. The questionnaire used in the first study – called the Music-empathizing-systemizing

inventory – was adapted from the short version of the general E-S inventory (Wakabayashi et al., 2006) and contains eight items from the original plus 44 items which describe the meaning of empathizing and systemizing in the music domain. For the second study, the music-empathizing-systemizing inventory was shortened to 18 items. In both studies, males scored higher on MS than did females, but only in study 1 did females score higher on the ME than males. This is reasonably congruent with E-S theory. There was also an effect of musical background, but this effect was not consistent between studies. In study 1, professional musicians scored significantly higher on MS than did amateur musicians, who in turn scored significantly higher than did nonmusicians. There was no effect of musical background on ME. In study 2, professional and amateur musicians did not differ from each other in MS, but both groups were higher in MS than nonmusicians. Professional musicians scored higher on ME than amateur musicians, who scored higher than nonmusicians. These results appear to suggest that both ME and MS increase with musical experience, but as the authors say, the effects are too inconsistent to draw a conclusion.

In the terms of Bharucha et al. (2006), music empathizers might be people who tend to process affect explicitly and structure implicitly, while systemizers might be more likely to process structure explicitly and affect implicitly. Chamorro-Premuzic and Furnham (2007) might say that music empathizers use music emotionally and music systemizers use music cognitively. In fact, they found that people who were more intellectually engaged were more likely to use music in a cognitive way, which could be seen as evidence that there are people with a more systemizing cognitive style who tend to appreciate music for its structural and systematic elements. On the other hand, they did not find gender differences between emotional and cognitive users of music, whereas Kreutz et al. (2008) did find sex differences between music empathizers and music systemizers, so there must be some differences between these constructs.

E-S theory is relatively new, and ME-MS theory even newer. Measures related to these theories are still undergoing validation. The dimension of empathizing, however, is much older than the theory, as the empathizing quotient is intended to measure general empathy by taking into account both cognitive and affective empathy (Baron-Cohen and Wheelwright, 2004; Baron-Cohen, 2009); however, it does not distinguish between the two types of empathy in the final score. Many psychology researchers see empathy as consisting of two components: cognitive and affective empathy (Davis, 1983; Baron-Cohen, 2003).

Cognitive empathy is the ability to understand the perspective of someone else, and affective empathy is the emotional reaction to the affective state of someone else.

One of the most widely-used and thoroughly validated empathy measurement tools is the interpersonal reactivity index (IRI; Davis, 1980; 1983). *Interpersonal reactivity* is essentially another term for empathy, if one conceptualizes empathy as consisting of four separate but related constructs. The IRI is able to separately measure not only cognitive and affective empathy, but also two subscales of each: respectively, perspective taking (PT) and fantasy (FS), and empathic concern (EC) and personal distress (PD). Each is measured with seven items, which participants answer using five-point Likert scales. PT assesses one's tendency to adopt the point of view of other people when interacting with them; FS measures one's tendency to imagine oneself in fictional situations; EC measures the tendency to feel concern for other people who are in unfortunate situations; and PD assesses the tendency to experience distress in response to the distress of others. In a 2004 paper about the development of the empathizing quotient, Baron-Cohen and Wheelwright themselves said that “the IRI is the best measure of empathy developed to date”, but suspected that some of the items did not directly assess empathy, instead assessing other phenomena related to empathy, such as imagination and mood regulation. Nevertheless, the present study used the IRI to investigate the possible relation between empathy and pitch processing.

2.5 Present study

The present study followed the methodology used by Brattico et al. (2010), with two modifications. First, individual differences in pitch processing were examined by assessing participants' personality dimensions and interpersonal reactivity, and comparing them to individual differences in the behavioural and neurophysiological responses. Secondly, a different affective task was used which is more closely related to interpersonal reactivity than the liking evaluation of the previous study. Participants were asked which emotion they perceive more in the cadences, and given the options of either happiness or sadness. In addition to allowing us to study the relationship between interpersonal reactivity and affective processing, this new task should let us see whether a different type of affective process – emotion perception – can also be differentiated from cognitive processing using ERP analysis, and whether it displays patterns similar to those of the evaluative affective task used previously; however, in the present paper, ERP differences during the preparation for the two

different tasks will not be reported. Should further analyses reveal any such differences, they will be reported elsewhere.

The stimuli were modified to fit the new affective task. In Brattico et al. (2010), the final chords in the stimulus cadences sometimes consisted of notes that were incongruous with the musical key, in order to create experimental conditions in which the final chord would be unexpected given the preceding tonal context. In both that experiment and the present experiment, these inappropriate stimuli were used in both the cognitive and affective tasks, as were the appropriate stimuli which contained no sound expectancy violations. Given the new affective task, ending chords that were off-key could no longer be used, because it would have been difficult to compose cadences which both a) contained an off-key chord and b) could be interpreted as expressing a positive emotion. Instead, half the stimuli were made to end on a chord containing one note which was out of tune by -30 cents (30% of a semitone). This way, expectancy-violating endings for the cadences were created which still resembled the other endings that resolved the cadences correctly. The cadences resolved in major and minor modes in order to vary the affective content of the stimuli using musical pitch. The major mode has been found to be associated with the expression of positive emotions, and the minor mode with negative emotions (e.g., Pinchot Castner & Crowder, 1990). For the purpose of ERP averaging, the stimuli were divided into four categories according to the characteristics of their ending chords: major-key endings containing one detuned note (henceforth called *major mistuned* stimuli), major-key endings containing no detuned notes (major in-tune), minor-key endings containing one detuned note (minor mistuned), and minor-key endings containing no detuned notes (minor in-tune).

