Frontal brain electrical activity (EEG) distinguishes *valence* and *intensity* of musical emotions

Louis A. Schmidt and Laurel J. Trainor
McMaster University, Hamilton, Canada

Using recent regional brain activation/emotion models as a theoretical framework, we examined whether the pattern of regional EEG activity distinguished emotions induced by musical excerpts which were known to vary in affective valence (i.e., positive vs. negative) and intensity (i.e., intense vs. calm) in a group of undergraduates. We found that the pattern of asymmetrical frontal EEG activity distinguished valence of the musical excerpts. Subjects exhibited greater relative left frontal EEG activity to joy and happy musical excerpts and greater relative right frontal EEG activity to fear and sad musical excerpts. We also found that, although the pattern of frontal EEG asymmetry did not distinguish the intensity of the emotions, the pattern of overall frontal EEG activity did, with the amount of frontal activity decreasing from fear to joy to happy to sad excerpts. These data appear to be the first to distinguish valence and intensity of musical emotions on frontal electrocortical measures.

Despite the fact that music is a powerful elicitor of emotion (Goldstein, 1980; Panksepp, 1995; Sloboda, 1991), and musicologists believe that the meaning of music lies in the emotions it describes or invokes (e.g., Cooke, 1959; Langer, 1959; Meyer, 1956), models of the emotion circuits in the brain have for the most part ignored emotions arising from musical stimuli. Yet music is used across cultures to express and inspire emotion, from declaring love to lamenting the death of a loved one to inspiring patriotic and military action (Trehub & Trainor, 1998). Psychological studies show that listeners are quite consistent in associating basic or primary emotions such as happiness, sadness, fear, and anger to musical compositions (e.g., Cupchick, Rickert, & Mendelson, 1982; Hevner, 1936; Nordenstreng, 1968; Wedin, 1972). Even children as young as 3

Correspondence should be addressed to Louis A. Schmidt or Laurel J. Trainor, Department of Psychology, McMaster University, Hamilton, Ontario, L8S 4K1, Canada;
e-mail: schmidtl@mcmaster.ca *or* ljt@mcmaster.ca

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years of age reliably associate musical excerpts and emotions (e.g., Cunningham & Sterling, 1988; Trainor & Trehub, 1992).

The biological significance of the emotional associations of music is perhaps most evident in the infancy period, where much of the interaction between preverbal infants and their caregivers involves regulation of the infants' states and the communication of emotional information. Parental singing provides one of the main means of such communication. When singing to their infants, caregivers sing more slowly, in a higher pitch, and with a more loving tone of voice than they sing otherwise (Trainor, Clarke, Huntley, & Adams, 1997). Infants prefer to listen to infant-directed over noninfant-directed singing, and appear to be particularly attracted by the loving tone of voice (Trainor, 1996). Mothers appear to be able to control the state of their infants through their style of singing, using different styles for putting their infants to sleep and playing with them (Rock, Trainor, & Addison, 1999). Furthermore, caregivers talk to infants in a singing-song manner called infant-directed speech or musical speech (e.g., Fernald, 1991), and preverbal infants respond differently to positive versus negative intonational messages in such speech (Fernald, 1993).

The strong association between music and emotion as well as the fact that music and/or musical speech play a vital role in early emotional communication suggest that a full understanding of how emotional information is processed in the brain will not be complete until responses to music are considered. The extant literature examining the psychophysiology of emotion in music has primarily focused on peripheral physiological measures. For example, there are documented relations between music and autonomic measures. Thayer and Levenson (1983) found that music added to stressful films was related to changes in skin conductance levels. Still more recent studies have noted changes in peripheral physiological measures during the presentation of different affective music excerpts. Krumhansl (1997) noted that sad excerpts produced the largest changes in heart rate, blood pressure, skin conductance, and temperature; fear excerpts produced the largest changes in blood transit time and amplitude; happy excerpts produced the largest changes in respiration measures.

