An Exploratory Study of Musical Emotions and Psychophysiology

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Abstract A basic issue about musical emotions concerns whether music elicits emotional responses in listeners (the 'emotivist' position) or simply expresses emotions that listeners recognize in the music (the 'cognitivist' position). To address this, psychophysiological measures were recorded while listeners heard two excerpts chosen to represent each of three emotions: sad, fear, and happy. The measures covered a fairly wide spectrum of cardiac, vascular, electrodermal, and respiratory functions. Other subjects indicated dynamic changes in emotions they experienced while listening to the music on one of four scales: sad, fear, happy, and tension. Both physiological and emotion judgments were made on a second-by-second basis. The physiological measures all showed a significant effect of music compared to the pre-music interval. A number of analyses, including correlations between physiology and emotion judgments, found significant differences among the excerpts. The sad excerpts produced the largest changes in heart rate, blood pressure, skin conductance and temperature. The fear excerpts produced the largest changes in blood transit time and amplitude. The happy excerpts produced the largest changes in the measures of respiration. These emotion-specific physiological changes only partially replicated those found for non-musical emotions. The physiological effects of music observed generally support the emotivist view of musical emotions.

A curious gap exists between the musicological and psychological literatures on emotion. Music is believed by musicologists (e.g., Cooke, 1959) to invoke a wide range of powerful and highly specific emotional states. Listeners report emotional responses as being the strongest motivation for listening to music (Pansepp, 1995). And, as will be reviewed briefly below, numerous experiments in the psychology of music find considerable consistency in emotional judgments of music. Yet, basic psychological studies of emotion rarely use music as stimulus materials, or consider how music might cause emotional responses. Recent summaries of the literature (Lewis & Haviland, 1993; Ekman & Davidson, 1994) contain only scattered references to studies with music. This omission is notable given that research on emotions, as opposed to perception and cognition, frequently uses auditory stimuli and more complex and naturalistic materials, such as pictures and films.

This gap may reflect the intuition that musical emotions are not, in some sense, like other emotions. Possible reasons for this lie in differences in both antecedents and consequences of emotions. Antecedents in real life are environmentally determined conditions that have perceived or real implications for the individual's well-being, and are usually followed by overt actions, such as withdrawal or aggression, or at least plans to maintain well-being and self-esteem (Schweder, 1993). Emotions are considered important for physically preparing the individual to perform these actions by changes in cardiac and respiratory systems, for example. In contrast, the musical antecedent does not usually have any obvious material effect on the individual's well-being, and is infrequently followed by direct external responses of a goal-directed nature. In cases where movement occurs, such as with dance and physical work, the music serves as background to the movement. It may facilitate or shape the physical activity, but the physical activity is not addressed toward the emotion-producing stimulus, that is, the music.

Two other notable differences between music and other emotion-producing conditions should be mentioned. First, many, if not most, emotional situations not involving music occur in social interactions. As such, the emotional reaction is mediated by knowledge of social behaviours, values, motivations, and so on, that would have an extended personal history and be strongly determined by cultural norms. Second, these emotional situations often involve a verbal component that would invoke a rich system of symbolic representations and semantic associations. In contrast, music listening is often done by an

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individual in isolation and, even when listening occurs in a social setting, it may not co-occur with social interactions. In addition, instrumental music — without words — is wide spread and yields reports of strong emotional reactions (e.g., Sloboda, 1991), suggesting that musical emotions, whatever they are, do not depend exclusively on the verbal content of song.

Despite these differences, reports of strong emotional reactions to music are prevalent and these reports do not distinguish between emotions experienced in reaction to musical and non-musical stimuli. Goldstein (1980) conducted a survey of intense emotional responses ('thrills,' characterized by a slight shudder, chill, or tingling sensation) experienced by a large sample of individuals including musicians and non musicians. Music was the stimulus that most often caused these responses, indicating that music is a powerful emotion-eliciting stimulus. In a related study, Pansepp (1995) recently found that this kind of response (called 'chills' by this author) occurs frequently for music listeners, and is more prevalent for sad than happy pieces of music. This difference is contrary to naive beliefs, undercutting the idea that subjects are simply responding according to common beliefs about music and emotion.

Sloboda (1991) reported responses to a questionnaire on musical emotions and examined the music for structural properties corresponding to the reported emotions. A large percentage of the respondents, ranging widely in musical expertise, reported strong physical responses to music. These included tears, shivers down the spine, and heart racing. Instrumental selections were analysed for musical content. Different structural features were fairly consistently associated with different physical responses. For example, tears were associated with harmony descending on the cycle of fifths to the tonic and melodic appogiaturas. Shivers were associated with enharmonic changes, new or unprepared harmony, and sudden changes of dynamics and texture. Heart racing was associated with repeated syncopation and instances when a prominent event occurred earlier than expected. These observations support Meyer's (1956) claim that musical emotions depend on confirmations and violations of expectancy, as discussed later.

Psychological studies of musical emotions generally find that listeners are consistent in assigning adjectives to musical selections. The classic study by Hevner (1936) obtained judgments on numerous adjectives. They fell naturally into eight groups, arranged intuitively in a circle to bring out the logical and presumed physiological relations between the groups. This two-dimensional representation corresponds quite closely with representations obtained for non-musical emotions (e.g., Roberts & Wedell, 1994) with two underlying dimensions of positive-negative and degree of activity. The response distributions to the music showed clear peaks and graded off as a function of distance around the circular representation. Some of the structural aspects of the music that determined adjective assignment were: major vs. minor mode; firm vs. flowing rhythm; and complex and dissonant vs. simple and consonant harmonies.

More recently, a study by Terwogt and Grinsven (1991) investigated children's emotional responses to instrumental pieces. Children and adults indicated the facial expression corresponding to the emotional weighting of the music, thus avoiding verbal labels. Children as young as five years of age assigned the intended emotion with above-chance accuracy. Similar results were found by Cunningham and Sterling (1988) who concluded that the abstract affective representation in music does not lag far behind sensitivity to other nonverbal emotional stimuli, such as facial and vocal expression. Dolgin and Adelson (1990) tested whether acoustic features of emotional speech (Scherer, 1981; Scherer, Koivumaki, & Rosenthal, 1972; Scherer & Oshinsky, 1977) find parallels in music. They composed pieces of varying articulation (staccato, legato), motion (step, skip), and tempo (allegro, moderato, largo). Above-chance accuracy was found as early as four years of age. Thus, emotional associations to music are established relatively early in development together with mappings to facial and vocal expressions of emotion.

Brown's (1981) results, however, indicate limits to the specificity of musical emotions. One set of stimulus materials was chosen to span six grades of sadness: "funereal, strong but sorrowful", "sadness tinged with romantic mystery", and so on. Neither non musicians nor musicians categorized the excerpts accurately, although the latter were more accurate when presented with the experimenter's verbal descriptions. More substantial agreement was found by listeners highly conversant with the relevant musical genre. In general, however, these results suggest musical emotions are distinguishable primarily at the level of basic emotions such as happy, sad, fear, and anger.

Limits to generality across cultures were suggested by a recent study by Gregory and Varney (1996). Subjects in their study were either from a western or from an (East) Indian cultural background, and the excerpts included pieces from western classical and Indian classical music. Listeners indicated which emotional adjectives applied to the music. Although overall the emotion judgments were similar across groups, differences appeared for specific pieces. Such cross-cultural comparisons are an important complement to studies of development and training in understanding the effects of learning in a cultural context on musical emotions, but little research has been done along these lines to date.