Leino et al. (2007) found that distinct ERP responses were elicited in participants by harmonically incongruous (off-key) but correctly tuned chords in a cadence, versus harmonically congruous (in-key) chords which contained mistuned notes. The former consisted of a bilateral early anterior negativity whose amplitude depended on the degree of harmonic incongruity (ERAN), while the latter elicited a bilateral fronto-central negativity (MMN). Since the present study used chords which contained mistuned notes but were otherwise congruous, it was expected that there would be a MMN in response to the mistuned stimuli and/or the stimuli which were rated as ending incorrectly. At the time of writing this, ERPs from the present experiment have not been averaged according to participant responses, but they will be at a later date. In the present paper, only the effects of cadence ending type on ERP waveforms are reported. According to the results from Brattico et al. (2010), a P600 and

a LPN in response to mistuned stimuli were also expected. Of interest was seeing whether an LPP would be elicited by either type of task (affective or cognitive), affective stimulus (major or minor resolution), or affective response (happy or sad). One might have expected brain response differences between musicians and nonmusicians, but on the other hand, Tervaniemi, Castaneda, Knoll, and Uther (2006) found MMN amplitude differences between amateur musicians and nonmusicians only following deviations in sound source location, and not following other acoustic feature deviations.

Participants of the present study had their personality assessed according to the Big-Five framework. Since they had to complete a battery of five psychometric tests (the results of two of which are discussed presently) before participating in a lengthy EEG experiment, a very brief Big-Five personality measure was needed. The chosen measure was the TIPI (Gosling et al., 2003). To measure individual differences in empathy, the IRI was used (Davis, 1980; 1983).

If the effects of personality and other individual differences observed by the likes of Chamorro-Premuzic and Furnham (2007) and Vuoskoski and Eerola (2009), for example, were the result of differences in the processing of music in the brain, we could expect to observe differences in the behavioural and ERP responses to the cognitive and affective tasks among participants with different individual difference ratings in the present experiment. According to the results of Chamorro-Premuzic and Furnham (2007), one could expect participants who were more open to experience to respond more quickly to the cognitive task, give behavioural responses more in line with music theory, and exhibit brain responses suggesting a higher sensitivity to the mistuned stimuli, such as higher-amplitude MMN or P600. Participants who were more neurotic, more introverted, or less conscientious might have responded more quickly to the affective task and exhibited heightened affective brain responses, such as a larger LPP. From Vuoskoski and Eerola (2009), participants scoring lower on emotional stability might have rated relatively more stimuli as being sad, and participants scoring higher on extraversion might rate relatively more stimuli as being happy. According to ME-MS theory (Kreutz et al., 2008), I expected that participants scoring high on interpersonal reactivity will respond more quickly to the affective task than participants who scored lower.

3 METHODS

3.1 Participants

Participants were recruited by sending an e-mail calling for volunteers for a brain and music experiment to most student association mailing lists of the University of Jyväskylä. The e-mail was written in Finnish and asked for people between the ages of 19 and 30 with normal hearing who are not on psychiatric medication. Participants were promised two free cinema tickets each in the e-mail and were given them once their session was over. 24 university students (mean age 24.6 years \pm 2.6 SD; 9 males) participated in the study and each completed the experiment without incident. Each participant was a native speaker of Finnish and understood English as well. The questionnaire and experiment interface (including instructions) were written in Finnish but the experimenter, not a speaker of Finnish, gave some guidance in English.

3.2 Questionnaire

The first thing participants did upon coming to the experiment was take the individual difference tests. These were administered via personal computer in the form of a five-page survey constructed using the survey creation system of Korppi, an online multipurpose study data system of the University of Jyväskylä (Lesonen, Pekkanen, Tawast, & Uuksulainen, 2001). The first page asked participants their name, gender, age, musical background, and amount of time spent listening to music. Musical background was answerable with the following four options, translated here into English from Finnish: “I am studying to be a professional musician / music is my profession”; “I play an instrument (or sing) as a hobby”; “I do not play an instrument or sing”; or “other” with the option of writing what one's musical background is. Participants specified how much time they spend listening to music by choosing one of the following three options, translated here from Finnish: less than one hour per day, between one and three hours per day, or more than three hours per day. The second page of the survey contained Rosenberg's Self-Esteem Scale (RSES; 10 items, 4-

point scale; Rosenberg, 1965) and the TIPI (10 items, 7-point scale; Gosling et al., 2003). The third page contained the Music Appreciation Scale (MAS; 17 items, 5-point scale; Zentner, in preparation). The fourth page consisted of the Twenty-Item Toronto Alexithymia Scale (TAS-20; 20 items, 5-point scale; Bagby, Parker, & Taylor, 1994) and on the fifth page was the IRI (28 items, 5-point scale; Davis, 1980). For the present report, only the results of the TIPI and IRI were analyzed. The data from the RSES, MAS, and TAS-20 were collected for a different study.

3.3 Stimuli

Stimuli consisted of five-chord cadences, each cadence 3000ms in duration. The first four chords were each 500ms long and the final chord was 1000ms. These chord sequences were programmed using MIDI and rendered in Apple's Logic Pro 9 software (Apple, 2009) using the default grand piano timbre of Logic Pro 9. All MIDI notes were identical in velocity. Rendered stimuli were in WAV file format.

10 different cadences composed for a previous study (Brattico et al., 2010) were modified and used in the present study. Each chord in the cadences contained four notes. Often two of these notes were of the same pitch class, e.g. a chord could contain two C notes. The modification consisted of retaining the first four chords (the tonal context) and giving the cadence a new fifth chord. The tonal contexts were originally written in the key of C major. For each of the 10 cadences, a new version was initially created ending in each of the following chords, for a total of 80 candidate stimuli: C major, C minor, G dominant 7, A minor, A major, D minor, E minor, or F major. These 80 stimuli were then played for a pilot group of five people who rated whether the cadences sounded happy or sad on a 7-point Likert scale. For each of the 10 tonal contexts, a cadence was selected such that the following criteria were met as optimally as possible: 5 cadences resolved in a major or dominant chord; 5 cadences resolved in a minor chord; the major or dominant cadences were on average rated as sounding happy; and the minor cadences were on average rated as sounding sad.