Studies of the central processing of musical stimuli have focused primarily on cognitive aspects such as rhythm, pitch, contour, and expectancy. What is clear from these studies is that many areas of the brain including frontal, temporal, and parietal regions are involved in music processing (Samson & Zatorre, 1992; Trainor, Desjardins, & Rockel, 1999), and that laterality effects can change with musical experience and the specific instructions given to subjects (Zatorre, Halpern, Perry, Meyer, & Evans, 1996). With respect to emotion, Blood, Zatorre, Bermudez, and Evans (1999) found fCBF changes in paralimbic regions as a function of the perceived pleasantness of musical stimuli. In the present study, we tested whether recent models of cortical regional brain activation in emotion were valid for distinguishing among musical emotions in adults.

Regional brain activation/emotion models

Although the two main dimensions of emotion are valence and intensity, there are few models relating emotion to brain activity that consider both dimensions. Some 20 years ago Davidson and his colleagues (Davidson, Schwartz, Saron, Bennett, & Goleman, 1979) suggested a model of emotion in which they argued that emotions are: (1) organised around approach-avoidance tendencies; and (2) differentially lateralised in the frontal region of the brain. The left frontal area is involved in the experience of positive emotions such as joy, interest, and happiness; the experience of positive affect facilitates and maintains approach behaviours. The right frontal region is involved in the experience of negative emotions such as fear, disgust, and sadness; the experience of negative emotion facilitates and maintains withdrawal behaviours.

Using EEG measures to index ongoing frontal brain electrical activity during the processing of different affects, Davidson and Fox have found substantial empirical support for the model in adults and infants (see, Davidson, 1993; Davidson & Rickman, 1999; Fox, 1991, 1994, for reviews). Greater relative left frontal EEG activity is routinely associated with the processing of positive affects (e.g., when viewing film clips containing pleasant scenes), whereas greater relative right frontal EEG activity is consistently linked with the processing of negative affects (e.g., when viewing film clips containing unpleasant scenes) (Jones & Fox, 1992). In addition, the motivational tendencies of approach and avoidance that underlie different types of emotion are known to be distinguishable on frontal EEG asymmetry measures. Sutton and Davidson (1997), for example, found that adults with greater relative left frontal EEG activity were likely to score high on psychometric measures of approach-related tendencies.

Importantly, the frontal activation/emotion valence model has been corroborated across several stimulus modalities, age groups, and measures. For example, Fox and Davidson (1986) found that asymmetrical frontal brain activity discriminated sweet and sour tastes in newborns. Specifically, newborns exhibited greater relative left frontal EEG activity to the presentation of sweet solutions and greater relative right frontal EEG activity to the presentation of sour solutions. With visual stimuli, an fMRI brain imaging study in adults found greater left hemisphere activity for positive pictures and greater right hemisphere activity for negative pictures (Canli, Desmond, Zhao, Glover, & Gabrieli, 1998).

The second model concerns the role of absolute frontal activation in the *intensity* of emotion. A number of investigators (Dawson, 1994; Henriques & Davidson, 1991; Schmidt, 1999; Schmidt & Fox, 1999) have argued that the pattern of absolute activation in the frontal region may reflect the intensity of affective experience. This notion is based on two sets of empirical evidence. The first body of evidence comes from studies that have shown that the processing of intense transient emotions is related to heightened overall activation in the frontal region. For example, Dawson and her colleagues (Dawson, Panagiotides, Grofer Klinger, & Hill, 1992) noted that infants exhibited an increase in overall frontal EEG activity during maternal separation which was paralleled by behavioural signs of distress.