Another recent trend in studies of musical emotion is to examine the time course of emotional responses. In an initial effort in this direction, Goldstein (1980) had subjects indicate the time and strength of thrill responses. The pattern of responses remained quite stable over repeated hearings by the same individual. Attenuated responses after injections of naloxone, an opiate antagonist, suggested a connection with emotion physiology. Waterman (1996) measured the number of emotion responses per bar of music. Systematic differences were found with certain bars receiving significantly more responses than others. These bars contained a number of the musical structures found by Sloboda (1991) to elicit emotional reactions. A study by de Vries (1991) used a technique developed by Clynes (1977) that measures finger pressure amplitude and direction on a finger rest. Excerpts with different emotions were reliably distinguished by the roughness of the force curve (fast vs. slow changes in force and angle), the skewness of the curve, and the angle of roughness.

Nielsen (1983) conducted an extensive analysis of musical tension using a pair of tongs that listeners pressed together to indicate the experienced degree of tension. The method produced strikingly regular tension curves that could be related to diverse musical factors, including dynamics, timbre, melodic contour, harmony, tonality, and repetition. This research has been extended more recently by Madson and Fredrickson (1993; Fredrickson, 1995). Krumhansl (1996) and Krumhansl and Schenck (1997) also obtained tension profiles using a computer display as the response mode. The former study found tension judgments correlated with melodic contour, note density, dynamics, harmony, and tonality, and corresponded with music-theoretic predictions (Lerdahl, 1988, 1996). The latter study examined correspondences between music and dance. Similar tension profiles were found for the music only condition and dance only conditions as well as similar qualitative emotion judgments. These results suggest music and dance can elicit similar emotional responses.

To summarize to this point, these experimental studies point to a number of generalizations. First, subjects report strong emotional responses to music. Second, verbal judgments of musical emotions are quite consistent across individuals and largely independent of musical training, although cross-cultural and developmental differences are observed. Third, the judgments are most consistent for basic emotions, such as sad, fear, happy, and angry, and may not reliably correspond with more fine-grained distinctions within these categories. Fourth, a variety of techniques show that emotion qualities change dynamically over time. These studies include a number of proposals as to how music produces affective responses, including parallels with emotion-signalling qualities of speech and analogs in physical movement. However, the primary focus has been on musical features that correspond with particular emotions, such as tempo, mode, dynamics, timbre, melodic contour, harmony, and tonality.

Before describing the present experiment and its rationale, an issue should be mentioned that arises in the philosophical literature on music. The issue is whether music elicits real emotional responses in listeners or simply expresses (or represents) emotions. Kivy (1990) calls those who hold the former view 'emotivists' and those who hold the latter view 'cognitivists.' The former believe that music elicits emotions that are qualitatively similar to non-musical emotions, that is, that the emotions are really experienced. The latter believe that the emotion is an expressive property of the music that listeners recognize in it, but do not themselves experience. Kivy rejects the emotivist position absolutely except to admit the possibility that prior associations (or psychopathology) may produce musical emotions. Note that these responses would be idiosyncratic across individuals. He judges current theories of emotions to be inadequate for understanding musical emotions. What for him is decisive is that "there are no behavioral symptoms of listeners actually experiencing [emotions] when attending to music..." (p. 151)

Meyer (1956), in his highly influential book on music and emotion, also questions the emotivist position: "...when a listener reports that he felt this or that emotion, he is describing the emotion which he believes the passage is supposed to indicate, not anything which he himself has experienced." Most relevant to the present study, he dismisses the importance of physiological changes in response to music, such as heart rate and skin conductance, as being inconclusive on two grounds. First, he claims that physiological changes do not correspond with musical patterns. Second, he claims that physiological changes, if they occur, may result simply from listeners' beliefs about the affective power of music. Nonetheless, Meyer (1956, p. vii) noted the potential rewards of an increased understanding of musical emotions, "This puzzling combination of abstractness with concrete emotional and aesthetic experience can, if understood correctly, perhaps yield useful insights into more general problems of meaning and communication." Toward this end, he developed a theory of musical emotions in which expectations play a central role. Expectations produce waves over time of tension and release from tension. Expectations are derived from both general psychological principles (such as Gestalt principles of perceptual organization) and knowledge of the style (such as tonality, harmonic progressions, and musical form). His proposals, as formalized by Narmour (1990), have recently received empirical support (Krumhansl, 1991, 1995, 1995/1996, 1997; Cuddy & Lunney, 1995).

The question of whether physiological measures change in response to music has not been studied extensively. One exception is a study by Thayer and Levenson (1983) that found that music added to a stressful film produced changes in skin conductance levels. A number of results also appear in clinical and therapeutic contexts. For example, Davis and Thaut (1989) found that music aroused autonomic nervous system responses (vascular construction, heart rate, musical tension, and finger skin temperature) even though subjects reported decreases in state anxiety and increases in relaxation. Studies by Standley (1991) and Davis-Rollans and Cunningham (1987) found self-reports of psychological state improved with musical manipulations, but physiological measures (heart and respiration rates, finger temperature) did not change consistently. Stronger physiological correlates of music were reported, however, by Guzzetta (1989). Music was associated with lower heart rates and higher peripheral temperatures.

On the psychological side, a basic issue is whether there are emotion-specific patterns in psychophysiology. This question has a long and vexed history that will be summarized only briefly here. A recent series of position papers on the subject appears in Ekman and Davidson (1994). One position, following William James (1890), assumes that different emotions are associated with unique patterns of physiological changes. It is hypothesized that these patterns differentiate the emotions, that is, identification of the emotion is determined by the physiological responses. An influential study by Schacter and Singer (1962) undercut this position by showing that undifferentiated arousal resulted in different reports of emotions depending on the subject's cognitive response to external events.

More recently, the first position — the physiological differentiation of emotions – has been strengthened by a series of studies by Ekman, Levenson and colleagues (e. g., Ekman, Levenson, & Friesen, 1983; Levenson, Ekman, & Friesen, 1990; Levenson, Carstensen, Friesen, & Ekman, 1991; Levenson, Ekman, Heider, & Friesen, 1992; Levenson, 1992, 1994). These studies suggest consistent differences in some physiological correlates of anger, fear, sadness, and happiness. The results in these last studies come primarily from two tasks. The first, the directed facial action task, instructs subjects to manipulate facial muscles to produce prototypical facial expressions. The second task, the relived emotions task, asks subjects to recall and relive emotional memories. The patterns of physiological changes will be described in more detail later when the present results are compared.

Zajonc and McIntosh (1992) provided a useful summary of the studies by Ekman, Levenson and colleagues and noted a number of related studies that did not obtain the same differences. A larger compilation of available studies that contrast two or more emotions was provided by Cacioppo, Klein, Berntson, and Hatfield (1993). They concluded there was little consistent support for an emotion-specific physiology across the studies reviewed. More recently, Boiten (1996) suggested that the autonomic response patterns found using the directed facial action task is a consequence of the muscular effort of producing the facial expression, rather than the emotional response *per se*.

The experiment reported here addressees these issues by measuring psychophysiologal changes during music listening. According to Hugdahl (1995, p. 8), "Psychophysiology is the study of brain-behavior relationships in the framework of peripheral and central physiological responses." Recording of psychophysiological responses is regarded as a "window" into the brain and mind. These responses include measures of the central nervous system (through electroencephalograms, event-related potentials, and more recently brain imaging techniques) and peripheral nervous system (electrodermal activity, heart and blood circulation, respiration, and muscular activity). The autonomic system includes the sympathetic and parasympathetic systems. The present study exclusively considers measures of peripheral nervous system function.