The cadences ultimately used in the actual experiment resolved in either the tonic (C major), dominant (G dominant 7), relative minor (A minor), or supertonic (D minor) chord. The harmony was varied in this way to create differences in the perceived affective sound of the stimuli without being excessively complicated. The aim was for the stimuli to sound as though they were expressing either a basic positive emotion or a basic negative emotion. They

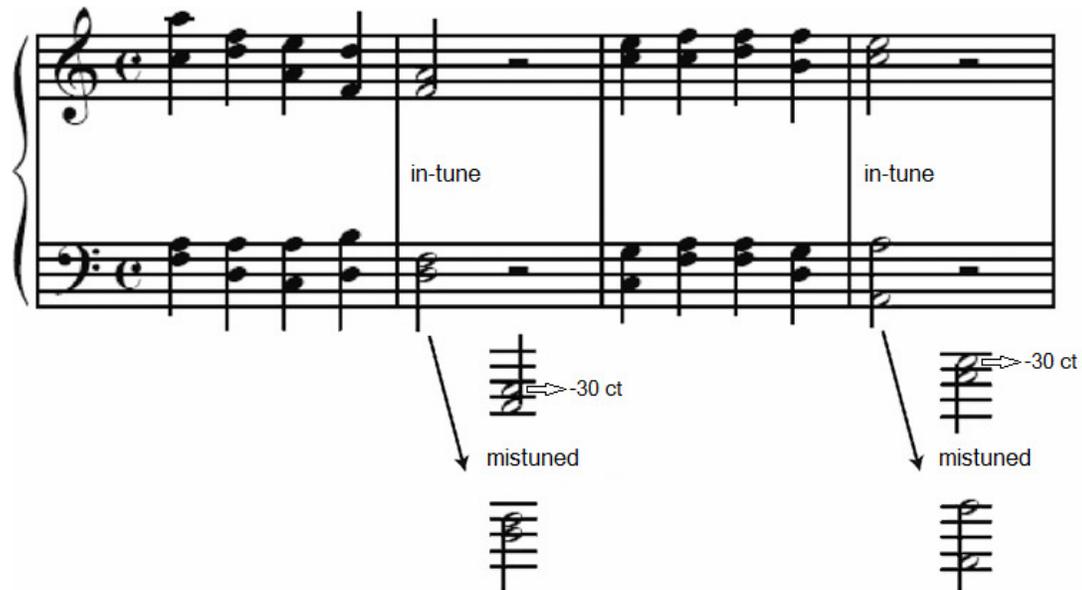


Fig. 1. Two examples of chord cadences used in the experiment, showing both in-tune and mistuned ending conditions. The mistuned chords each contain one note detuned by 30 cents.

were transposed into 8 different keys to create 80 cadences. A duplicate of each of these eighty cadences was made which contained a tuning error, for a total of 160 stimuli.

The tuning errors found in 80 of the 160 stimuli occurred in the final chord of the cadence and consisted of one note – the dominant note of that chord – which was lowered in pitch by thirty cents so that it was out of tune. Ending chords always contained only one dominant note. Detuning was performed by rendering the notes to be detuned separately from the rest of the cadence, lowering their pitch by thirty cents, and then mixing them back in with the rest of the cadence. The pitch shifting and mixing was carried out in the software Ableton Live (Ableton AG, 2008) using a pitch shifting algorithm which does not preserve duration, thus in theory producing no pitch shifting artifacts. The duration and pitch of the other notes in these mistuned stimuli remained unaltered. Each stimulus was presented twice – once for the affective task and once for the cognitive task – accompanied by a visual cue preparing the participant for the task to be performed in response to the stimulus. There were thus 320 experimental trials in total. Five of these were chosen at random at the beginning of each experiment to be used for practice before starting on the experimental items.

3.4 Design and procedure

Upon completing the survey, participants were led to another room in which the experiment would take place. They sat in an armchair and were fitted with a 32-electrode EEG cap. They faced a computer monitor on which visual cues would be presented, wore headphones through which the auditory stimuli would be presented, and held a computer keyboard that they would use to respond to the experimental items. Setup took around half an hour and the experiment itself took around thirty-five minutes. When the experiment began, the monitor displayed the following, translated here from Finnish:

You will listen to brief music samples, regarding which you will be given two types of task:

1. You need to judge whether the end of the sample sounds happy or sad.
2. You need to judge whether the end of the sample sounds correct or incorrect.

Listen to each excerpt in its entirety. While listening, keep your eyes on the screen. As soon as the sample ends, respond by pressing the appropriate key: i = happy, s = sad, o = correct, v = incorrect.

The keys participants pressed to respond to the tasks corresponded to the first letter of the words happy, sad, correct, and incorrect in Finnish (iloinen, surullinen, oikein, väärin). Participants completed five practice trials before continuing with the 320 experimental trials.

Each trial began with one of two written cues presented on the monitor: either “happy or sad?” or “correct or incorrect?”. After 1000ms, the words were replaced with a cross (+) in the middle of the screen and one of the 160 auditory stimuli played. Each stimulus lasted 3000ms, the final chord occurring 2000ms in. 2048ms after the offset of the final chord – or 3048ms post-onset – the next trial began. Aside from two stretch breaks during the experiment, the presentation of the trials did not stop and could not be sped up or slowed down by the participant.