A second set of evidence concerns data from studies examining the relation among resting measures of absolute frontal activation and emotion in different affective styles. For example, Davidson and his colleagues (Henriques & Davidson, 1991) noted a pattern of greater relative right frontal EEG activity in depressed adults. The pattern of frontal asymmetry was a function of low EEG activity in the left frontal lead. They speculated that low activity in the left frontal region in depression may reflect an inability to experience positive affect. More recently, Schmidt and Fox (1994) found that adults who were highly social exhibited greater overall frontal activity in both frontal hemispheres in anticipation of social encounter (a state measure) compared with low social adults. They speculated that the pattern of heightened overall frontal activity in highly social adults may reflect the presence of heightened positive affect. Indeed, measures of sociability and positive affect are known to be highly related (Costa & McCrae, 1980). Even more recently, Schmidt (1999) found that adults who self-reported *both* high shyness and high sociability exhibited greater relative right frontal EEG activity that was characterised by hyperactivity in both the left and right frontal brain regions in resting conditions compared with adults self-reporting other combinations of shyness and sociability. Schmidt (1999) speculated that the pattern of heightened activity in both the left and right frontal region during resting conditions in high shy/high social adults may reflect a predisposition to experience both heightened positive and negative affect. Moreover, it is possible that this pattern of hyperactivity in both the left and right frontal area may be linked to an approach-avoidance conflict and the observations of increased behavioural anxiety which is known to characterise this shy subtype during unfamiliar social situations (Cheek & Buss, 1981).

A third model considers both dimensions of emotion (Heller, 1993). Heller argues that the frontal and right parieto-temporal regions are involved in emotion. The frontal region is involved in the modulation of emotional valence in the same manner as that proposed by Davidson and his colleagues: Greater relative left frontal activity during the processing of positive emotions and greater relative right frontal activity during the processing of negative emotions. However, Heller further postulates that the right parietal region is involved in the modulation of autonomic and behavioural arousal, with higher levels of right parieto-temporal activity associated with higher levels of arousal. In summary, the model proposed by Davidson and Fox suggests that asymmetrical frontal EEG activity may reflect the *valence* of emotion experienced, whereas the model proposed by Dawson and Schmidt suggests that absolute frontal EEG activity may reflect the *intensity* of emotion experience. The model proposed by

Heller suggests that asymmetrical frontal EEG activity may reflect the valence of emotion similar to the Davidson and Fox models, whereas right parieto-temporal activity may reflect the intensity of emotion. There are relatively few empirical studies which have tested these models in general and still fewer studies that have tested these models with auditory affective stimuli in particular.

The present study

The present study had two main purposes. The first goal was to examine whether different musical excerpts induce different affective states that can be indexed by measuring brain activity. As Krumhansl (1997) has recently noted, two recently edited books (Ekman & Davidson, 1994; Lewis & Haviland, 1993) on emotion have contained little reference to music. This is surprising given, as noted previously, that music is known to be a powerful elicitor of emotion. One recent study in the extant literature, however, did find that right frontal EEG activity was significantly attenuated in a group of depressed adolescents following exposure to rock music (Field et al., 1998). In addition, the study noted above by Blood et al. (1999) related fCBF measures to the processing of affective musical stimuli, although this brain-based measure is more intrusive than scalp recorded electrocortical measures and this may preclude its use with some populations.

The second was to examine whether we could use measures of regional EEG activity to differentiate emotions along the two dimensions of *valence* and *intensity* simultaneously. In doing so, we would: (1) be able to compare the three separate models of regional brain activity in emotion described above; and (2) overcome one of the main limitations of valence models, which are unable to make fine distinctions among emotions within valence. For example, because joy, happiness, and interest are all positive emotions associated with greater relative left frontal activation, and fear, sadness, and disgust are all negative emotions associated with greater relative right frontal activation, the pattern of asymmetrical frontal activity yields little in terms of distinguishing among emotions within the positive and negative category. By using the models discussed above, we may be able to make more precise distinctions among different types of emotions within valence. We attempted to directly relate valence and intensity of emotional experience to regional brain activity.

We recorded ongoing region brain electrical activity (EEG) in a group of undergraduates while they were presented with orchestral musical excerpts designed to induce joy, happiness, fear, and sadness. Four orchestral excerpts were selected after being pre-rated by a group of undergraduates on dimensions of emotional valence and intensity. The four pieces were rated to represent: intense-unpleasant (fear), intense-pleasant (joy), calm-pleasant (happy) and calm-unpleasant (sad).