The present investigation is of an exploratory nature. It sought to obtain a fairly wide spectrum of physiological measures of cardiac, vascular, electrodermal, and respiratory function on the same subjects while listening to music. These measures were taken continuously (at one-second intervals) during the music. Six excerpts were chosen to represent (two selections each) the emotions of sad, fear, and happy. Each of the excerpts was approximately three minutes in duration. Each excerpt was preceded by a 90-second period of silence during which baserate measures were collected. These values were subtracted from the pre-music measure to control for individual differences and overall changes that might occur during the experimental session. In addition, listeners gave self-report ratings of their emotional responses during the excerpts. Because the primary emphasis is on dynamic changes that occurred during the musical excerpts, independent groups of listeners made dynamic ratings of the degree of sadness, fear, happiness, and tension they experienced while listening.

METHODS

Subjects

Forty Cornell University students participated as subjects in the experiment collecting dynamic emotion judgments of the six musical excerpts. Ten listeners were in each of the four conditions in which they indicated the experienced degree of sadness, fear, happiness, or tension. Three additional subjects participated, but their data were invalid because of equipment failure. On average, the subjects had taken 7.8 years of instruction on musical instrument or voice and had played music for 7.6 years. Fourteen were currently playing music, and on average they had taken one course in music at the college level. They listened to music an average of 17.3 hours per week, of which 5.6 hours were listening to classical music.

Thirty-eight students at the University of California at Berkeley participated as subjects in the experiment measuring physiological responses to the six excerpts. The data for four additional subjects were incomplete, in part because of equipment failure, and were not included in the data analysis. On average, they had studied musical instruments or voice for an average of 3.3 years, played music for 7.6 years, and had taken one course in music at the college level. Three were currently playing music. The average number of hours per week listening to music was 14.2, of which 1.6 was to classical music.

Apparatus

In the experiment collecting dynamic emotion quality judgments, an audio tape recorder played the music at a comfortable loudness level over headphones. The audio tape was made from the videotape used in the physiology study. A Macintosh IIcx computer with the MAX software presented an interface containing a slider that subjects adjusted to indicate their responses. A foot pedal was used to signal the beginning of each 90-second pre-music interval.

In the physiological study, the music was played by one channel of a videotape player. The measures were recorded using polygraphs and a computer and sampled a range of responses from cardiac, vascular, electrodermal, and respiratory systems (see, for example, Gottman & Levenson, 1992; Gross, Fredrickson, & Levenson, 1994; Levenson, Carstensen, & Gottman, 1994, for additional information). These included: 1) cardiac interbeat interval (IBI), measured in milliseconds, with shorter IBIs taken to indicate a higher level of cardiovascular arousal; 2) pulse transmission time to the finger (FPTT), measured in milliseconds, with shorter pulse transmission times indicative of greater autonomic (sympathetic) activation; 3) finger pulse amplitude (FPA), a measure of the amount of blood in the periphery, with reduced amplitude indicating greater vasoconstriction and associated with greater autonomic (sympathetic) activation; 4) pulse transmission time to the ear (EPTT), another measure of blood flow; 5) respiration intercycle interval (ICI), measuring the time between successive inspirations in milliseconds; 6) respiration depth (RD), which is the point of maximum inspiration minus the point of maximum expiration; 7) respiration-sinus asynchrony (RSA), 8) systolic blood pressure (SBP), 9) diastolic blood pressure (DBP), 10) mean arterial pressure (MAP), 11) skin conductance level (SCL), with increased skin conductance indicative of greater autonomic (sympathetic) activation; and temperature on the finger (TEM) measured in degrees Fahrenheit. The computer processed the physiological measure on-line, computing second-by-second averages for each physiological measure.

Stimulus materials

The stimulus materials consisted of six excerpts of approximately three minutes in duration from the beginning of the following pieces: 1) Gustav Holst: *Mars — the Bringer of War* from *The Planets*, Orchestre National de France/Lorin Maazel, 2) Antonio Vivaldi, *La Primavera* (Spring) from *The Four Seasons*, Catherine Mackintosh/King's Consort/Robert King, 3) Tomaso Albinoni, *Adagio* in G minor for Strings and Orchestra, Berlin Philharmonic/Herbert von Karajan, 4) Modest Mussorgsky, *Night on Bare Mountain*, Philadelphia Orchestra/Eugene Ormandy, 5) Samuel Barber, *Adagio* for Strings, Op. 11, Los Angeles Philharmonic Orchestra/Leonard Bernstein, 6) Hugo Alfven, *Midsommarvaka*, Swedish Radio Symphony Orchestra/Esa-Pekka Salonen. The excerpts by Albinoni and Barber were chosen to represent sadness, those by Holst and Mussorgsky were chosen to represent fear, and those by Vivaldi and Alfven were chosen to represent happiness. Each excerpt was preceded by a 90-second interval to collect baseline rates of the physiological measures, and followed by a 90-second interval during which they filled out a questionnaire about the emotions they experienced during the excerpt. The excerpts were always played in the order given above.

Procedure

In the dynamic emotion rating experiment, subjects were randomly assigned to one of four conditions. The ten subjects in the first condition were instructed to continuously adjust the position of the slider on the display to indicate the amount of sadness they experienced while listening to the music. The instructions to the ten subjects in each of the other three conditions were identical except that they were instructed to judge fear, happiness, and tension, respectively. All subjects had a short practice experiment to become familiar with the display and ask any questions they might have about their assigned task.

Subjects also filled out a short questionnaire about the emotional effects of the music after each excerpt. Specifically, they were asked to rate how they felt while listening to the music using a rating scale from 0 - 8 on: Afraid, Amused, Angry, Anxious, Contemptuous, Contented, Disgusted, Embarrassed, Happy, Interested, Relieved, Sad, and Surprised. In addition, they were asked to rate on the same scale the Pleasantness and Intensity of the music, and how Familiar they were with it before the experiment. At

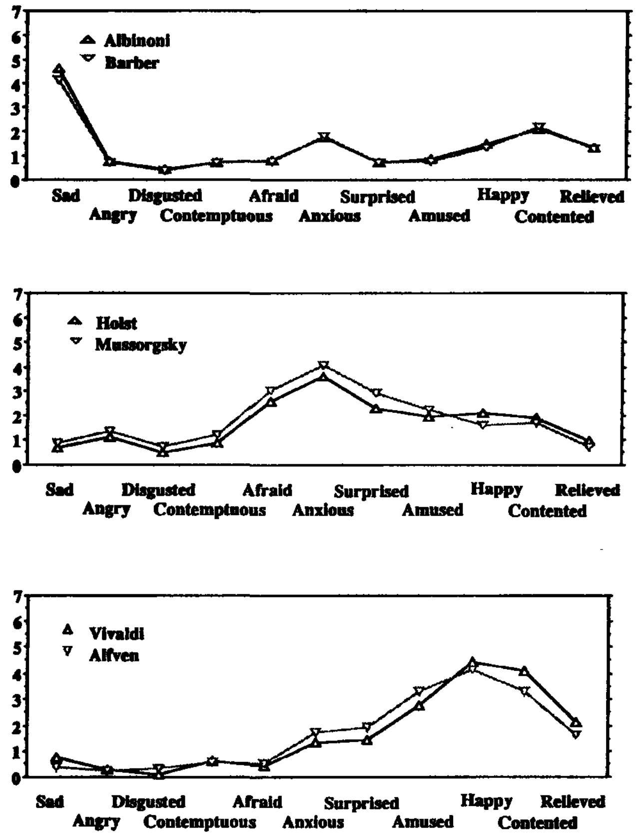

Figure 1. Shows the emotion self-report measures for each of the six excerpts averaged over the two experiments. In one experiment, listeners made dynamic emotion ratings and in the other their physiological responses were recorded. Inter experiment agreement was strong. The Albinoni and Barber excerpts were chosen to represent sad, the Holst and Mussorgsky excerpts to represent happy, and the Vivaldi and Alfven excerpts to represent happy. The measures were very similar for each pair of excerpts. Two scales, Embarrassed and Interested, were not included because they did not differ across excerpts.

the end of the experiment, they filled out a short questionnaire including questions about their musical training.

