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MUSIC-INDUCED EMOTIONS: PSYCHOPHYSIOLOGICAL CORRELATES AND INDIVIDUAL DIFFERENCES

- Doctoral thesis abstract -

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Cap. 1. Emotions and music: Definitions, perspectivesand theories of emotions induced by music

Emotions induced by music have only recently drawn the attention of scholars in cognitive and affective sciences (for reviews see Juslin & Vastfjall, 2008; Scherer & Zentner, 2001). Field studies have confirmed that music pervades everyday life and some of its most important functions are related to mood change and emotion regulation (DeNora, 1999; Juslin, Liljestrom, Vastfjall, Barradas, & Silva, 2008; J. A. Sloboda, O'Neil, & Ivaldi, 2001). In daily life, music generally increases positive affect, alertness, and focus in the present (J. A. Sloboda et al., 2001). In addition, it helps “venting strong emotions”, “revving up” or “calming down” (DeNora, 1999).

Despite previous debates on whether music *induces* emotions in listeners (i.e., the so-called “emotivist” position), or only *expresses* emotions that listeners can recognize (i.e., the “cognitivist” position) (see Kivy, 1990; Scherer & Zentner, 200)), a developing literature has supported the view that music induces subjective (e.g., self-reported sadness), behavioral (e.g., crying), and physiological changes (e.g., heart rate [HR] deceleration) that are characteristic of emotions (for reviews see Bharucha, Curtis, & Paroo, 2006; Juslin & Vastfjall, 2008; Koelsch, 2005; Scherer & Zentner, 2001). In addition, the mechanisms by which music induces emotions (e.g., semantic associations, emotional contagion based on observation of facial and vocal expressions; see Bezdek & Gerrig, 2008; Hietanen, Surakka, & Linnankoski, 1998; L.O. Lundqvist & Dimberg, 1995) may not be specific to music, but this possibility has only recently started to be investigated (for reviews, see Juslin & Vastfjall, 2008; Scherer & Zentner, 2001). The present report contributes to this developing literature on musical emotions by investigating for the first time the psychophysiological and cognitive mechanisms by which operatic music induces specific emotions.

One way to support the emotivist position has been to identify physiological responses during music listening (e.g., Krumhansl, 1997). This approach has extended the studies on the physiological differentiation of emotion induced by facial expressions (e.g., Ekman, Levenson, & Friesen, 1983), images (e.g., Codispoti, Bradley, & Lang, 2001), and even natural sounds (e.g., Bradley & Lang, 2000). These studies indicated that only certain emotions (e.g., fear, disgust) can be distinguished based on their autonomic signatures (for review see Levenson, 1992), but the effects sizes were small or medium (Cacioppo, Berntsen, Klein, & Poehlmann, 1997). These findings are not suprising considering the limited emotional saliency of images and words presented in laboratory settings. Recent psychophysiological studies have used more complex and ecological stimuli such as films, and consequently induced more robust experiences of emotion and physiological responses (e.g., Frazier, Strauss, & Steinhauer, 2004; Kreibig, Wilhelm, Roth, & Gross, 2007).

Like films, music has been shown to produce physiological changes that distinguish emotional experiences (for an illustration of stimuli and methods, see **Table 1**). In two landmark studies, Krumhansl (1997) and Nyklícek, Thayer, and Van Doornen (1997) measured a large array of cardiovascular, respiratory, and electrodermal responses in association with self-report measures of emotion induced by music. Not only that musical stimuli induced discriminable physiological changes, but they were also significantly associated with emotional experiences. For instance, sadness ratings correlated positively with cardiac interbeat intervals (IBI), systolic (SBP), dyastolic (DBP), and mean blood pressure, and negatively with skin conductance level (SCL) and finger temperature (Krumhansl, 1997; see also Khalfa, Isabelle, Jean-Pierre, & Manon, 2002). In contrast, fear experience correlated positively with finger and ear pulse transmission time, and negatively with finger pulse amplitude (Krumhansl, 1997). Indeed, emotions could be differentiated based on certain physiological responses (e.g., respiratory sinus arrhytmia (RSA), finger pulse amplitude, IBI, and left ventricular ejection time; Nyklícek et al., 1997). Emotional arousal was best (i.e., 62.5% of the variance) explained by physiological changes (Nyklícek et al., 1997). In line with these results, an early review of psychophysiological studies on musical emotions concluded that high-arousing music characterized by fast tempo, high rhythm and loud dynamic induced increased HR and muscle tension, whereas low-arousing music characterized by slow tempo, legato style and soft dynamic induced decreased HR, muscle tension, and SCL, as well as increases in skin temperature (Bartlett, 1996). Since this review was published, several studies have extended the psychophysiological measures to facial muscle activity, and endocrine assays. For instance, a recent study found increased zygomatic activity at the beginning of happy, but not sad music (L. O. Lundqvist, Carlsson, & Juslin P. N., 2009; but see also Grewe, Nagel, Kopiez, & Altenmuller, 2007a). Another study found that listening to choir music decreased cortisol levels (G. Kreutz, Bongard, Rohrmann, Hodapp, & Grebe, 2004; but see also Nater, Abbruzzese, Krebs, & Ehlert, 2006). In addition, musical emotions have been investigated using electroencephalographic (e.g., Sammler, Grigutsch, Fritz, & Koelsch, 2007) and functional neuroimaging (Koelsch, Fritz, DY, Muller, & Friederici, 2006) methods.

Psychophysiological studies have more recently focused on the coherence between subjective, behavioral, and physiological components of musical emotions. L. O. Lundqvist et al. (2009) measured several psychophysiological responses during listening of pop songs composed especially for this study in order to limit the contribution of explicit memory to the genesis of musical emotions. The authors reported a pattern of association between music characterized by fast tempo, high sound level and major mode, and happyness ratings, increased zygomatic activity, greater SCL and lower finger temperature (L. O. Lundqvist et al., 2009). Another study correlated subjective feelings, action tendencies (e.g., desire to move), and physiological activity in music listening, and found that in the majority of participants, the psychological reactions (i.e., increased self-rated arousal) occurred without changes in zygomatic activity and SCL (Grewe et al., 2007a). This pattern of results was interpreted as evidence for the cognitivist position, although the participants were clearly instructed to rate the emotions they felt, and not those expressed by the music. Self-reported emotions that were not accompanied by physiological changes in this study do not exclude the possibility that participants developed musical emotions. For instance, in light of the observation that music induces a more nuanced range of emotions than the traditional dimensional and basic emotions models imply (Zentner, Grandjean, & Scherer, 2008), the dimensional ratings used in the study of Grewe et al. (2007) may not have been suitable for measuring musical emotions. Newly-developed questionnaires such as the Geneva Emotional Music Scale (GEMS) are based on taxonomies that accurately describe musical emotions (see Zentner et al., 2008). There is currently no study that associates musical emotions measured using a domain-specific instrument, and psychophysiological responses.