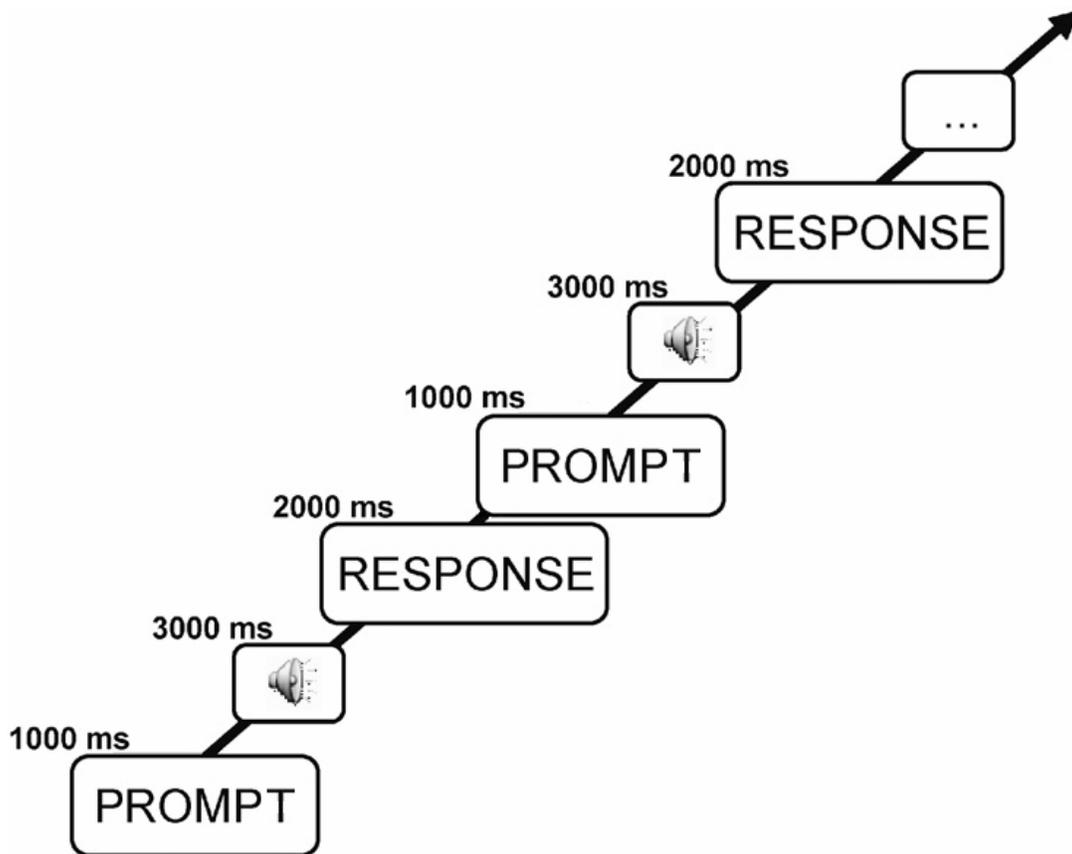


Fig. 2. Schematic illustration of the experimental procedure.

EEG recording began after the participants had read the instructions. In addition to recording data from the participant's scalp, the EEG software also received data from the experiment presentation software. Triggers were sent to the EEG software upon the onset of the visual prompts, the onset of the cadences, the onset of the final chords, and the keystroke responses of the participants, so that electric potentials related to these events could be studied. Unique index numbers were given to each of the following triggers: the 160 cadences and ending chords (ending chords had the same index as their cadences), the affective prompt, the cognitive prompt, the 4 response keystrokes, the onset of a break, and the *enter* key, which could be used to end a break or start the experiment. Keystroke triggers were recorded any time that key was pressed, regardless of whether it was pressed at an appropriate time or not.

3.5 Data Analysis

3.5.1 Behavioural and questionnaire data

Variables were computed based on participants' behavioural responses. "RT" is the average reaction time for all responses to experimental items. Reaction times were measured as the time elapsed between the onset of the final chord in each item and the button press response to that item. Since it was possible for participants to give a response which did not match the task – for example, answering "happy" or "sad" when asked "correct or incorrect?" – only reaction times for task-relevant responses were averaged. "Affective RT" is the average reaction time for appropriate responses to the affective task and "cognitive RT" is the same but for the cognitive task. "Frequency of 'happy' response" is the percentage of appropriate responses to the affective task which categorized the stimulus as sounding happy when it ended, and thus the percentage which did not categorize it as sad. "Frequency of 'correct' response" is the percentage of appropriate responses to the cognitive task which categorized the final chord as sounding correct, and thus the percentage which did not categorize it as being incorrect. "Frequency of expected responses" took into account whether the participants' responses matched what was expected by the experimenters according to music theory. For this purpose, major-key cadences were assumed to sound happy, minor-key cadences were assumed to sound sad, cadences with a mistuning at the end were assumed to sound incorrect, and cadences with no mistuning were assumed to sound correct. Responses which agreed with these assumptions, based on the characteristics of the stimuli they were responding to, were counted as expected responses, and those which disagreed were counted as unexpected responses. Responses which were not appropriate for the current task were not counted. "Frequency of expected responses" was equal to the number of expected responses divided by the total number of expected and unexpected responses. Behavioural response variables were tested for correlation with each other and with individual difference variables from the questionnaire results, namely the five TIPI subscales and the four IRI subscales. T-tests were performed to see whether reaction times to the two tasks differed from each other, and whether reaction times to the four ending chord categories – major in-tune, major mistuned, minor in-tune, and minor mistuned – differed from each other.

3.5.2 ERP data

The EEG (512 Hz sampling rate) was recorded with a 32-electrode cap, which had the following electrodes according to the extended 10-20 international system: FP1, FP2, AF3, AF4, F3, F4, F7, F8, Fz, FC1, FC2, FC5, FC6, T7, T8, C3, C4, Cz, CP1, CP2, CP5, CP6, P3, P4, P7, P8, Pz, PO3, PO4, O1, O2, Oz. The following non-scalp electrodes were also applied: EOG1 above and to the left of the left eye, EOG2 below and to the right of the right eye, two reference electrodes each applied to an earlobe, left mastoid, right mastoid, and ECG1 and ECG2 on the left and right wrists, respectively, near the ulnar and radial arteries.