In the physiological experiment, physiological sensors were attached to the subjects who were seated in a comfortable chair. They were told that they would hear several short musical excerpts while their physiological responses were being monitored. They filled out the same questionnaire after each excerpt about the emotional effects of the excerpts, and the same questionnaire at the end of the experiment about their musical training.

RESULTS

Emotion quality ratings of the six excerpts

The first step in analysing the data was a check that the selections chosen did represent the intended emotions of sad, fear, and happy. The questionnaire ratings of the 13 emotion qualities of the excerpts were used for this purpose. These were made by subjects in both experiments, those who made dynamic emotional quality judgments and those whose physiology was measured. Their responses were very similar; the interexperiment correlations for the six excerpts were all greater than $r(11) = .97$, $p < .0001$. (Intersubject correlations were also highly significant.) Consequently, the ratings for the two groups of listeners were averaged with the results plotted in Figure 1. Two of the 13 ratings were not included in the figure: Embarrassed, because the ratings of the excerpts were uniformly low on this scale, and Interested, because the ratings of the excerpts were uniformly high on this scale. The 11 remaining emotion quality scales clearly differentiated between the intended emotions.

The correlations on these 11 scales for the matched pairs of excerpts were $r(9) = .97$, .95, and .96 for Sad (Albinoni-Barber), Fear (Holst-Mussorgsky), and Happy (Vivaldi-Alfven) excerpts, respectively, all significant at $p < .0001$. The correlations for unmatched pairs ranged from -.16 to .42 and none were statistically significant. As intended, the Albinoni-Barber pair was rated much higher for Sad than the other emotion qualities. The Holst-Mussorgsky pair was rated highest for Anxious, but also quite highly for Afraid and Surprised. Similarly, although the Vivaldi-Alfven pair was rated highest for Happy, high ratings were also found for Amused and Contented. One aspect of these findings will be relevant when physiological measures are considered. The maximum values for the three excerpts are very similar. This is important because a difference in physiological measures might be due to the magnitude of the intensity of the emotion, rather than the quality of the emotion. The very similar maximum values found here eliminate this as a confounding factor.

To explore the relations between the emotion quality ratings further, a factor analysis of the emotion quality ratings for the six excerpts (averaged over the two experiments) was performed. The orthogonal solution (varimax method) contained two factors. The factor loadings of each emotion on the two factors is shown in Figure 2. The first factor (with Eigenvalue 7.24) accounted for 66% of the variance. The second factor (with Eigenvalue 3.39) accounted for 31% of the variance. The factor analysis recovered the familiar circumplex of emotional qualities as found, for example, by Hevner (1936) and Roberts and Wedell (1994). The positive emotions, centered around Happy in the upper right, separated from the negative emotions with Angry and Sad at the other extreme. The emotions with high activity levels, such as Surprised and Amused, separated from Sad with low activity at the other extreme. The particular sampling of emotion terms seems to have been non-uniform across the space, with clusters of emotion terms in the upper two quadrants. This results from the similar emotion quality ratings for the emotions

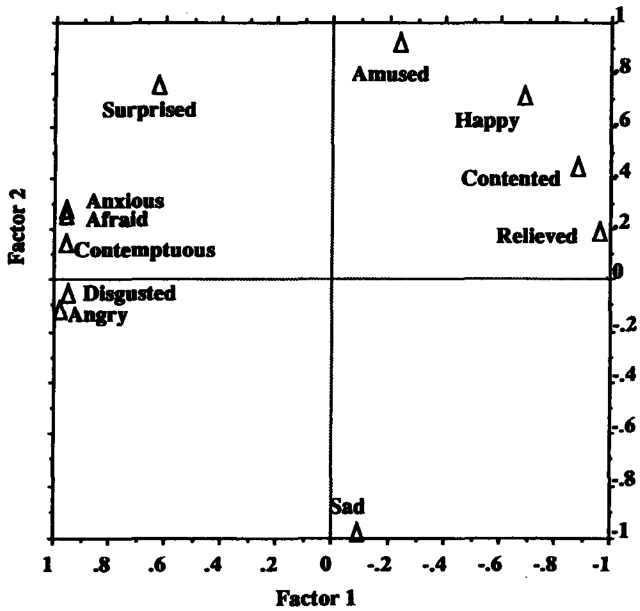

Figure 2. Shows the results of the factor analysis on the eleven self-report measures averaged over the two experiments. Two scales, Embarrassed and Interested, were not included because they did not differ across the excerpts. The figure plots the factor loadings on the two factors found by the analysis. The analysis recovers the circumplex of emotional qualities found for non-musical emotions, with underlying dimensions of pleasantness and activity.

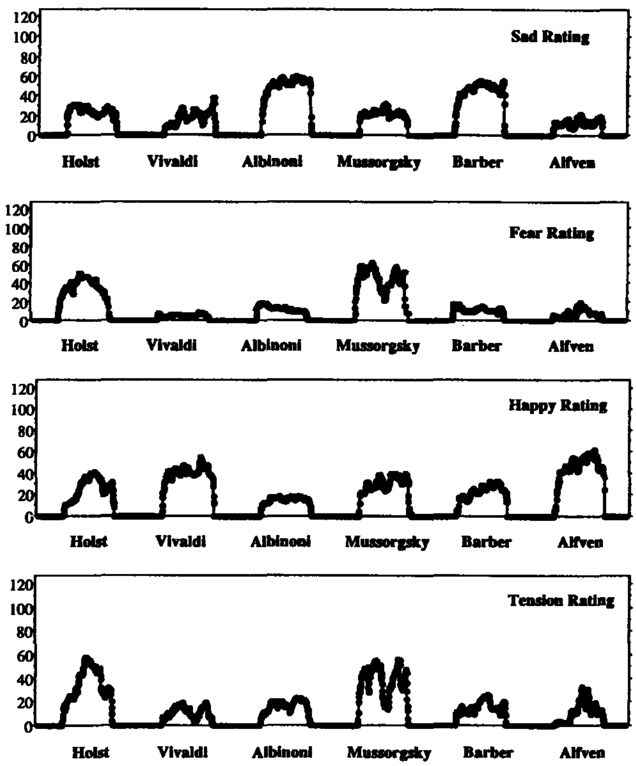

Figure 3. Shows the dynamic emotion ratings for the six excerpts at one-second intervals. The Albinoni and Barber excerpts were selected to represent sad, the Holst and Mussorgsky excerpts to represent fear, and the Vivaldi and Alfven excerpts to represent happy. Different groups of listeners rated the excerpts on continuous scales of sad, fear, happy, and tension.