Chills (i.e., tremor or tingling sensations passing through the body as the result of sudden keen emotion or excitement) are involuntary bodily reactions that have been extensively studied in relation to musical emotions. Two landmark studies indicated that the great majority of people were susceptible to chills (J. Sloboda, 1991), and these bodily phenomena were associated with musical emotions, especially sadness and melancholy (Panksepp, 1995). Musical events such as crescendos and a solo instrument (e.g., a soprano's voice) emerging from a softer orchestral background induced chills (Grewe, Nagel, Kopiez, & Altenmuller, 2007b; Panksepp, 1995). Confirming Panksepp's (1995, pp. 197) hypothesis that "people who exhibit the most chills tend to be individuals of high emotional responsitivity and sensitivity", a recent study found that chill responders were less sensation-seeking, and more reward dependent (Grewe et al., 2007b). Chills correlated with increased SCL (Grewe et al., 2007b; Rickard, 2004) and activation in neural structures from the reward system (Blood & Zatorre, 2001). However, more extensive studies on the physiological correlates of chills are necessary. In addition, the potential association of chills with specific musical emotions has not been explored.

The duration of musical stimuli is one of the aspects that differentiates studies of musical emotions (see **Table 1**). Many studies used short (i.e., several seconds), monotonic musical stimuli. It has been suggested that less than one second of music is sufficient to prime an emotional meaning (e.g., Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005; Peretz, Blood, Penhune, & Zatorre, 2001). For instance, 3-5 s orchestral fragments from operatic compositions supported emotional categorizations in listeners (Watt & Ash, 1998). However, most of these studies involved forced-choice responses that increased the difficulty of emotional valenceprocessing, especially in the case of short, low-dynamic musical fragments (Bigand et al., 2005; Peretz et al., 2001). Correct categorization of the emotional content of music may only reflect the emotions that listeners *perceive* in music, for one second is certainly not enough time to develop an emotional response to music (for various perspectives, see Kettunen, Ravaja, Naatanen, & Keltikangas-Jarvinen, 2000; Lang, Bradley, & Cuthbert, 1997; Lazarus, 1984). Indeed, repeated exposure and longer durations of musical stimuli polarised psychophysiological responses in musical emotions (e.g., Witvliet & Vrana, 2007). Hence, psychophysiological studies generally used longer stimuli (i.e., ranging from 6 to 600 s; see Table 1), and it has been argued that: "while the duration periods of each treatment varied considerably [in that study], use of the full music pieces was considered to have greater external validity when investigating emotional responses to music than using shortened excepts of identical length" (Rickard, 2004, pp. 376; see also Grewe et al., 2007a; Nater et al., 2006). The duration of music, as well as the integration of music with coherent visual and semantic cues (e.g., watching the singing-acting performance of a singer on stage) are essential for developing an emotional response to musical performance (see Bezdek & Gerrig, 2008; Scherer & Zentner, 2001). Therefore, the present study used a fragment of operatic music that included multiple musical, semantic, and visual cues that were expected to generate differentiated emotional responses.

The musical performance (i.e., singing-acting) of an operatic music singer on stage involves musical, semantic and visual components that contribute to emotional responses in listeners. These sources may support the genesis of emotion either independenly or in interaction. Research on film music supports the latter posibility. For instance, music presented during the opening scene of a film influenced the emotional valence of words that participants used in their continuations of the narratives (Vitouch, 2001). In addition, judgements of characters displaying neutral emotions were significantly affected by the emotional content of the music that accompanied the film (Tan, Spackman, & Bezdek, 2007). Lyrics are also important in emotional responses to music. The emotional effects of music and lyrics were dissociated by combining musical fragments with lyrics that conveyed the same emotion or another emotion (Ali & Peynirciolu, 2006; Stratton & Zalanowski, 1994). These studies indicated that lyrics enhanced emotion in sad and angry music. Furthermore, these emotions readily transferred to images that were arbitrarily associated with songs (Ali & Peynirciolu, 2006). The reverse is also empirically supported: visual cues such as facial expressions are preattentionally integrated with vocal cues and influence the emotional judgement of the latter (de Gelder, Bocker, Tuomainen, Hensen, & Vroomen, 1999). In light of the observation that vocal and musical expressions of emotions rely on the same mechanisms (see Juslin & Laukka, 2003; Scherer, 1995), it seems likely that facial expressions also influence the emotional processing of music. Hence, music, lyrics, and visual cues seem to interact in the genesis of musical emotions. This interaction of sensory and semantic information may explain why live operatic music is so effective in inducing specific emotions (e.g., Ashley, 2000). However, this intriguing hypothesis has not been investigated to date.

Cap. 2. Emotions induced by opera music: Psychophysiological effects of music, plot and acting

We investigated subjective and physiological emotional responses to operatic music. In order to maximize external validity, we chose a dramatically coherent and musically complex excerpt from Tosca by Giacomo Puccini. The soprano Maria Callas and the baritone Tito Gobbi gave a legendary interpretation of the main characters in Tosca, and their 1964 live performance at Covent Garden was fortunately recorded on film. In this performance, both artists impress by their emotional identification with the characters,and the way they deliver the mixture of lust and hate, fear, emotional vulnerability and indignation through their voice (Huck, 1984). Studying the psychophysiology of emotion during this performance offers us an opportunity to catch a scientific glimpse of the emotional force that artists such as Maria Callas have inspired. The present study had three experimental conditions that investigated the contributions of music, plot, and acting performance to emotional responses. First, participants listened to the musical excerpt. Then, they read a summary of the plot and listened to the same musical excerpt again. In the third condition, they re-listened to music while they watched the subtitled film of this acting performance. In between conditions, we measured music-induced emotions using both dimensional, and specific music-induced emotion questionnaires. During the experimental conditions, cardiovascular, electrodermal and respiratory responses were continuously recorded, and the participants kept track of their musical chills.

Since there are very few psychophysiological studies of emotions in operatic music (and operatic music is so diverse), the present study was consequently exploratory. Based on the musical and dramatic content of this musical excerpt, we expected that it would induce a pattern of emotions characterized by increased unpleasant emotions (e.g., sadness) and decreased pleasant emotions (e.g., joyful activation, peacefulness). In addition, based on the literature in related areas (e.g., sadness induced by films), we expected a change in the sympathovagal balance, with vagal withdrawal and sympathetic activation, as well as decreases of SCL and respiratory rate (RR). We were specifically interested in the way each successive layer of complexity influenced music-induced emotions and their physiological correlates.

The results of this study confirmed that music listening, learning the plot, and watching the acting performance had specific effects on emotional responses measured at the subjective and physiological levels.