Both the preprocessing of, and the subsequent ERP extraction from, the EEG recordings were performed with EEGLab (Delorme and Makeig, 2004) and custom integrated Matlab functions. A high-pass filter of 0.5 Hz was applied to the recordings. Independent component analysis was performed on each recording, and components which represented electrical potentials caused by eye movement or blinking were removed. Electrodes which appeared to produce noise of significantly high amplitude were removed and interpolated. A low-pass filter of 40 Hz was then applied and epochs were extracted which started 100 ms before, and ended 2000 ms after, the final chord in each presented stimulus. For each participant, four files were created which each contained epochs from the presentation of cadences with one of the following endings: major in-tune, major mistuned, minor in-tune, and minor mistuned. The aim was to study the effects of the different stimulus types. The ERP effects of task and response type were not studied at this time, but may be explored in a later study. The 100 ms pre-onset interval served as a baseline. Epochs in which the amplitude of one scalp channel exceeded $\pm 100 \mu\text{V}$ were rejected.

The average number of accepted trials per participant was 71.8 ± 11.0 (SD) for the major in-tune ending chords, 71.0 ± 10.4 (SD) for the major mistuned ending chords, 71.3 ± 11.6 (SD) for the minor in-tune ending chords, and 71.1 ± 10.5 (SD) for the minor mistuned ending chords. Average EEG curves were computed for each participant across all trials following each of the four stimulus categories. Difference curves were made by subtracting the amplitude of the major in-tune curve from the major mistuned curve, and the minor in-tune curve from the minor mistuned curve. Peak latencies of the ERP responses were extracted from broad time intervals in which ERP effects were likely to occur, by finding in each of these time intervals the electrode showing the largest peak. Negative peaks were searched for in the time intervals 300-500 ms and 900-1100 ms. Positive peaks were looked for in the time intervals 400-600 ms, 600-800 ms, and 1600-1800 ms. Peak latencies were

used to quantify the mean amplitudes of the ERP responses to the different stimulus categories. The amplitudes of the curves recorded from each of the electrodes F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, Oz, and O2 were averaged within the ± 20 ms window surrounding the peak latency. The mean amplitudes of the ERP responses were then compared with a general linear model with repeated measures (analysis of variance or ANOVA). The factors included were Tuning (in-tune, mistuned), Mode (major, minor), Anterior–posterior (frontal, central, parietal, occipital), Laterality (left, middle, right), Musical background (non-musician, music as a hobby, professional musician/post-secondary music student), and the covariate Gender (male, female). The mean ERP amplitudes from electrodes Fz, Cz, Pz, and Oz were also correlated with participants' scores on the TIPI (Gosling et al., 2003) and IRI (Davis, 1980; 1983). The significance level was adjusted for type I errors using the Bonferroni correction.

4 RESULTS

4.1 Questionnaire data

Of the 24 participants, 15 were female and 9 were male. The mean age of the participants was 24.6 years \pm 2.6 SD. No participants reported being professional musicians or music degree students. 8 participants indicated they played a musical instrument or sang as a hobby, 10 said they did not play an instrument or sing, 5 opted for the response “other”, and one participant's response to this question was lost by accident (it was not possible to contact her after this problem was noticed). Of the participants who answered “other”, one did not give a clarification, and the others gave the following clarifications, here translated from Finnish:

1. I am studying to be a school teacher and we have compulsory piano lessons. Those compulsory lessons are now finished but I still play sometimes.
2. sporadic singing
3. I sing to myself a lot.
4. As a child, I sang in a choir and played recorder and a bit of guitar, but I have never had a very systematic relationship with music.

For the purpose of analysis, these participants were added to the other categories based on their written comments and the researcher's discretion. The participant who wrote the first clarification was counted as though he played an instrument as a hobby and the other three who wrote clarifications were counted as though they were not musicians. The participant who did not provide a clarification and the participant whose answer was lost were not included in analyses related to this variable.

A number of correlations were found between different individual difference scales. The personality factors agreeableness and emotional stability correlated positively and significantly with each other, $r=.573$, $p=.003$. Emotional stability also correlated positively

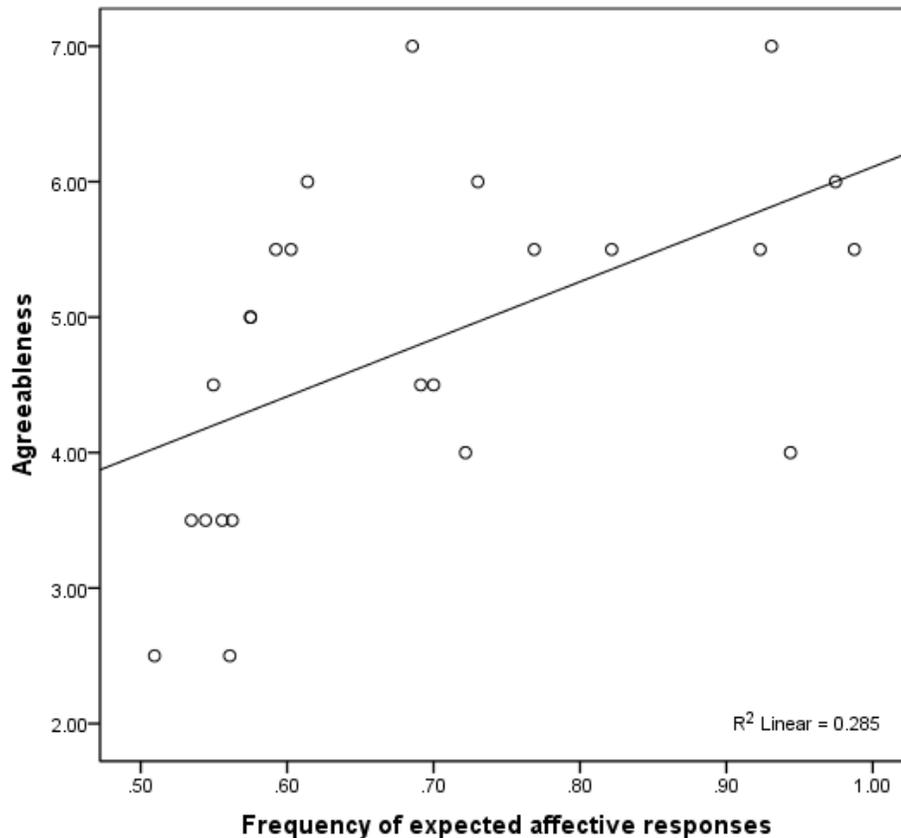


Fig. 3. Correlation Agreeableness × Frequency of expected affective responses.