Anxious, Afraid, and Surprised and for the emotions Happy, Amused, and Contented. The most important finding of this analysis is that the musical excerpts span the entire range of emotions found in non-musical studies. Thus, the emotional responses to music do not appear to occupy a restricted range of the space.

Dynamic ratings of Sad, Fear, Happy and Tension

Figure 3 shows the dynamic ratings of the six excerpts for Sad, Fear, Happy, and Tension that the computer coded on a scale from 0 to 127. As intended, the ratings of Sad were higher for the Albinoni and Barber excerpts than the other excerpts. Similarly, the Fear ratings were higher for the Holst and Mussorgsky excerpts than the others, and the Happy ratings were higher for the Vivaldi and Alfven excerpts than the others. Analyses of variance showed in each case that the ratings of the intended emotion were significantly higher than the unintended emotions; the effect of the excerpt type was statistically significant (at $p < .0001$) for all three rating scales ($F(2,1165) = 1283.60$, $MS_e = 82.9$ for Sad; $F(2,1165) = 1723.74$, $MS_e = 67.8$ for Fear; $F(2,1165) = 620.82$, $MS_e = 91.0$ for Happy).

Tension correlated ($r(1168) = .90$, $p < .0001$) most strongly with Fear ratings across the six excerpts, and Sad and Happy correlated negatively ($r(1166) = -.40$, $p < .0001$). A factor analysis of the correlations recovered two factors (Eigenvalue = 1.91 and proportion of variance = 48% for Factor 1, and Eigenvalue = 1.37 and proportion of variance = 35% for Factor 2). Fear and Tension both loaded positively on the first factor, and Happy loaded positively and Fear loaded negatively on the second factor. Thus, the dynamic ratings supported the same two-dimensional structure as the emotion quality ratings.

Although Tension correlated most strongly overall with Fear ratings, it also correlated to some degree with Happy and Sad ratings. A multiple regression predicting Tension from Sad, Fear, and Happy gave a highly significant correlation ($R(3,1168) = .94$, $p < .0001$). Fear contributed most strongly (standardized coefficient = . 92, $p < .0001$) to the correlations, although Sad (standardized coefficient = .21, $p < .0001$) and Happy (standardized coefficient = .26, $p < .0001$) both contributed significantly. More particularly, tension correlated quite strongly with the dominant emotion of the excerpts when they were analysed separately. For the Vivaldi and Barber excerpts, Tension correlated more strongly with the dominant emotion of Sad ($r(385) = .83$) than with Fear ($r(385) = .32$) or Happy ($r(385) = .51$). For the Holst and

TABLE 1
Average physiological measures (change scores from baserate)

Physiological Measures	All Excerpts	Sad Excerpts	Fear Excerpts	Happy Excerpts
IBI	9.29	10.87 A	8.93 B	8.06 B
FPTT	2.07	2.01 B	2.64 A	1.53 C
FPA	-.408	-.444 B	-.624 C	-.150 A
EPTT	2.90	2.70 B	3.32 A	2.66 B
ICI	-285	-205 A	-325 B	-324 B
RD	-39.1	-36.4 A	-34.5 A	-46.4 B
RSA	-10.7	-9.43 A	-12.3 A	-10.3 A
SBP	1.58	2.42 A	.892 C	1.44 B
DBP	.919	1.50 A	.535 C	.726 B
MAP	1.15	1.70 A	.718 C	1.04 B
SCL	-.401	-.459 C	-.384 B	-.360 A
TEM	-.154	-.205 B	-.193 B	-.062 A

Note: The letters indicate statistical significance of differences. Excerpts with the same letter were not significantly different. Letters are assigned alphabetically from the largest to the smallest mean. When the changes were negative, A signifies the smallest negative change, C the largest negative change.

Mussorgsky excerpts, Tension correlated more strongly with the dominant emotion of Fear ($r(393) = .89$) than with Happy ($r(393) = .82$) or Sad ($r(393) = .37$). For the Vivaldi and Alfven excerpts, Tension correlated quite strongly with the dominant emotion of Happy ($r(384) = .64$), although it correlated more strongly with Fear ($r(384) = .73$ and less strongly with Sad ($r(384) = .22$). (All correlations are significant at $p < .0001$.) Thus, Tension appears to be a multivalent quality, influenced to some degree by all three emotions, especially Fear and the dominant emotion of the excerpt.

Average physiology measures during musical excerpts
The physiological data were pre-processed in the following way. For each measure, the average value during the 90-second pre-music interval was computed. These averages were then subtracted from the physiological measures during the three-minute musical selections. This procedure corrected for individual differences and overall changes in physiology that might occur during the experimental session. The following analyses consider only the physiological measures corrected for the pre-music baserates.

Compared with the pre-music baserate levels, music had a significant effect (at $p < .0001$) on all twelve physiological measures, as shown in the first column of Table 1. The values analysed were the measures taken at one-second intervals (averaged over subjects) during the 90-second pre-music interval compared with those during the three-minute musical selection. Cardiac interbeat interval (IBI) increased; that is, heart rate slowed. Pulse transmission time to the finger (FPTT) increased. Finger pulse amplitude (FPA) decreased. Pulse transmission time to the ear (EPTT) increased. Respiration intercycle interval (ICI) decreased; that is, breathing rate increased. Respiration depth (RD) and respiration-sinus asynchrony (RSA) decreased. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) all increased. Skin conductance level (SCL) and temperature on the finger (TEM) both decreased.

As can be seen in the next three columns of Table 1, the same directions of difference were found when the intended Sad (Albinoni-Barber), intended Fear (Holst-Mussorgsky), and intended Happy (Vivaldi-Alfven) excerpts were analysed separately, and the differences were all highly significantly (at $p < .0001$) different from zero. Thus, the presence of music produced changes in physiology, and the changes were generally similar for the three excerpt types. The remaining analyses take various approaches to the question of whether residual differences in physiological measures correspond to the intended emotions of the excerpts.

Effect of excerpt type on average physiology
Analyses indicated that the physiological measures were different for the intended Sad (Albinoni-Barber), intended Fear (Holst-Mussorgsky), and intended Happy (Vivaldi-Alfven) excerpts. The values analysed were the measures taken at one-second intervals (averaged over subjects) during the 90-second pre-music interval compared with those during the three-minute musical selection. Because of the slightly different durations of the excerpts there were 387 observations for the sad excerpts, 395 for fear excerpts, and 386 observations for the happy excerpts. The means that the analysis of variance found to be different from one another (by a Fisher PLSD test) are indicated by different letters under the means shown in the table. Letters are assigned alphabetically from the largest to the smallest mean. When the changes were negative, A

TABLE 2
Correlations between dynamic emotion ratings and dynamic physio-logy ratings

Physiological Measures	Tension Ratings	Sad Ratings	Fear Ratings	Happy Ratings
IBI	−.05	.14*** A	−.01 B	−.15*** C
FPTT	.23***	.10** B	.16*** A	−.09** C
FPA	−.35***	−.14*** B	−.31*** C	.24*** A
EPTT	.19***	.07* B	.15*** A	.03 C
ICI	−.15***	.05 A	−.12*** B	−.16*** C
RD	.00	.00 A	.00 A	−.09* B
RSA	−.17***	−.02 A	−.11*** B	−.13*** C
SBP	−.10**	.37*** A	−.23*** C	−.14*** B
DBP	−.09*	.41*** A	−.24*** C	−.14*** B
MAP	−.08*	.37*** A	−.25*** C	−.10** B
SCL	−.10***	−.36*** C	.06 A	−.08* B
TEM	−.24***	−.35*** C	−.20*** B	.21*** A

Note: Levels of significance are indicated (* for $p < .05$, ** for $p < .001$, *** for $p < .0001$). The letters indicate the order of the correlation, starting with A for the largest correlation, ending with C for the smallest correlation. In the case of negative correlations, C is assigned to the largest negative correlation.

signifies the smallest negative change, C the largest negative change. Excerpts with the same letter were not significantly different (at $p < .05$).