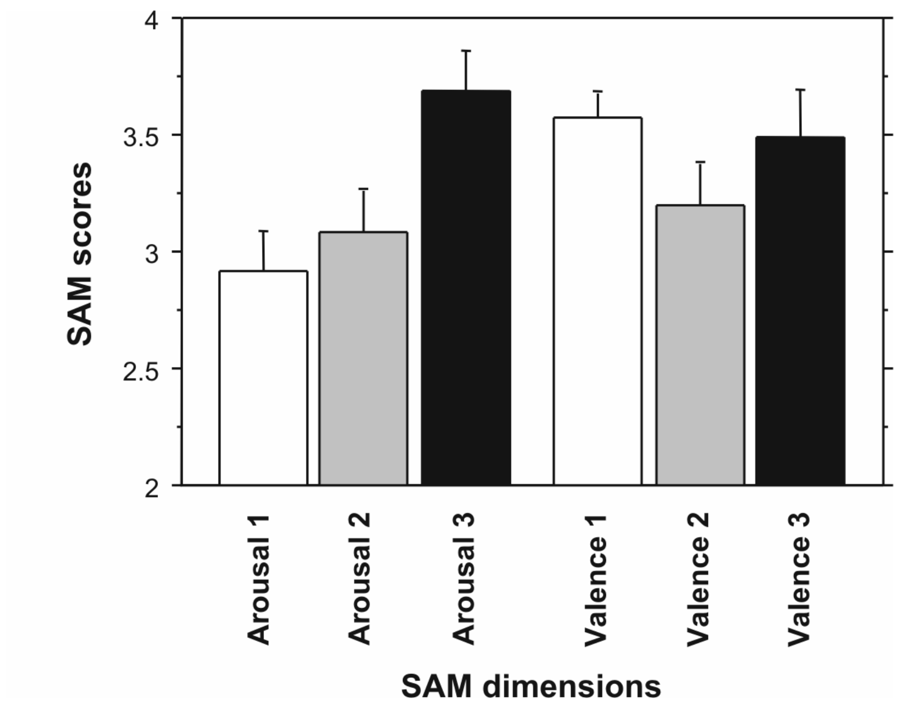

Fig. 1. *Changes in emotional arousal and valence (SAM) induced by music listening (1), learning the plot (2), and watching the acting performance (3).*

In comparison to expected mean scores, music listening increased, as one would expect, emotional arousal and valence. In addition, music listening decreased RR, IBI and SCL, in comparison to baseline physiology. These results seem to extend previous observations that sad music is associated with decreased SCL, and sadness induced by music is well discriminated by respiratory changes (Krumhansl, 1997; Nyklícek et al., 1997). Moreover, our observation of decreased SCL associated with this music excerpt is also in line with studies that induced sadness by directed facial action tasks (Ekman et al., 1983; Levenson, 1992).

It may seem that the pattern of reduced RR and SCL, and increased HR (i.e., decreased IBI) in the music listening condition is contradictory. Early observations indicated that the minor tonalities of music increased HR (Hyde & Scalapino, 1918), whereas the tempo of music influenced RR (Diserens, 1920). Bernardi and colleagues (2009) have recently reported that music crescendos or emphases (e.g., in Nessun dorma from Puccini's Turandot) induced skin vasoconstriction along with increases in blood pressures and HR. There was also increased breath depth during music crescendos, but these modulations of respiratory power were independent of cardiovascular modulations. The present study also shows that music listening independently modulated RR and HR, and the former correlated with negative valence, wonder and transcendence. Also in line with the present results, Nakahara, Furuya, Francis, & Kinoshita, (2010) found that playing Bach's No. 1 Prelude with emotional expression increased HR and decreased RR in pianists, in comparison to playing the same piece without emotional expression. Therefore, these studies suggest that music-induced emotions can independently modulate cardiovascular and respiratory activities, and this pattern of physiological hanges may contribute to the receptiveness or arousal to music (Bernardi et al., 2009; the present study) and the capacity ofperformers to incorporate expressiveness in their performance(Nakahara, Furuya, Francis, & Kinoshita, 2010).

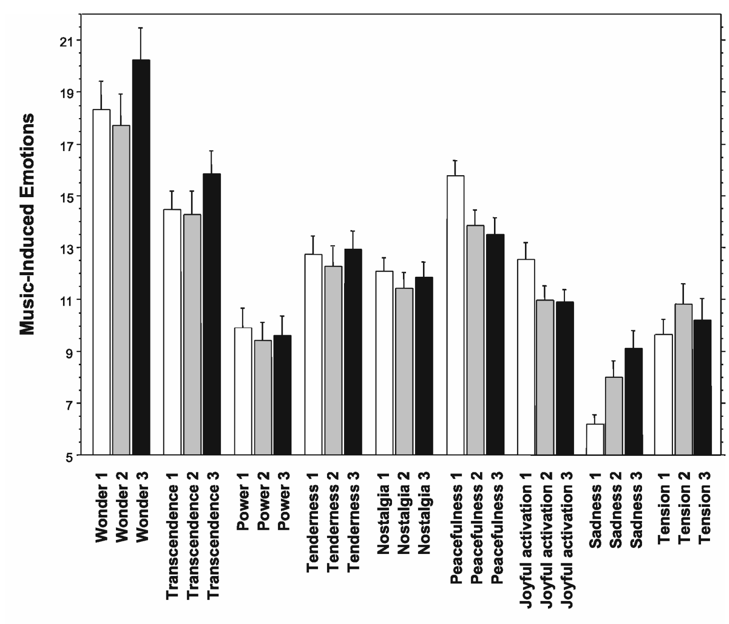

Fig. 2. *Changes in GEMS scores induced by music listening (1), learning the plot (2), and watching the acting performance (3).*

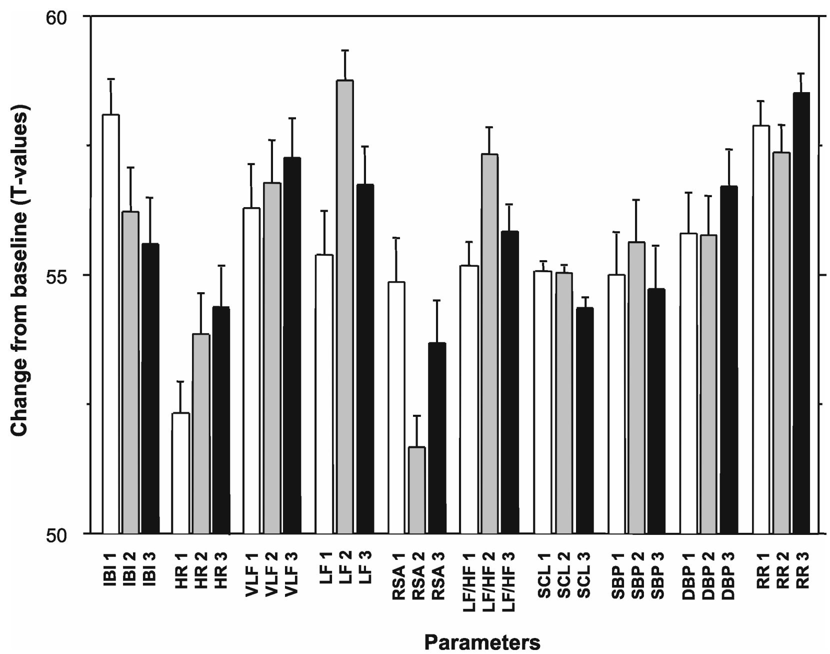

Fig. 3. *Changes in interbeat intervals (IBI), heart rate (HR), power in the very low frequency (VLF), and low frequency (LF) bands of heart rate variability, respiratory sinus arrhythmia (RSA), sympathovagal balance (LF/HF), skin conductance level (SCL), systolic blood pressure (SBP), diastolic blood pressure (DBP), and respiratory rate (RR) induced by music listening (1), learning the plot (2), and watching the acting performance (3).*

Our control analyses on the data from an independent sample indicated that re-listening to the musical excerpt for three times did not increase emotional arousal and valence, or induced additional physiological changes by itself. Whereas there were no differences between the conditions of the control experiment, which argued that repeated music listening alone did not affected the subjective and physiological measurements, the relevance of the physiological measurements from the control experiment is limited. There were differences in IBI and RR between the sample used in the main and control experiments, respectively. This was probably due to the reduced sample size in the control experiment (N = 9, in comparison to N = 37 in the main experiment).