with the interpersonal reactivity subscale of perspective taking, $r=.517$, $p=.010$, and the personality factor extraversion had a negative correlation with the interpersonal reactivity subscale personal distress, $r=-.518$, $p=.009$. Perspective taking correlated positively and significantly with empathic concern, $r=.609$, $p=.002$.

4.2 Behavioural data

The speed of participants' responses did not differ significantly between the affective and cognitive tasks, $t=1.45$, $p=.159$. Responses of “happy” did not differ significantly in speed from responses of “sad”, $t=1.41$, $p=.171$, nor did “correct” responses from “incorrect” responses, $t=.665$, $p=.512$. The frequency of expected responses to the affective task correlated positively with agreeableness, $r=.534$, $p=.007$. This correlation is plotted in Figure 3. No other significant correlations were found between any behavioural variable and any of the personality and IRI variables.

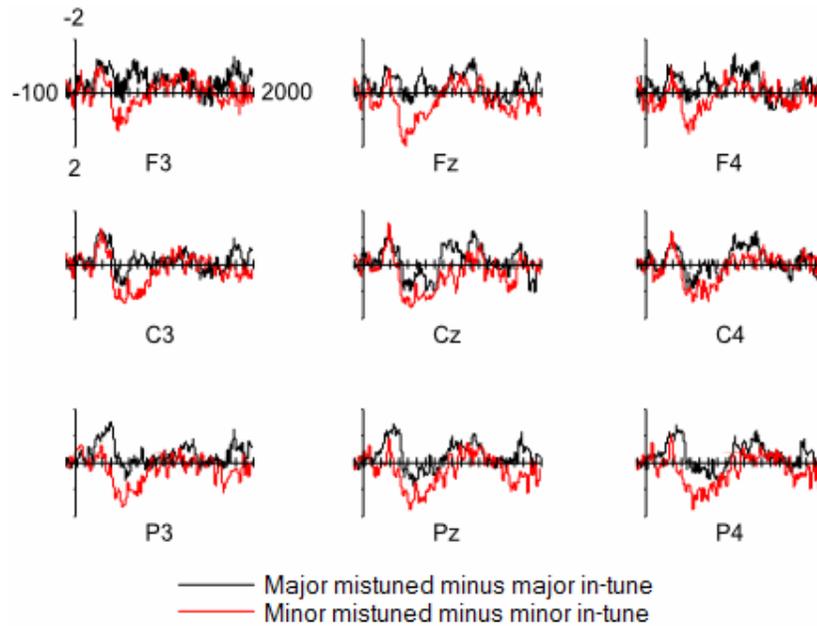


Fig. 4. Averaged ERP difference curves; major mistuned stimuli – major in-tune stimuli & minor mistuned stimuli – minor in-tune stimuli.

4.3 ERP data

At 300-500ms after the onset of the ending chord, ERP waveforms averaged according to the characteristics of the ending chord of the stimuli displayed a significant interaction Mode x Tuning, $F(1,571)=19.6$, $p=.000$, $\eta_p^2=.5$. A paired samples t-test revealed that this was due to a significant difference in amplitude following major resolutions which did not contain a mistuned note versus every other type of final chord (major mistuned, $t=3.61$, $p=.001$; minor in-tune, $t=3.28$, $p=.003$; minor mistuned, $t=3.41$, $p=.002$). The other types of final chord did not elicit significantly different mean amplitudes from each other. Following the in-tune major stimuli, the ERP had on average a higher positive amplitude, $M=1.57\mu\text{V}$, while following the other stimuli the average amplitudes were lower negative or positive values (major mistuned, $M=-.068\mu\text{V}$; minor in-tune, $M=.259\mu\text{V}$; minor mistuned, $M=-.150\mu\text{V}$).

At 600-800ms, at 900-1100ms, and at 1600-1800ms, significant effects of Tuning on ERP amplitudes were observed, $F(1,229)=6.5$, $p=.020$, $\eta_p^2=.3$; $F(1,89)=6.0$, $p=.025$, $\eta_p^2=.2$; and $F(1,65)=4.7$, $p=.044$, $\eta_p^2=.2$, respectively. A significant interaction Mode x Tuning on ERP was also observed between 600-800ms, $F(1,200)=10.7$, $p=.004$, $\eta_p^2=.4$. At 600-800ms, mistuned stimuli elicited positive ERP responses which were significantly larger in amplitude