Predictions

We made the following predictions based on the three regional brain activation models described above and the behavioural ratings of the selected musical excerpts.

Asymmetric frontal activation and emotion valence hypothesis. We predicted that the pattern of asymmetrical frontal EEG activity would distinguish the valence of affective musical excerpts as predicted by the models articulated by Davidson, Fox, and Heller. Specifically, we expected a significant valence by hemisphere interaction: Greater relative left frontal EEG activity during the presentation of the joy and happy musical excerpts and greater relative right frontal EEG activity during the presentation of the fear and sad musical excerpts.

Regional brain activation and emotion intensity hypothesis. We tested two predictions concerning regional brain activation and emotion intensity relations based on the models articulated by Davidson, Schmidt, Dawson, and Heller. First, we expected a significant main effect for the intensity of affective musical excerpts on overall frontal EEG activity: The pattern of overall frontal EEG activity would distinguish the intensity of the affective musical excerpts across valence as predicted by the models articulated by Davidson, Schmidt, and Dawson; high intensity affective musical excerpts would be associated with more frontal activity compared with low intensity affective musical excerpts.

Second, we hypothesised that right parietal activity would distinguish the intensity of the affective musical excerpts across valence as predicted by the model articulated by Heller. Specifically, based on the behavioural ratings of the stimuli, we predicted overall frontal and right parietal EEG activity would decrease as intensity decreased from the fear to the joy, to the happy to the sad excerpt.

METHOD

Subjects

These were 59 (29 males, 30 females) right-handed undergraduates who were recruited from psychology courses and ranged in age from 18 to 34 years (M = 21 yrs, SD = 2 yrs). All subjects endorsed the use of only the right hand on all of the objects listed on the Oldfield measure of handedness (Oldfield, 1971). Left-handed individuals were excluded because they may differ in hemispheric specialisation for emotion (Heller & Levy, 1981).

Affective musical stimuli and apparatus

The musical stimuli comprised four orchestral excerpts that reflected different affective valence (i.e., pleasant vs. unpleasant) and intensity (i.e., intense vs.

calm): *intense-unpleasant emotion* (e.g., fear), *Peter and the Wolf* by Prokofiev, wolf excerpt; *intense-pleasant* (e.g., joy), *Brandenburg Concerto No. 5* by Bach, first movement; *calm-pleasant emotion* (e.g., happy), *Spring* by Vivaldi, second movement; and *calm-unpleasant emotion* (e.g., sadness), *Adagio* by Barber. These stimuli were pre-rated by a group of undergraduates ($n = 237$) using two bipolar adjectives (e.g., pleasant vs. unpleasant and excited vs. calm) from a paper and pencil version of the self-assessment manikin (SAM; see Lang & Greenwald, 1988). Table 1 presents the pre-ratings of the musical excerpts. Musical excerpts were presented with a Sony CD-player (Model No. CFD-8/2) and synchronised with the EEG data collection.

Procedures

Subjects were briefed about the EEG procedure and a consent form was signed. They were instructed that it was important to ''feel the mood'' that the music evokes. Each of the four musical excerpts was presented for approximately 60 seconds.

Electroencephalogram (EEG) recording

The EEG was recorded continuously during each of the 60 s musical excerpts using a lycra stretch cap (Electro-Cap, Inc.) with electrodes positioned according to the International 10/20 Electrode Placement System (Jasper, 1958). Electrode impedances were below 10 K ohms at each site and within 500 ohms between homologous sites.