Learning the plot before listening to the musical excerpt the second time (in the main experiment) induced a pattern of emotional changes that included reduced peacefulness, joyful activation, and increased sadness. At the physiological level, learning the plot decreased RSA and increased LF-HRV. The change in RSA reflects vagal suppression that has been associated with negative emotional states and traits, such as anxiety and depression (Bleil, Gianaros, Jennings, Flory, &Manuck, 2008; Miu et al., 2009). The summary of the plot that the participants read before they re-listened to the musical excerpt described negative emotional events (e.g., Scarpia tortures Cavaradossi and harasses Tosca; see Supplementary materials). Therefore, we argue that the sadness induced by learning the plot triggered vagal suppression that was neither explained by concomitant respiratory changes (i.e., RR was controlled for in the analyses of RSA), nor by re-listening to the musical excerpt by itself. The increase in LF-HRV suggests that learning the plot also facilitated sympathetic activity. However, LF probably reflects a complex interplay between sympathetic andvagal influences on the heart (Eckberg, 1997; Miu et al., 2009), so the effect of learning the plot on sympathetic activity should be taken with caution. Overall, learning the plot significantly influenced music-induced emotions and changed sympathovagal balance in the direction of greater preparedness for action.

Watching the acting performance increased emotional arousal and valence (SAM) compared to the first two experimental conditions. Furthermore, it increased wonder and transcendence (GEMS). Notably, wonder and transcendence are emotions that are specifically induced by music (Zentner et al., 2008). In comparison to music listening and learning the plot, watching the acting performance added social-emotional and visuospatial cues to the musical experience: facial expressions, gestures and postures, translated lines, and scenery. These factors probably contributed to the semantic processing of music and vocal expressions, and we argue that this experimental condition best approximated the full musical experience of listeners attending a live opera performance. Watching the acting performance decreased IBI and SCL in comparison to music listening. Previous studies reported that music-induced sadness ratings correlated positively with IBI and negatively with SCL (Krumhansl, 1997; Nyklícek et al., 1997). In addition, watching the acting performance was also related to significantly more music-induced chills. Another recent study showed that music-induced chills correlated with increased SCL and HR (Guhn, Hamm, &Zentner, 2007). The apparent divergence between these previous results and the present findings of increased wonder and transcendence associated with decreased IBI and SCL, and increased music-induced chills may be explained by differencesin experimental design and measures. First, previous studies used short excerpts from classical orchestral music, whereas we focused on opera. Second, the previous studies investigated music listening alone, whereas our observations are based on a condition that involved music listening while watching the acting performance. Third, their conclusions are based on comparisons between music expressing negative and positive emotions, identified using basic emotions questionnaires. In the present experiment, watching the acting performance induced wonder and transcendencemeasured using GEMS. Overall, our results show for the first timethat watching the acting performance contributes to music-induced wonder and transcendence that are associated with decreased IBI and SCL, and increased chills.

In summary, both music listening (compared to baseline), and watching the acting performance (compared to music listening) decreased IBI and SCL. As shown in Fig. 3, IBI followed the same decreasing trend, whereas SCL remained at the same level after learning the plot compared to music listening. This means that learning the plot did not significantly influence these physiological variables, but they nonetheless remained at the level induced by music listening (i.e., they did not return to baseline). Therefore, music listening decreased RR, IBI, and SCL, learning the plot had no effect on these measures, and watching the acting performance significantly decreased IBI and SCL again. This indicates that IBI and SCL are the main physiological variables that are influenced by music listening and watching the acting performance. The only variables that were specifically influenced by learning the plot were RSA and LF-HRV, which indicates that they are sensitive to the addition of meaning in this context.

Therefore, we argue that the sadness induced by learning the plot triggered vagal suppression that was neither explained by concomitant respiratory changes (i.e., RR was controlled for in the analyses of RSA), nor by re-listening to the musical excerpt by itself. The increase in LF-HRV suggests that learning the plot also facilitated sympathetic activity. However, LF probably reflects a complex interplay between sympathetic and vagal influences on the heart (Eckberg, 1997; Miu et al., 2009), so the effect of learning the plot on sympathetic activity should be taken with caution. Overall, learning the plot significantly influenced music-induced emotions and changed sympathovagal balance in the direction of greater preparedness for action.Therefore, these studies suggest that music-induced emotions can independently modulate cardiovascular and respiratory activities, and this pattern of physiological changes may contribute to the receptiveness or arousal to music (Bernardi et al., 2009; the present study) and the capacity of performers to incorporate expressiveness in their performance (Nakahara, Furuya, Francis, & Kinoshita, 2010).

Cap. 3. A field study of emotions in a live opera performance: Individual differences in empathy, visual imagery, and mood

Very limited empirical evidence exist on the influence of social factors (i.e., music listening in group) on musical emotions. For instance, two recent studies reported that the number of chills does not differ between individual and group listening of music (Sutherland et al., 2009), but social feedback influences the emotional ratings of several music fragments (Egermann, Grewe, Kopiez, &Altenmuller, 2009). Although such laboratory and Internet-based experiments in which individual and group conditions are compared can draw attention to the basic mechanisms underlying musical emotions, field studies are essential for testing these social and emotional mechanisms in their natural environment (Juslin&Vastfjall, 2008; Scherer, 2004; Scherer &Zentner, 2001). This approach has already provided valuable data on the frequency and functions of music listening in everyday life (Juslin, Liljestrom, Vastfjall, Barradas, & Silva, 2008; Sloboda, O'Neil, &Ivaldi, 1991), and the factorial structure of musical emotions (Zentner, Grandjean, & Scherer, 2008). However, field studies have remained elusive as to the mechanisms of musical emotions. To our knowledge, there is only one field study that measured emotional ratings, electrodermal and respiratory responses in a small sample of spectators (i.e., 27 listeners) during several live performances of Wagner’s operas given in the festival theatre of Bayreuth in 1987-1988 (Vaitl, Vehrs, &Sternagel, 1993). These limited results suggested that physiological responses differed between opera leitmotivs, and there was a weak correspondence between physiological and subjective measures of emotions. Considering that the contribution of various mechanisms (e.g., empathy, visual imagery) underlying musical emotions may differ between laboratory conditions and natural social situations (Juslin&Vastfjall, 2008), this field study was designed to investigate for the first time the influence of empathy, visual imagery and affective mood, while controlling for the effects of personality, musical preferences, age and sex on multimensional measures of musical emotions during a live opera performance in a concert hall.