The largest changes in interbeat interval (longer IBIs, slower heart rate), the three measures of blood pressure (increased SBP, DBP, MAP), and skin conductance level (decreased SCL) occurred for the Sad excerpts. The largest changes in finger temperature (decreased TEM) occurred for Sad and Fear excerpts. The largest changes in measures of pulse transmission time (increased FPTT and EPTT) and amplitude (decreased FPA) occurred for the Fear excerpts. Respiration intercycle interval changes (decreased ICI, faster breathing rate) were largest for the Fear and Happy excerpts. The only measure that produced the largest effect for just the Happy excerpts was respiration depth (decreased RD). The only measure that was not significantly different across the three excerpt types was respiration-sinus asynchrony (RSA). Thus, the measures generally differentiated between the excerpt types, with the largest effects generally occurring for the Sad and Fear excerpts and the smallest effects found for the Happy excerpts.

Correlations between dynamic emotion ratings and dynamic physiology measures

Table 2 shows the correlations between the dynamic emotion quality ratings and the dynamic physiology measures. The values in the analysis were the measures taken during the 3-minute musical selection from which the values during the 90-second pre-music interval were subtracted. With the large number of degrees of freedom (1166), many of the correlations were significant although their magnitude was small. For ease of comparison with Table 1, letters are shown below the correlations to indicate the order of the correlations beginning with the largest correlation (designated by A) and ending with the smallest (or most negative) correlation (designated by C).

Consistent with the previous analysis, the largest correlations with the Sad ratings were on cardiac interbeat interval (positive correlation with IBI), the three measures of blood pressure (positive correlations with SBP, DBP, MAP), skin conductance level (negative correlation with SCL), and finger temperature (negative correlation with TEM). The largest correlations with the Fear ratings were with finger and ear pulse transmission time (positive correlations with FPTT and EPTT) and finger pulse amplitude (negative correlation with FPA). The largest correlations with the Happy ratings were on the respiration measures of intercycle interval, respiration depth, and respiration-sinus asynchrony (negative correlations with ICI, RD, and RSA), although the first and third also correlated quite strongly (and both negatively) with the Fear ratings. Respiration depth (RD) only correlated significantly (negatively) with the Happy ratings. The correlations were similar (in sign and magnitude) when the correlations were done between the physiological measures and the Sad ratings for the Sad excerpts only, the Fear ratings for the Fear excerpts only, and the Happy ratings for the Happy excerpts only. This analysis produces results highly consistent with the previous analysis.

Correlations between dynamic physiology measures and time

Because the dynamic emotion quality ratings indicated quite sustained values of the intended emotion over the duration of the excerpts, it is possible that the physiological changes observed would increase over time. To assess this, the dynamic physiology measures were correlated

TABLE 3
Correlations between time during excerpts and dynamic physiology ratings

Physiological Measures	All Excerpts	Sad Excerpts	Fear Excerpt	Happy Excerpts
IBI	−.21*** (dec.)	−.04	−.44*** (dec.)	−.07
FPTT	−.11** (dec.)	−.04	−.29*** (dec.)	.01
FPA	−.19*** (inc.)	−.44*** (inc.)	−.27*** (inc.)	.23*** (dec.)
EPTT	−.05	−.07	−.18** (dec.)	.04
ICI	−.09* (inc.)	−.10* (inc.)	−.05	−.10
RD	.08* (dec.)	.05	.22*** (dec.)	−.06
RSA	−.10** (inc.)	−.07	−.06	−.18** (inc.)
SBP	.185*** (inc.)	.48*** (inc.)	.28*** (inc.)	−.05
DBP	.19*** (inc.)	.47*** (inc.)	.22*** (inc.)	.058
MAP	.23*** (inc.)	.54*** (inc.)	.26*** (inc.)	.07
SCL	−.81*** (inc.)	−.85*** (inc.)	−.79*** (inc.)	−.90*** (inc.)
TEM	−.71*** (inc.)	−.96*** (inc.)	−.94*** (inc.)	−.65*** (inc.)

Note: Levels of significance are indicated (* for $p < .05$, ** for $p < .001$, *** for $p < .0001$). (inc.) refers to cases where the effect size increases over time, that is: 1) where the average effect of music on the physiological measures is positive and the correlation with time is positive, and 2) where the average effect of music on the physiological measures is negative and the correlation with time is negative. (dec.) refers to cases where the effect size decreases over time, that is: 1) where the average effect of music on the physiological measures is positive and the correlation with time is negative, and 2) where the average effect of music on the physiological measures is negative and the correlation with time is positive.

with time from the beginning of the musical excerpts. Many of the correlations shown in Table 3 are statistically significant. Note especially the very strong correlations with skin conductance level (SCL) and temperature on the finger (TEM). The notations by the correlations indicate whether the magnitude of the effect (whether positive or negative) increases or decreases over time.

Looking across the columns of Table 3, the correlations differed across the Sad, Fear, and Happy excerpts, and the pattern depended on the physiological measure. Of the six physiological measures that correlated most strongly with the dynamic ratings of Sad, none returned to baserate and all but cardiac interbeat interval (IBI) showed an increased effect over time. Of those correlating most strongly with the Fear ratings, the results were mixed. Two (finger and ear pulse transmission time, FPTT and EPTT) returned to baserate. Only finger pulse amplitude (FPA) increased over time. The effect of respiration-sinus asynchrony (RSA), which correlated most strongly with the Happy ratings, showed an increased effect over time, and the same trend was found for the other two respiration measures (intercycle interval, ICI, and respiration depth, RD) that correlated most strongly with the Happy ratings. These results showed that the strongest physiological effects for each emotion type generally tended to increase over time, or at least did not strongly return toward baserate levels.

Factor analysis of dynamic physiology measures

To better understand the relations between the physiological measures, a factor analysis was computed for the dynamic physiology measures recorded during the music. The orthogonal solution (varimax) contained the six factors shown in Table 4. The table shows only those factor loadings that were greater than .50. Factor 1 (Eigenvalue = 3.43, proportion variance = 29%) consisted of the three measures of blood pressure. Factor 2 (Eigenvalue = 1.66, proportion variance = 14%) consisted of skin conductance level (SCL) and finger temperature (TEM), both of which decreased markedly during the musical excerpts (see Table 3). Factor 3 (Eigenvalue = 1.51, proportion variance = 13%) consisted of the three measures of respiration. Factor 4 (Eigenvalue = 1.22, proportion variance = 10%) consisted of finger pulse transmission time (FPTT, weighted positively) and finger pulse amplitude (FPA, weighted negatively). Factor 5 (Eigenvalue = 1.00, proportion variance = 8%) consisted of cardiac interbeat interval (IBI), and Factor 6 (Eigenvalue = .89, proportion variance = 7%) consisted of ear pulse transmis-

TABLE 4
Factor analysis of dynamic physiology measuresorthogonal solution

Measure	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
IBI	–	–	–	–	.91	–
FPTT	–	–	–	.76	–	–
FPA	–	–	–	–.87	–	–
EPTT	–	–	–	–	–	.94
ICI	–	–	.79	–	–	–
RD	–	–	.54	–	–	–
RSA	–	–	.74	–	–	–
SBP	.91	–	–	–	–	–
DBP	.95	–	–	–	–	–
MAP	.97	–	–	–	–	–
SCL	–	.89	–	–	–	–
TEM	–	.86	–	–	–	–