The EEG was collected with SA Instrumentation Bioamplifiers from four scalp locations: left and right mid-frontal (F3, F4) and parietal (P3, P4). These sites represent the left and right hemispheres and anterior and posterior regions of the brain. All electrodes were referenced to the central vertex (Cz) during

TABLE 1
Means and standard deviations of pre-ratings of affective valence and intensity of musical stimuli

	Musical excerpt			
Measure	*Peter and the Wolf* (Prokofiev)	*Brandenburg Concerto No. 5* (Bach)	*Spring* (Vivaldi)	*Adagio* (Barber)
Pleasantness	2.05 (1.59)	8.27 (1.03)	7.91 (1.44)	2.91 (1.95)
Intensity	6.18 (2.26)	3.59 (2.68)	2.45 (2.48)	1.91 (1.31)

Note: Adjectives rated on a scale of 1–9.

recording. The data were bandpass filtered between 1 Hz and 100 Hz and digitised at 512 Hz. Electrooculographic (EOG) activity was also recorded to facilitate subsequent EEG artifact editing. Two Beckman miniature electrodes were placed on the external canthus and the supra-orbital area of the right eye.

EEG data reduction and analysis

The EEG data were visually scored for artifact due to eye blinks, eye movements, and other motor movements, using software developed by James Long Company (EEG Analysis Program, Caroga Lake, NY). This program removes data from all channels if artifact is present on any one channel. The conditions did not differ in the amount of artifact-free data used in the analyses; the number of artifacted-epochs ranged between 15 to 19 across the four conditions.

All artifact-free EEG data were analysed using a discrete Fourier transform (DFT), with a Hanning window of 1 s width and 50% overlap. Power (microvolts-squared) was derived from the DFT output in the alpha band (8–13 Hz). A natural log (*ln*) transformation was performed on the EEG data to reduce skewness.

RESULTS

Analyses of variance (ANOVA) with Gender (male, female) as a between-subjects factor and Valence (pleasant, unpleasant), Intensity (Intense, Calm), and Hemisphere (left, right) as within-subjects factors were performed on *ln*(EEG alpha power 8–13 Hz) separately for the frontal and parietal regions. The parietal analysis showed no significant main effects or interactions. The frontal analysis showed no significant main effect of or interaction involving Gender. There was, however, a significant Valence by Intensity by Hemisphere interaction for the frontal region, $F(1, 58) = 4.11$, $p < .047$ (see Figure 1).

To examine this triple interaction, separate 2 × 2 ANOVAs were computed with Valence and Hemisphere, Intensity and Hemisphere, and Valence and Intensity as within-subjects factors. The dependent measure was again *ln*(EEG alpha power 8–13 Hz).

The Valence by Hemisphere analysis revealed significant main effects for Valence, $F(1, 58) = 17.88$, $p < .0005$, and Hemisphere, $F(1, 58) = 13.67$, $p < .0005$, and a significant interaction between Valence and Hemisphere, $F(1, 58) = 10.76$, $p < .002$. Consistent with previous literature and our first prediction, positively valenced musical excerpts elicited greater relative left frontal EEG activity, whereas negatively valenced musical excerpts elicited greater relative right frontal EEG activity (see Figure 1). In addition, positively valenced (i.e., joy and happy) musical excerpts elicited significantly less frontal EEG power (i.e., more activity) compared with negatively valenced (i.e., fear and sad) musical excerpts, and there was significantly less frontal EEG power (i.e., more activity) in the left compared with the right hemisphere across valence.

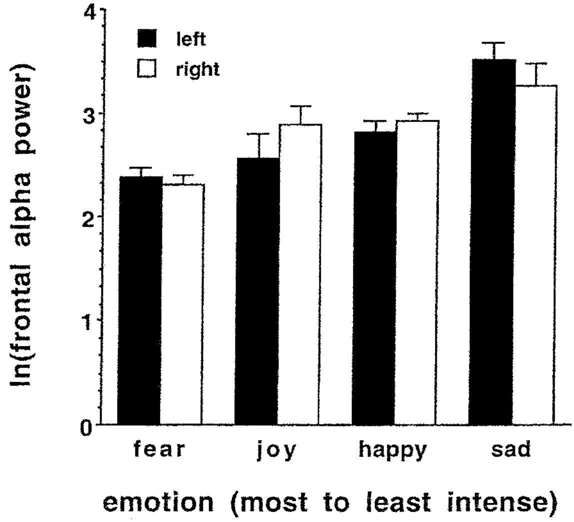

Figure 1. Differences among the four musical excerpts on left and right frontal EEG alpha power (Note that EEG power is inversely related to activity, thus lower power reflects more activity; Lindsley & Wicke, 1974). (Error bars represent the standard error of the mean.)