This study was designed to investigate the relationships between empathy, visual imagery, and affective mood on musical emotions and chills measured during a live opera performance in a concert hall. The analysis of our results followed several lines: (1) describe the specific emotions associated with each act of the opera performance; (2) determine the degree to which empathy, visual imagery, and affective mood predicted musical emotions and chills; (3) contrast musical emotions between samples selected for extreme scores of empathy and visual imagery; and finally, (4) explore the relationships between musical emotions and chills.

The present study compared between measures of affect administered immediately after each act. Participants were repeatedly instructed to complete the questionnaires as soon as an act finished, based on the emotions that they felt during that act, while ignorring distractors. Applauses would have been a powerful distractor for our participants, hadn't the director wanted to emphasize the emotional and dramatic continuity between the acts by not lifting the courtain for applauses in this production. Therefore, we argue that our self-report measurements reliably reflected the emotions induced by each act of the opera performance. The pattern of results obtained with PANAS indicated that joviality and self-assurance gradually decreased after the second and third act, but fear and sadness significantly increased only after the third act. The scores of other emotions, less relevant to the music (e.g., guilt, attentiveness), also changed. GEMS scores reflected the emotions associated with each act even more specifically: the hopelessness of Butterfly in act II induced a decrease of power scores; sadness increased in act II and peaked in act III – complementary, tenderness, peacefulness, and joyful activation decreased in acts II and III; wonder and transcendence specifically increased in act III. In addition, the emotion of tension from GEMS, as well as the frequency of self-reported musical chills gradually increased and the difference reached significance in the third compared to the first act. In addition to the sensitivity to emotional change that was demonstrated by PANAS-I, GEMS showed an impressive specificity to the emotions (e.g., sadness) that are captured in the musical score. Moreover, we believe that the increases in wonder and transcencence that were specifically reported by the participants after act III had at least two sources: first, the ritualistic suicide of Butterfly is probably perceived by spectators as a superior gesture of honor, which inspires “aesthetic awe” (Konecni, 2008); second, act III allows the soprano that plays Cio-cio-san to display her gamut of vocal and dramatic skills. Therefore, we suggest that GEMS is sensitive to both structural, and performance features of music (Baltes et al., 2010; Scherer &Zentner, 2001).

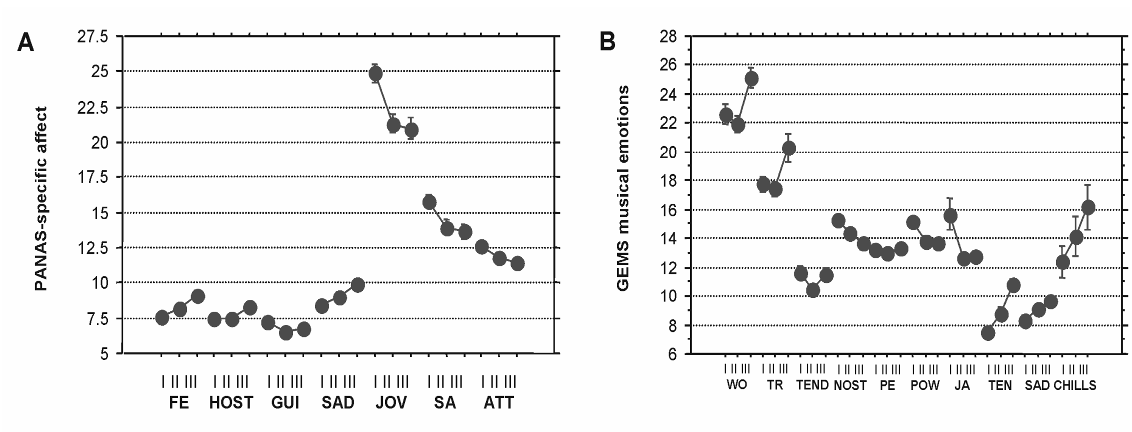

Fig. 3.1 *Emotions during each act of the opera performance, as reflected by PANAS-II and GEMS. Abbreviations: FE, fear; HOST, hostility; GUI, guilt; SAD, sadness, JOV, joviality; SA, self-assurance; ATT, attentiveness; WO, wonder; TR, transcencence; TEND, tenderness; NOST, nostalgia; PE, peacefulness; POW, power; JA, joyful activation; TEN, tension*

The regression analyses were focused on empathy, visual imagery, and affective mood as independent variables, and sadness from PANAS, wonder, transcendence, sadness, tension from GEMS, and chills measured after each act, as dependent variables. We found that empathy contributed to the prediction of wonder after the second act. This confirmed our hypothesis that empathy predicts emotions that are associated with acting (Baltes et al., 2010). Visual imagery also contributed to the explained variances of: (1) GEMS-wonder, and transcendence after the first act; (2) GEMS-sadness after the second act; and (3) chills after the second and third act. We followed up these effects in comparisons of emotions between participants selected for scores of empathy and visual imagery in the extreme quartiles. These analyses indicated that more empathetic participants reported increased levels of attentiveness and tenderness on PANAS, as well as peacefulness on GEMS. Overall, these results suggest that empathy and visual imagery influence musical emotions, and their involvement does not overlap. As shown in Table 1, the associations of empathy and visual imagery with emotions were non-trivial (sr2 > 0.1), which provides sufficient support to further test the involvement of these mechanisms in the genesis of musical emotions in more controlled laboratory conditions. For instance, an ongoing study in our laboratory manipulates empathy in a between-subject experimental design, and tests the impact of this manipulation on self-reported musical emotions and the associated physiological activity (see also Van Lange, 2008). Also, a recent study differentiated between two cognitive styles of music listening: music-empathizers who prefere to tune to the emotional content of music and the feelings that the composer wanted to convey, and music-systemizers, who choose to focus their attention on the structural aspects of music (Brattico& Jacobsen, 2009; Kreutz, Schubert, & Mitchell, 2008). Considering that music-empathizers are presumably more frequent among women, we would have expected to find a statistical interaction of sex, empathy, and opera act on musical emotions. However, the sex distribution of our samples selected for extreme empathy scores was not homogenous (e.g., only six men with empathy scores in the upper quartile). Our ongoing laboratory study is also looking into the interaction of empathy and sex on musical emotions.

The regression analyses also indicated that negative and positive mood contributed to the prediction of emotions such as sadness, transcendence, and tension. The affective mood before the performance was significantly associated with sadness after acts I and II, and transcendence after act I. This indicates that the effects of previous mood on these musical emotions started to wane after the performance began, probably because the spectators' attention was drawn by the opera performance, and music induced succesive "emotion episodes" that gradually changed the affective tone (Scherer &Zentner, 2001). However, the significant association of tension after the third act with previous positive mood represents a noteworthy exception – a pleasant mood before the performance may facilitate the effects of opera-related emotions on overall mood at the end of the performance. We suggest that if one is in a positive mood, it is more likely that s/he will be absorbed in the music performance, and will report a music-congruent change in mood at the end of the performance. Briefly, spectators that come to an opera performance in a positive mood may be more open to experiencing the emotions that singing-acting expresses.