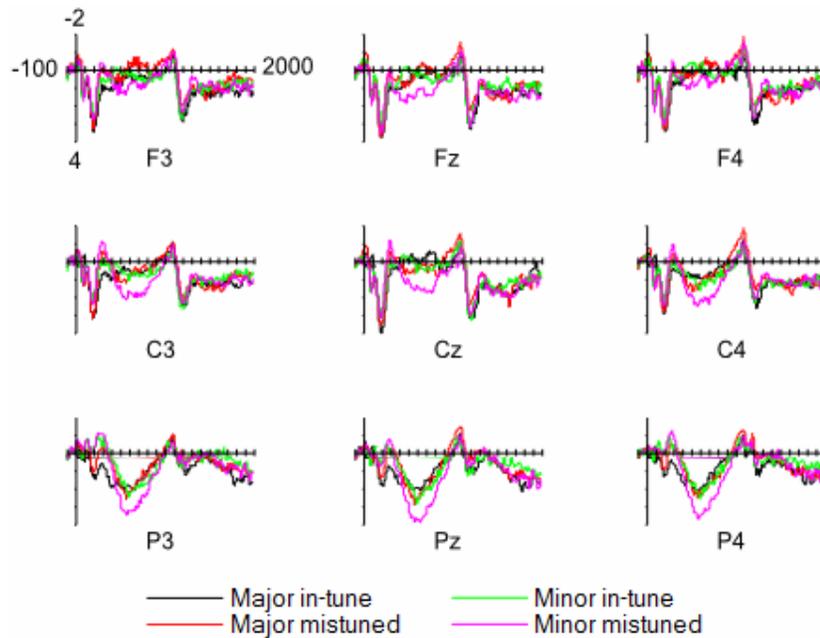


Fig. 5. Averaged ERP curves; major in-tune, major mistuned, minor in-tune, and minor mistuned stimuli.

than the responses elicited by correctly tuned stimuli, which were also, on average, positive; however, when only major-key resolutions were considered, the difference in responses to the two types of tuning was not significant. The significant difference remained when only minor-key resolutions were considered. In other words, there is a relatively late (peaking between 600-800ms) positive ERP component in response to minor-key, mistuned ending chords. In the 900-1100ms range, correctly tuned stimuli elicited a positive mean amplitude, while mistuned stimuli elicited a negative mean amplitude. There is thus no positive enhancement for mistuned stimuli at this latency, but rather a negative enhancement. At 1600-1800ms, however, this pattern reversed and we observed again a relatively high positive ERP for mistuned stimuli and a relatively low positive ERP for in-tune stimuli. No effect of Mode was observed at these latter latencies.

A number of significant correlations were observed between measures of individual difference and amplitudes of ERPs in response to the different categories of stimulus. These correlations are listed in Table 1. At 300-500ms, occipital (Oz) ERP amplitudes following major in-tune ending chords correlated negatively with both openness to experience, $r=-.53$, $p=.008$, and empathic concern, $r=-.53$, $p=.007$. Parietal (Pz) ERP amplitudes to major mistuned chords at this latency correlated negatively with the personal distress scale, $r=-.52$, $p=.009$. At 400-600ms, frontal (Fz) ERP amplitudes to minor mistuned endings correlated

positively with emotional stability, $r=.55$, $p=.005$. At 900-1100ms, central (Cz) ERP amplitudes to major mistuned stimuli correlated positively with openness to experience, $r=.57$, $p=.004$, and ERP amplitudes at Pz correlated positively with empathic concern levels, $r=.53$, $p=.008$. ERPs at 1600-1800ms in the occipital region of the scalp correlated negatively in amplitude with the fantasy scale following minor in-tune chords, $r=-.52$, $p=.010$, and with empathic concern following both major in-tune chords, $r=-.54$, $p=.007$, and minor mistuned chords, $r=-.60$, $p=.002$. No significant effects or interactions involving Musical background were observed on stimulus category ERPs.

Table 1

Significant correlations between ERP amplitudes and individual difference scales.

Time window	Variable 1 (ERP amplitude at one electrode for one stimulus type)	Variable 2 (individual difference scale)	<i>r</i>	<i>p</i>
300-500	Oz; major in-tune ending	Openness to experience	-0.53	0.008
	Oz; major in-tune ending	Empathic concern	-0.53	0.007
	Pz; major mistuned ending	Personal distress	-0.52	0.009
400-600	Fz; minor mistuned ending	Emotional stability	0.55	0.005
900-1100	Cz; major mistuned ending	Openness to experience	0.57	0.004
	Pz; minor mistuned ending	Empathic concern	0.53	0.008
1600-1800	Oz; minor in-tune ending	Fantasy	-0.52	0.010
	Oz; major in-tune ending	Empathic concern	-0.54	0.007
	Oz; minor mistuned ending	Empathic concern	-0.60	0.002

5 DISCUSSION

Participants in this study, who were either non-musicians or amateur musicians, answered the IRI measure of trait empathy (Davis, 1980; 1983) and the TIPI measure of personality dimensions (Gosling et al., 2003), and performed judgments of correctness and perceived emotion on the same musical chord cadences. The cadences varied somewhat in musical content and were transposed over eight keys. The final chords of the cadences were manipulated in order to induce variation in the judgments of the participants. One half of the final chords were positive-sounding major or dominant 7 chords, and the other half were negative-sounding minor chords; one half contained a dominant note which was detuned by 30 cents, and the other half was perfectly tuned. Effects of empathy, personality, and final chord type were expected to be observed in the behavioural and electrophysiological responses.

Response times did not differ significantly between affective and cognitive tasks, nor did they correlate significantly with personality or empathy dimensions. It seems as though affective and cognitive processing in this sort of task do not differ in speed. The results also suggest that individuals differing in personality or trait empathy do not differ in the speed of one type of pitch processing versus the other. There could still however be some dimensions of individual difference that would interact with the type of task, but that were not examined in the present experiment.

Early ERP responses appeared to be sensitive to the manner in which the cadence stimuli resolved. The reduced positivity between 300-500ms following mistuned major-key stimuli relative to in-tune major-key stimuli could be a MMN, since the MMN has been observed in tests involving mistuned chords before (e.g., Leino et al., 2007; Garza Villarreal, Brattico, Leino, Østergaard, & Vuust, 2011). The absence of such an effect for minor-key stimuli could mean that mistunings do not sound as inappropriate in minor-key music as they do in major-key music. Detunings of the sort used in the experiment might be interpreted as sounding, e.g., sad in a minor context, while people might not know how to interpret them in a major context. However, the amplitudes of the ERPs following minor-key cadence resolutions did not differ significantly from those following major mistuned resolutions,

suggesting similar brain responses to all three categories of stimuli, and a different response to the fourth category: major in-tune. It could thus be possible that, rather than the minor mistuned stimuli sounding relatively congruous, all minor-key stimuli sounded, on average, incongruous. Perhaps listeners expected a major-key ending to the cadences. If so, this could indicate an oversight on the part of the experimenter, as the cadences were intended to be ambiguous as to how they would end.