Average correlation between dynamic quality ratings and variables on each factor

	Factor1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Tension	–.09*	–.17***	–.10**	.29***	–.05	.19***
Sad	.38***	–.36***	.01	.12***	.14***	.07*
Fear	–.24***	–.07	–.08*	.24***	–.01	.15***
Happy	–.13***	.06	–.13**	–.17***	–.15***	.03

Note: Only the factor weights greater than .50 in the factor analysis are shown. Levels of significance are indicated (* for $p < .05$, ** for $p < .001$, *** for $p < .0001$) for the average correlations of the variables on each factor. In computing the average correlation between the dynamic quality ratings and the variables on Factor 4, the signs were taken into account; that is, the correlation for finger pulse amplitude (FPA) was subtracted from the correlation for finger pulse transmission time (FPTT) before.

sion time (EPTT). This analysis showed these groups of physiological measures varied independently during the musical selections.

The correlations between each of these groups of variables and the dynamic emotion ratings were then averaged, with the results shown at the bottom of the table. The Tension judgments correlated significantly with the variables on all factors except one. This can be understood because of its correlations with all three emotions (described above). Recall that, although Tension correlated most strongly with Fear overall, it also correlated to some degree with Sad and Happy especially when they were the dominant emotion of the excerpt. Thus, we would expect Tension to correlate with a broad spectrum of the physiological measures, and this is confirmed by the present analysis.

More centrally, these correlations distinguished among the three judgments of Sad, Fear, and Happy. Consistent with the other analyses, the variables on Factor 1 (the blood pressure variables, SBP, DBP, and MAP) correlated most strongly with the Sad ratings. In addition, those on Factor 2 (skin conductance and temperature, SCL and TEM) also correlated most strongly (and negatively) with the Sad ratings, and the variable on Factor 5 (cardiac interbeat interval, IBI) also correlated most strongly with the Sad ratings. The variables on Factors 4 and 6 (pulse transmission time to finger and ear, FPTT and EPTT, and finger pulse amplitude, FPA) correlated most strongly with the

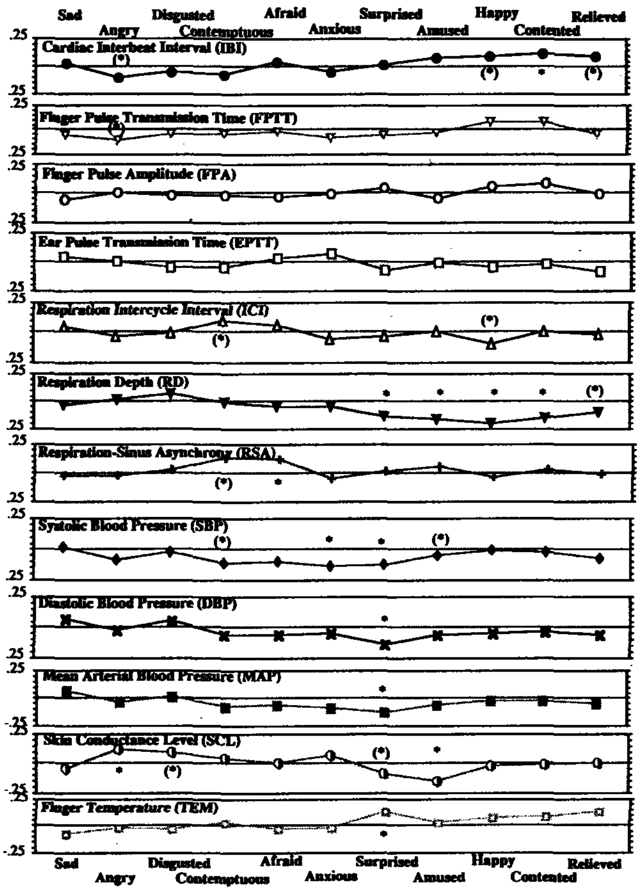

Figure 4. Shows the correlations between the self-report judgments and the psychophysiological measures. Correlations that are significant at $p < .05$ are indicated by *; those that are marginally significant at $p < .10$ are indicated by (*). Unlike the correlations with dynamic emotion ratings, few of these correlations were significant.

Fear ratings. Finally, the respiration measures on Factor 3 (intercycle interval, ICI, respiration depth, RD, and respiration-sinus asynchrony, RSA) correlated most strongly (and negatively) with the ratings for Happy.

Self-report of emotions and average physiological measures

The final analysis considering the relations between emotions and physiological measures used the self-report measures of emotions listeners gave immediately after hearing the excerpt. The analysis was based on the average for each subject for each physiological measure during each musical excerpt. These were correlated with the self-reports of emotions made immediately after hearing the excerpts. The resulting correlations are graphed in Figure 4. Significant correlations (at $p < .05$) are indicated by an asterisk. To consider trends, marginally significant (at $p < .10$) correlations are indicated by an asterisk in parentheses.

As can be seen, few of the correlations between self-reports and average physiological measures were either significant or marginally significant. Nor did they correspond with correlations using dynamic measures of physiology and emotion. For example, whereas dynamic Happy ratings correlated negatively with cardiac interval (IBI), the self-report ratings of Happy, Contented, and Relieved correlated positively. None of the self-report correlations for finger pulse transmission time (FPTT), finger pulse amplitude (FPA), or ear pulse transmission time (EPTT) were significant. Of the respiration measures, correlations of self-report Afraid with average respiration intercycle interval (ICI) and respiration-sinus asynchrony (RSA) tended to be positive, whereas the dynamic measures were positively related. Respiration depth (RD) correlated positively with the range of emotions surrounding Happy, but negatively with dynamic Happy ratings. The blood pressure variables (SBP, DBP, and MAP) corresponded most closely in the two analyses. These were more positively correlated with self-report Sad than were self-report emotions in the range of Anxious and Surprised. For the last two measures, skin conductance level (SCL) and finger temperature (TEM), the few significant or marginally significant correlations show no correspondence with those obtained with the dynamic physiology data.

DISCUSSION

Five features characterize this exploratory study. First, the experiment measured a wide range of psychophysiological responses typically associated with emotion. Second, the music, all instrumental pieces, was intuitively chosen to represent three basic emotions. Third, both the data collection and the data analysis emphasized temporal variations in the measures over time. The physiological and subjective emotion measures were both taken at one-second intervals during the three-minute excerpts. Fourth, the instructions for the subjective measures asked subjects to judge their own emotional reactions to the music, not the emotion expressed by the music. This was intended to ascertain whether the reports of emotions felt during listening corresponded with physiological measures. Fifth, the analyses concentrated on the internal consistency of the subjective and physiological measures, rather than *a priori* hypotheses concerning physiological correlates of musical emotions. However, specific comparisons with non-musical emotion physiology will be considered later.

The first finding was that the six selections did, as indicated by self-report measures, produce the intended emotions. Both groups of listeners, those who gave dynamic emotion quality ratings and those whose physiological measures were taken, reported very similar responses to the selections. Intersubject consistency was also very strong. The subjects judged their response to the excerpts by Albinoni and Barber to be strongest for the emotion of sad. They judged their response to the excerpt by Holst and Mussorgsky to be strongest for the emotions of anxious, afraid, and surprised. They judged their responses to the excerpt by Vivaldi and Alfven to be strongest for the emotion of happy, followed by amused and contented. That the latter two cases showed graded responses between intuitively similar emotions is consistent with the patterns of responses found, for example, by Hevner (1936), and supports the idea that musical emotions are not differentiated at fine-grained levels within basic emotion categories.