A new and significant line of results indicated that individual differences in visual imagery contributed to the prediction of musical chills after acts II and III. Chills are extensively used as an indicator of individual emotional peaks (Grewe, Kopiez, &Altenmuller, 2009). Indeed, we found that chills correlated with several musical emotions during each act. For instance, chills were significantly associated with sadness, wonder, tension and nostalgia after the final act. This supports the view that musical chills are informative measures of musical emotions, and they may be sensitive to structural and performance features of music.

In summary, this field study investigated the complex relationships between empathy, visual imagery, affective mood on the one hand, and musical emotions and chills on the other. We provided empirical support for the involvement of these mechanisms in the genesis of musical emotions measured in the natural environment where they occur. This opens the perspective for laboratory studies in which these mechanisms are manipulated, and physiological measures of musical emotions are also included. These pioneering results also illustrate the potential of field studies to contribute to the development of multidimensional theories of musical emotions. Concert halls are an exciting place to study musical emotions!

Cap. 4. Affective space and a comparison of music-induced emotions between musicians and non-musicians.

The objectives of the present study were: (1) to explore the affective space of Vivaldi's Four Seasons; and (2) to compare the emotional arousal and valence of the Four Seasons between musicians and non-musicians. Although Vivaldi's masterpiece is widely known, we expected differences in familiarity between musicians and non-musicians, and consequently we controlled for this variable in the comparisons of emotional responses. We hypothesized that the movements of Vivaldi's Four Seasons would cover the entire affective space (i.e., positive and negative valence with varying degrees of emotional arousal), considering the composer's intention to suggest the features of different seasons in his music. Another hypothesis was that, although we controlled for differences in familiarity with this particular composition, musicians would perceive the Four Seasons as less emotionally activating and pleasant than non-musicians, due to their knowledge of baroque music style.

A visual inspection of the affective space presented in Fig. 1 clearly indicates that the slow movements had the lowest arousal scores. The Largo e pianissimo sempre from the Spring was the least activating movement from all the concertos. Therefore, the present results suggest that the differences in tempo were the major influence on the perceived emotional arousal of the movements in Vivaldi's Four Seasons, and extend previous observations on the relationship between music tempo and emotional arousal (Holbrook, 1990; Husain, Thompson, &Schellenberg, 2002; Scherer &Zentner, 2001).

The valence scores were exclusively distributed in the right half of the affective space, that is, all the movements were perceived as pleasant. However, there were significant differences between the valence scores of various movements, with the Adagio molto from the Autumn being perceived as the least pleasant, and the first Allegro from the Spring being the most pleasant. Whereas the former movement suggests the peacefulness of outdoor sleep that follow the celebration of the harvest, the second suggests the joyfulness associated with the happiness of birds, the flowing of streams and the gentle blow of the zephyr. Therefore, the difference in valence between these movements seems to distinguish between the peacefulness and joyfulness that the composer wanted to suggest. The Allegro spring is also the most popular and best known movement of Vivaldi's Four Seasons, with no differences in familiarity between musicians and non-musicians in this study. Not surprisingly, excerpts from this movement have also been used in previous psychophysiological research as happy music. For instance, using several second excerpts from this movement, Krumhansl (1997) found that it induced emotions of happiness, amusement and contentment that were associated with faster breathing rate and decreased respiration depth. The pleasant and activating affect associated with this movement from Vivaldi's Four Seasons may have contributed to its popularity among listeners.

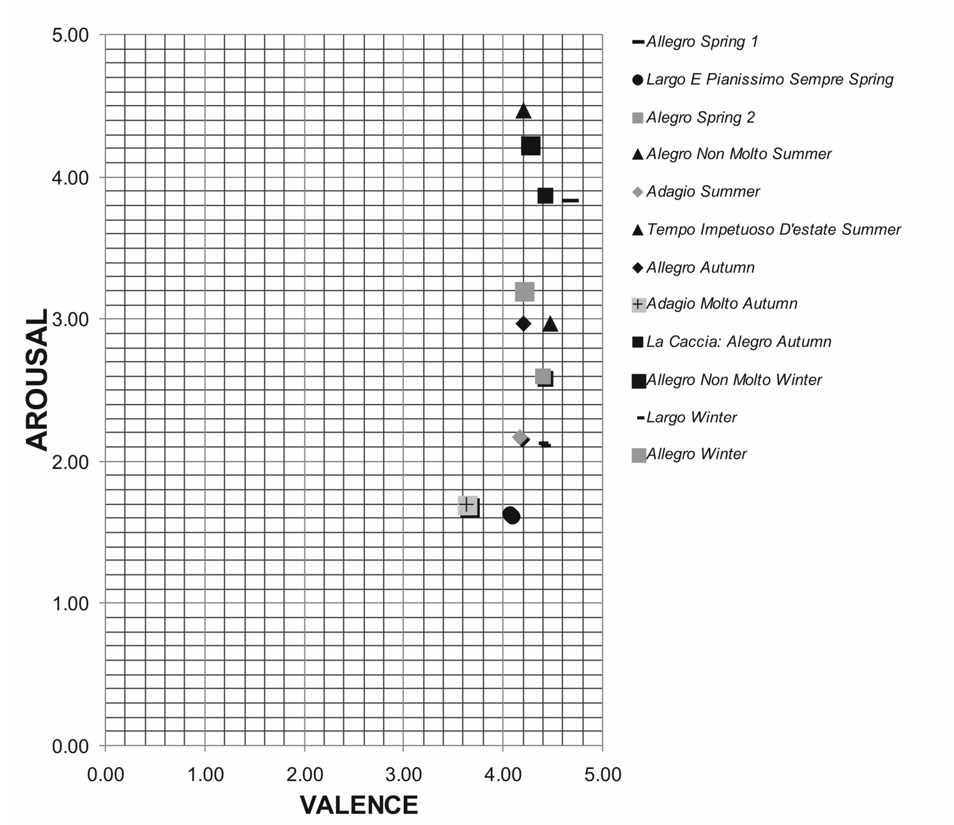

Fig. 1 *The affective space of Vivaldi's Four Seasons.*

By comparing between groups of musicians and non-musicians, the present study found only two significant differences related to the emotional arousal triggered by the Adagio molto autumn and the emotional valence induced by the Allegro non-molto summer. We believe that these movements may not be incidentally associated with affective differences between musicians and non-musicians. Musicians' aesthetic judgments may be focused on the novelty and originality of music (Ystok et al., 2009) – with them being more familiar with the features of the baroque musical style, the Adagio movement from the Autumn may have stood out as more original and thus more inciting. Intriguingly, probably Vivaldi also found this movement particularly original since he returned to it, by simply transposing it and making it the middle movement (Il Sonno) of Opus 10, no. 2 (Pincherle, 1957). Perhaps for the same reasons of novelty and originality, the musicians in the present study found the Allegro Non-Molto Summer as less pleasant than non-musicians. Quoting from Picherle's (1957, p. 192) musical analysis, this movement "fall[s] back into a more conventional realm with restless figuration intended to depict […] the summer thunderstorm". In summary, we found discrete differences in affect between musicians and non-musicians, and we suggest that these differences are related to the formal training in musical grammar that gives musicians an advantage in appreciating the originality of a musical piece, and detecting fine changes in musical structure (e.g., dynamics, intensity, instrumentation, tonal norms).