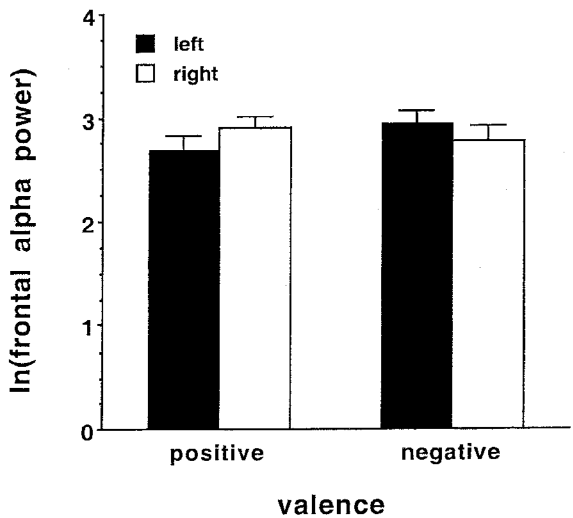

Figure 2. The Valence by Hemisphere interaction. Note that EEG alpha power is inversely related to activity; thus lower power reflects more activity. The positive/left was significantly lower than the positive/right frontal power (pairwise *t*-test, $df = 58$, $p < .001$); and the negative/left was significantly greater than the negative/right frontal power (pairwise *t*-test, $df = 58$, $p < .003$). (Error bars represent the standard error of the mean.)

The Intensity by Hemisphere analysis revealed significant main effects of Intensity, $F(1, 58) = 386.09$, $p < .0005$, and Hemisphere, $F(1, 58) = 13.67$, $p < .0005$, but no interaction. Consistent with the previous analysis, there was significantly less frontal EEG power (i.e., more activity) in the left compared with the right hemisphere across intensity. Consistent with our second prediction, high intensity (i.e., joy and fear) musical excerpts elicited significantly less overall frontal EEG power (i.e., more activity) compared with low intensity (i.e., happy and sad) musical excerpts. Furthermore, there was a significant correlation between adults' ratings of intensity (see Table 1) and overall frontal EEG power, $F(1, 58) = 17.87$, $p < .001$ (see Figure 1).

The Valence by Intensity analysis revealed significant main effects of Valence, $F(1, 58) = 17.88$, $p < .0005$, and Intensity, $F(1, 58) = 17.88$, $p < .0005$. Consistent with the above analysis, high intensity and positively valenced musical excerpts elicited significantly lower EEG power (i.e., more activity) compared with low intensity and negatively valenced affective musical excerpts. The Valence by Intensity interaction was also significant, $F(1, 58) = 12.14$, $p < .002$. As can be seen in Figure 3, for both positive and negative affective musical excerpts, there was lower frontal EEG power (i.e., more activity) for high intensity than low intensity excerpts, but the degree of this relation was more extreme for the positively than negatively valenced excerpts. This effect may be the result of the choice of excerpts. As shown in Table 1, the fear excerpt was rated as very much more intense than any of the other excerpts.