It is nevertheless possible that the MMN was modulated in some way by affective processes related to the different ending modes of the stimuli. This would be somewhat unexpected, however, given a previous study by Koelsch, Kilches, Steinbeis, and Schelinski (2008) in which negativities in response to incongruous musical stimuli were not affected by emotional expression; however, their findings differ from the present findings in that the incongruity was created by unexpected chords, the negativity was identified as an ERAN, and the affective characteristics were manipulated by having the music sound either neutral or expressive. Perhaps more information could be revealed by averaging the ERP curves according to participant behavioural response rather than stimulus category.

Later ERP responses, peaking between 600-800ms also seemed to depend on the mode and tuning of the ending chord. In this case, however, a difference in amplitude was observed between minor-key in-tune and mistuned chords, and not between major-key in-tune and mistuned chords. Minor mistuned cadence resolutions elicited a higher positive potential than did minor in-tune endings, which elicited on average a low positive potential. This positive enhancement for stimuli violating pitch expectations could be interpreted as a P600 component. To this author's knowledge, the P600 has not been studied in relation to mistunings, instead having been observed following chords and melodic notes which are out of key (Besson & Faïta, 1995; Patel et al., 1998). For example, in the study of Brattico et al. (2010), from which the present study borrowed much of its methodology, the researchers also believe they observed a P600, but the pitch expectancy violations in that study consisted of cadence-final chords which were out of key, not out of tune. Perhaps the P600 can be elicited by notes which are out of tune as well. Patel et al. (1998), based on previous psycholinguistic research involving the P600, suggested that the P600 is an indicator of musical and linguistic syntax violation. The musical equivalent to linguistic syntax has been believed to concern harmony, i.e. appropriate chords (Patel et al. 1998; Koelsch et al., 2000), and not subtle pitch differences in notes. Perhaps either the role of the P600 or the meaning of musical syntax need to be revised, or perhaps the phenomenon presently observed is not an example of the

P600. Its apparent absence when the target chord is major is indeed unusual. An alternative interpretation is that the positive enhancement at 600-800ms is a LPP, an indicator of affective stimulus processing.

Some ERP amplitudes correlated with IRI subscales related to affective empathy – the empathic concern and personal distress scales. For instance, the parietal amplitudes of ERPs to major-key mistuned stimuli between 300-500ms correlated negatively in amplitude with the personal distress scale, which may suggest enhanced early negativity in the parietal regions of more empathic individuals. Perhaps people who have higher affective empathy have a stronger affective response to off-putting stimuli, such as chords containing mistuned notes. Other individual difference scales –empathic concern, fantasy, emotional stability, and openness to experience – also correlated with ERP amplitudes, but it is unclear at this moment what these correlations mean. There was a negative correlation between the personality trait openness to experience and ERP amplitude in the range 300-500ms in response to major in-tune ending chords. Perhaps people who are open to experience are more likely to elicit an MMN in response to major-key, properly tuned resolutions. It could be that such individuals, better able to adapt to new experiences, could become acclimatized to the frequent mistuned stimuli and begin to expect them. They may also possess a processing bias that makes unusual (e.g., out of tune) stimuli appear to occur more frequently than they really do, further contributing to the relative unexpectedness of perfectly congruous ending chords. This is, however, purely speculation on the part of the author. In line with research by Tervaniemi et al. (2006), MMN amplitude did not differ significantly between hobby musicians and nonmusicians, nor did any other ERP amplitudes.

Participants who scored higher on agreeableness were more likely to rate the emotional quality of the stimuli in accordance with music theory, i.e. major cadences are happy and minor cadences are sad. Ladinig and Schellenberg (2011) found that their participants who scored higher on agreeableness tended to have more intense emotional responses to music. It could be that agreeable people are more susceptible to emotions encoded in music. Although in the present study, the agreeableness scale did not correlate with empathy, Nettle and Liddle (2008) found evidence that it is related to social-cognitive theory of mind (ToM), but not social-perceptual ToM. Social-perceptual ToM is the ability to detect the mental state of another person, while social-cognitive ToM is the ability to reason about someone's mental state, for example predicting someone's behaviour based on their emotions. Both of these abilities are part of the concept of cognitive empathy described

earlier. Perhaps the processing of musical emotions makes use of social-cognitive ToM in order to reason about the mental state of the composer or the meaning of musical harmony. More generally, the present results may support the involvement of cognitive empathy in the processing of emotion expressed by music, and of affective empathy in affective responses to dissonant music.

In line with previous research on violations of harmony or tonality, the present study showed early negative and late positive ERP responses to cadence-final chords containing mistuned notes; however, these responses appeared to be modulated in unforeseen ways by the mode in which the chord resolved the preceding cadence. This could be a sign that musical pitch can influence brain responses to pitch incongruities through affective or sensory processing. Participants' interpersonal reactivity, emotional stability, and openness to experience scores correlated significantly with some ERP amplitudes to certain types of ending chord, for instance the personal distress scale correlated negatively with early parietal ERP amplitudes following major mistuned chords. This could indicate that personality and empathy differences are related with musical pitch processing. A significant correlation with personality was also observed in the behavioural data: Participants scoring higher on agreeableness were more likely to rate major-key cadences as happy and minor-key cadences as sad. The initial exploration into individual differences in pitch processing presented here has provided some nebulous but promising evidence of the manners in which our brains differ in how they process music. This topic will continue to be researched via the further analysis of the present data, and the collection of new data from a younger age group.

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