In conclusion, the present study found that all the movements of Vivaldi's Four Seasons are exclusively perceived as pleasant, with slower movements inducing less emotional arousal than faster movements. In addition, we found discrete differences in the affect that this music induced in musicians and non-musicians, and suggest that these differences are related to the increased focus of musicians on original features of certain movements in relation to the others. This study encourages efforts to map the affective space of entire musical compositions, which would be useful in behavioral interventions aimed at supporting emotion regulation in everyday life, and enhancing cognitive recovery in clinical populations.

Cap. 5. Cognitive empathy manipulation influences music-induced emotions and physiological activity

The main aim of this study was to test the causal relationship between cognitive empathy and music-induced emotions. Cognitive empathy was manipulated during music listening and we measured music-induced emotions and physiological activity. We used two music stimuli with sad and happy content, respectively, in order to test the effects of empathy on emotions induced by music with divergent emotional valence. The general hypothesis was that in comparison to the low empathy condition, the high empathy would increase music-induced emotions and physiological activity. Considering that multimodal displays of music that incorporate facial expressions, gestures and body postures in addition to sounds may facilitate empathy with the performer (Livingstone & Thompson, 2009), we used video recordings of the two music pieces performed in concerts.

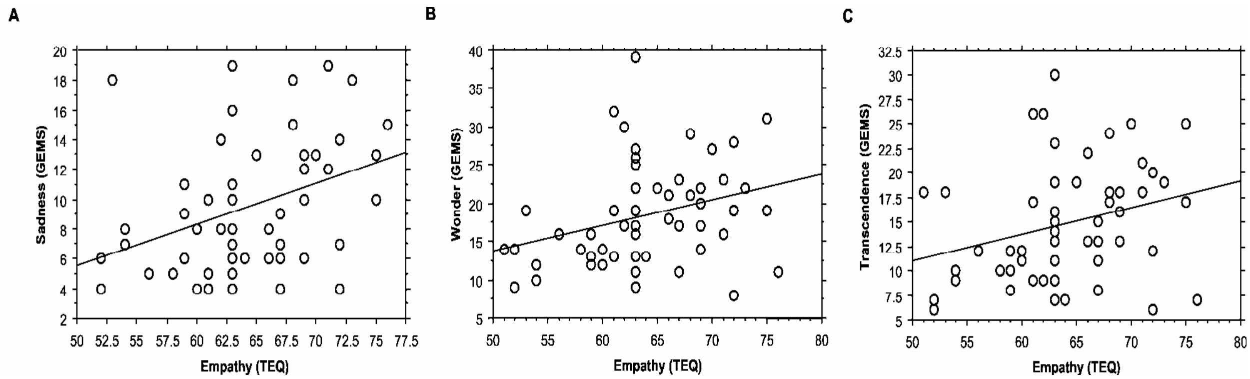

Fig.5.1 *Relationships between trait empathy and music-induced sadness (A), wonder (B) and transcendence (C) after listening to Gelido. Abbreviations: TEQ, Toronto Empathy Questionnaire; GEMS, Geneva Emotional Music Scales.*

Two lines of evidence reported here strongly connected empathy and music-induced emotions. The most important was based on the manipulation of cognitive empathy and showed that the deliberate efforts made by listeners to empathize with the musical performer, and imagine her feelings related to the music she performed, facilitated music-induced emotions and physiological activity. These effects were highly specific in two ways. First of all, the emotions that empathy facilitated were closely related to the emotional content of the music: in the high compared to the low empathy conditions, nostalgia and sadness increased after listening to Gelido, whereas power and joyful activation increased after listening to Rataplan.

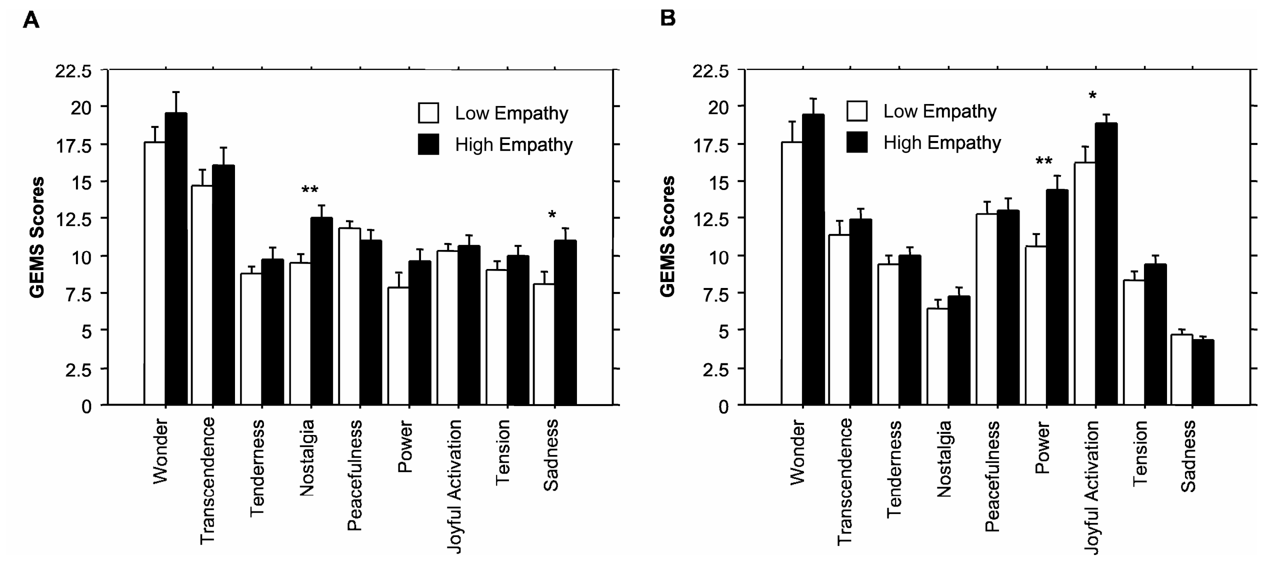

Fig. 5.2 *Comparison between the low and high empathy conditions on music-induced emotions after listening to Gelido (A) and Rataplan (B). Abbreviation: GEMS, Geneva Emotional Music Scales. * $p< 0.05$, ** $p< 0.01$.*