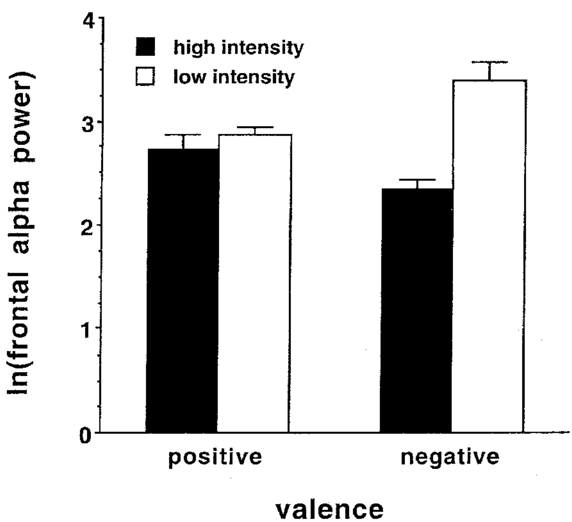

Figure 3. The Valence by Intensity interaction. For both positive and negative excerpts, there was greater frontal power (i.e., lower activity) in the low intensity than in the high intensity case, but the difference was more extreme for the negative excerpts. (Error bars represent the standard error of the mean.)

DISCUSSION

Asymmetrical frontal activation distinguishes the valence of musical emotions. We found that the pattern of ongoing brain activity (EEG) measured at the anterior portion of the scalp distinguished the valence of musical emotions. Subjects exhibited greater relative left frontal EEG activity during the presentation of positively valenced musical excerpts (i.e., joy and happy) and greater relative right frontal EEG activity during the presentation of negatively valenced musical excerpts (i.e., fear and sad). These findings are consistent with the frontal activation/emotion valence models articulated by Davidson, Fox, and Heller (see Davidson, 1993; Fox, 1991; Heller, 1993, for reviews) in which they argue that the experience of positive emotions is lateralized to the left anterior region of the brain, whereas the experience of negative emotions is lateralised to the right anterior region of the brain. These results show that musically induced emotions activate the same frontal brain regions as emotions induced through other modalities.

Overall frontal activation distinguishes the intensity of musical emotions. We also noted a relation between overall frontal activation and the intensity of the musical emotions. Subjects exhibited significantly greater overall activity in the frontal region of the brain as the affective musical stimuli became more intense. More specifically, overall frontal EEG activity decreased from the presentation of the fear to the joy to the happy to the sad excerpt, consistent with the behavioural ratings of intensity. These findings are consistent with the frontal activation/emotion intensity models articulated by other researchers (e.g., Davidson et al., 1979; Dawson, 1994; Schmidt, 1999; Schmidt & Fox, 1999) in which they argue that the pattern of absolute frontal activation may reflect the intensity of emotional experience, with greater frontal activation reflecting a more intense emotional experience.

It is important to note that within-subject differences in regional brain activation during the presentation of the musical excerpts were specific to the frontal region. Contrary to Heller's (1993) model, we did not find differences in parietal activity during the presentation of the musical excerpts as a function of intensity. There are at least two seemingly plausible explanations for this. One is that, although the stimuli we used were intense enough to elicit frontal differences, they may not have been robust enough to elicit right parietal activation. Second, although much of the previous empirical research in this domain has utilised visual stimuli to elicit emotional responses, we used auditory stimuli to elicit emotion. Accordingly, it may be that the lack of parietal differences is due to differences in stimulus modalities. That is, the stimuli used might have tended to elicit an internal focus rather than an external focus to environmental stimuli. The parietal effects may require attention to the external world.

Implications. The present findings are of theoretical importance. We have shown that musical excerpts induce frontal brain activity that is consistent with emotions induced through other modalities. Emotions have long been described along two dimensions, valence and intensity. We have shown that the pattern of frontal brain activity reflects both dimensions. By examining both asymmetry and overall power of frontal brain activity, we are able to distinguish between emotions within valence (i.e., between happy and joy and between fear and sad emotions). These findings also extend previous studies which have distinguished among emotions within valence on autonomic measures (Ekman, Levenson, & Friesen, 1983; Levenson, 1992) to central measures. The present results have implications for the study of emotion and personality development in that the origins of individual differences in personality may be linked to the manner by which an individual experiences and regulates different types of emotions.

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