This underscores the fact that empathy is based on the understanding of the target's state of mind (Decety& Jackson, 2006; Livingstone & Thompson, 2009), which in this case referred to the thinking and feeling of the performer in relation to the music. The selectivity of these effects could not have been discovered hadn't we used a multidimensional music-induced emotions questionnaire such as GEMS (Zentner et al., 2008). Second of all, empathy changed the physiological activity in a manner that was coherent with the music-induced emotions. In comparison to the low empathy, the high empathy condition decreased SCL during Gelido, and increased HR and RR during Rataplan. Previous studies showed that music-induced sadness is associated with SCL decreases (Baltes, Avram et al., 2011; Khalfa, Isabelle, Jean-Pierre, &Manon, 2002; Krumhansl, 1997), and happiness correlates with HR and RR increases (Bernardi et al., 2009; Nyklicek et al., 1997). In addition, HR increases have also been associated with imagining other's feelings (Preston et al., 2007). Therefore, the present study showed that cognitive empathy selectively enhanced the emotions that were related to the content of the music, and increased the coherence of these emotions with the underlying physiological changes. To our knowledge, this is the first study that causally implicates cognitive empathy in the genesis of music-induced emotions, and supports the view that this mechanisms is a central route by which music induces emotions (Scherer &Zentner, 2001).

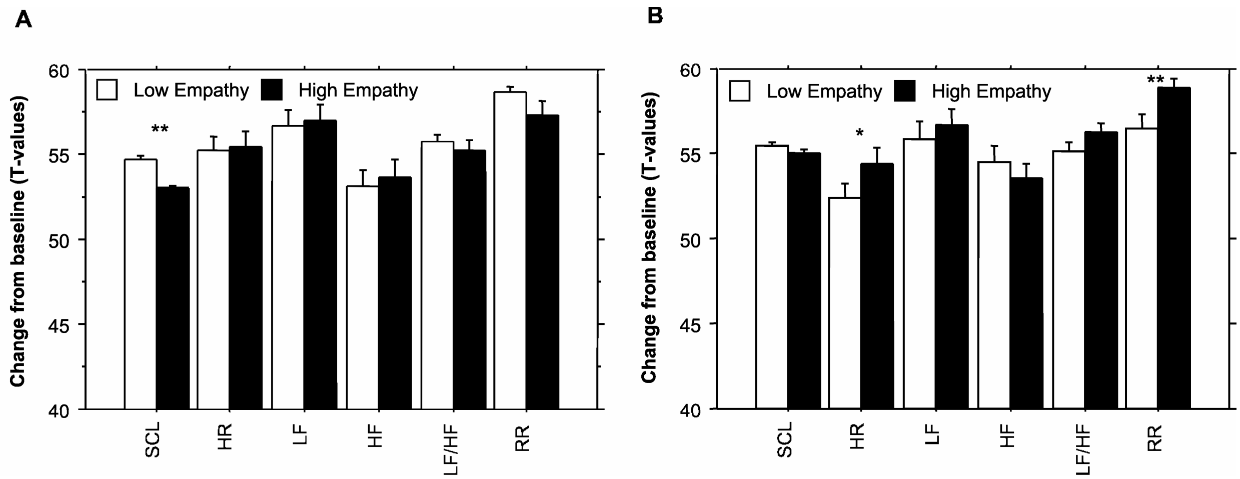

Fig.5.3 *Comparison between the low and high empathy conditions on physiological activity during Gelido (A) and Rataplan (B). Abbreviations: SCL, skin conductance level, HR, heart rate; LF, power in the low frequency band of heart rate variability; HF, power in the high frequency band of heart rate variability; RR, respiration rate. * p< 0.05, ** p< 0.01.*

The second line of evidence was related to dispositional empathy. In the present dataset, trait empathy significantly predicted sadness, wonder and transcendence after listening to Gelido. This is in line with previous findings that focused on "musical empathy" and enjoyment of negative emotions in music (Garrido& Schubert, 2011), or trait empathy and emotions such as wonder experienced during a live opera performance (Baltes, Miclea et al., 2011). One may question why wasn't trait empathy also related to the positive emotions induced by Rataplan. Various studies have described interactions of empathy and emotional valence (Davis et al., 1987; Levenson&Ruef, 1992), and would support a claim that trait empathy is selectively related to negative emotions. We believe that such an explanation would be artificial and premature in the present context. It is possible that negative emotions (e.g., sadness) induced in the laboratory are simply more salient than positive emotions (Rottenberg, Ray, & Gross, 2007). In addition, studies have only recently started to use multidimensional scales for music-induced emotions, such as GEMS. It remains to be verified whether trait empathy is specifically related to emotions of a certain valence, or specific music-induced emotions (e.g., wonder). Future studies might also investigate whether the effects of trait empathy and active empathizing on music-induced emotions are independent or not. One may speculate that trait empathy moderates the effects of empathizing on emotions.

In conclusion, this experimental study indicated that voluntarily empathizing with a musical performer can modulate negative and positive music-induced emotions, as well as their underlying physiological activity. Considering that musical performance offers a context in which listeners seek to resonate with the feelings of the performer in relation to the music, it is likely that cognitive empathy is incidentally used to enhance aesthetic emotions in everyday music listening.

Cap.6. Conclusions and final discussion. Implications and future directions

The studies presented in this doctoral thesis underscore music as a complex stimulus, that can make someone experience various and multiple emotions in a brief period of time. No other stimuli, words or images, has such a complex effect.

The results presented in this thesis emphasize some important implications for future research on music-induced emotions, in general, especially by operatic music.

First, this thesis is one of the few research papers leading the field of experimental psychology of music, in Romania, and these studies are among the first exploring operatic music, at international level.

Second, the conceptually rigorous experiments reveal the multiple emotional sources contributing to the development of operatic music - induced emotions, and some of the mechanisms underlying this process.

Third, this is among the first Romanian contributions to the psychophysiology of music-induced emotions leading to the understanding of this challenging and controversial music and emotion research field.

Fourth, as far as we know, the field study presented in this paper, is the first study exploring emotions induced by live operatic music, using a representative sample (i.e., 120 participants) for the audience present to the opera performance, that day. Moreover, we used a recent (GEMS) domain specific instrument (both in the field and laboratory study) for assessing emotions induced by operatic music, which allowed us to catch specific emotions induced by the opera performance, correlated with physiological responses.

Additionally, as far as we know, we had the first attempt to map the affective space of an entire musical composition, arguing how this kind of attempt could be useful to future research and clinical applications.

Furthermore, we extended previous observations (Bigand et al., 2005) showing that there are no significant differences between musicians and non-musicians, as far as music-induced emotions are concerned.

Moreover, contrasting other previous studies, we utilized as musical stimuli entire musical pieces, or musically and dramatically coherent musical excerpts, leading to better external validity of our results.

As far as the mechanisms underlying music-induced emotions are concerned, the study we manipulated empathy in (Study 4) is the first one causally involving cognitive empathy in the genesis of musical emotions, supporting the perspective suggesting that this mechanism is a central route by which music induces emotions.

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