A two-dimensional representation of the emotional reactions to the six excerpts was recovered by a factor analysis of these self-reports. The circular representation, with emotions separated according to positive versus negative valence and degree of activity, corresponds with that typically found in studies of non-musical emotions (e.g., Roberts & Wedell, 1994). The grouping of emotion terms was clear within this two-dimensional space. In it, the emotion of afraid was close to a number of other emotions including surprised, anxious, and contemptuous. The emotion of happy was close to a number of other emotions including amused, contented, and relieved. Thus, the emotional responses reported in reaction to the musical excerpts not only coincided with the intended emotions, but produced a pattern of relations between emotions that conformed with those that arise from studies of non-musical emotions.

The dynamic ratings of emotion over time also showed the intended emotions of the chosen excerpts. The ratings of the intended emotions maintained a fairly high level that was sustained throughout the excerpts with local variations. Thus, music may be a particularly good stimulus for inducing and maintaining an emotion for extended periods of time. Dynamic ratings of tension were also obtained for possible interest in connection with other studies measuring tension (Nielsen, 1983; Madson & Fredrickson, 1993; Fredrickson, 1995; Krumhansl, 1996; Krumhansl & Schenck, 1997). Tension correlated most strongly with fear, although it also correlated quite strongly with the dominant emotion of the particular excerpt. This suggests that tension is a multivalent quality, influenced by the predominant emotional response to the music. A factor analysis of the dynamic emotion ratings again recovered a two-dimensional representation, with one factor corresponding to fear and tension, and the other factor corresponding to happy and sad (on opposite ends of the dimension). This representation was consistent with that obtained from the self-report measures.

With these results in hand, we can now turn to the psychophysiological measures themselves. Given the complexity of the data, with 12 different physiological measures and second-by-second measures for six three-minute long excerpts, it seemed desirable to conduct analyses that would look for convergences. A number of general patterns emerged from these analyses. The first result was that the presence of music significantly affected all twelve physiological measures, and the direction of the changes was the same for all three excerpt types. The changes were: longer cardiac interbeat interval (increased IBI, slower heart rate), longer pulse transmission times to ear and finger (increased FPTT and EPTT) and reduced blood amplitude at the finger (decreased FPA), decreases in respiration intercycle interval, depth, and respiration-sinus asynchrony (decreased ICI, which means a faster breathing rate, and decreased RD and RSA), higher systolic, diastolic, and mean arterial blood pressure (increased SBP, DBP, and MAP), and lower skin conductance and finger temperature (decreased SCL and TEM). Thus, the presence of music had effects on all of these physiological measures.

Five analyses were conducted to assess emotion-specific physiology in the present study. The first four of these used the physiological data recorded at one-second intervals throughout the musical selections (corrected for baserate levels during the pre-music interval). The focus on these dynamic measures is motivated by the idea that musical emotions may exhibit time-locking to variations in expectations over time as suggested by Meyer (1956). This proposal is consistent with a number of studies that show temporal variations in reported emotions (Goldstein, 1980; de Vries, 1991; Nielsen, 1983; Krumhansl 1996; Krumhansl & Schenck, 1997). The fifth analysis uses the average physiological data for each individual for each of the excerpts, and correlates these with self-reports of emotion. To anticipate the results, the first four analyses generally converged on fairly consistent relations between physiology and either the excerpt type or the dynamic ratings of emotion quality. However, these results did not generally match those obtained from emotion self-reports and physiological averages.

The first analysis examined whether the physiological measures differed by excerpt type. All but one (respiration-sinus asynchrony, RSA) showed reliable differences. The Albinoni and Barber excerpts, chosen to represent sad, produced the largest differences in: interbeat interval (longer IBIs, slower heart rate), the three measures of blood pressure (increased SBP, DBP, MAP), skin conductance level (decreased SCL), and finger temperature (decreased TEM); the effect size of this last measure was comparable to that found for fear excerpts. The Holst and Mussorgsky excerpts, chosen to represent fear, produced the largest differences in: pulse transmission time (increased FPTT and EPTT), pulse amplitude (decreased FPA), respiration intercycle interval changes (decreased ICI, faster breathing rate), and finger temperature (decreased TEM). As just noted, this last effect was similar to that for the sad excerpts, and the effect of respiration intercycle interval was similar to that for happy excerpts. Finally, the Vivaldi and Alfven excerpts, chosen to represent happy, produced the largest differences in: respiration intercycle interval changes (decreased ICI, faster breathing rate), and respiration depth (decreased RD); as just noted, the former effect was similar in magnitude to that for the fear excerpts.

These patterns were substantiated and clarified somewhat in the second analysis that correlated the dynamic physiology ratings with the dynamic ratings of emotion quality (sadness, fear, and happiness). The pattern of correlations separated by system. Sad was associated with changes in measures of cardiac and electrodermal systems, fear with changes in cardiovascular measures, and happy with respiration measures. Despite the significance of many of the correlations, it should be emphasized that their magnitudes were generally quite small. This might be explained partially by the fact that physiological systems show characteristic temporal patterns (lags and limits in the rapidity with which they can change). An approach to this might be to conduct analyses with the measures smoothed or lagged in various ways; initial explorations along these lines showed some promise but were not pursued further.

The third analysis correlated the dynamic physiological measures with time since the beginning of the excerpt. The rationale for this was that if the music really is affecting the physiology, the effects should be stable or perhaps even increase over time. Sixteen of the measures (out of 36 — 12 measures for each of sad, fear, and happy excerpts) showed increased effects over time, five showed decreases, and no significant trend in either direction was found for the remaining 15 measures. The increases were most regular for the variables most strongly affected by the sad excerpts.

Fourth, a factor analysis of the physiological measures during the music was performed to understand better the relations among these measures. Six factors emerged corresponding to blood pressure, skin conductance and temperature, respiration, heart rate, and two factors for the pulse transmission times and pulse volume. The average correlations with the dynamic sad, fear, and happy ratings were calculated for the variables on each of these factors. As expected based on the above analyses, the dynamic ratings of sad correlated strongest with the factors of the blood pressure, skin conductance and temperature measures, and cardiac intercycle interval. The dynamic ratings of fear correlated strongest with the factors of pulse transmission time and amplitude. The dynamic ratings of happy correlated strongest with the factor with the respiration measures. Tension correlated with the variables on all but one factor (cardiac interbeat interval), suggesting again that it is influenced to some degree by more than one emotional response.

The final analysis considered individual subjects' self-reports of the strength of emotions they felt during the excerpts. These were correlated with their average physiological measures. Few of the relations were reliable, nor did they correspond with the results just summarized. These largely negative results suggest that averaging the physiological measures across the entire excerpts gives far less systematic results than considering how the physiological measurements change dynamically over time. In other words, it would seem that dynamic variations in the measures are important indicators of musical emotions, and this information is lost when the physiological measures are averaged over whole excerpts. In addition, individual differences in the use of the self-report scales or physiological responsiveness may have obscured physiology correlates with emotions.

Having summarized these analyses, we are ready to consider correspondences between the present results and those obtained in previous studies of emotion physiology. First, I will consider the summary of the data from Ekman et al. (1983), Levenson et al. (1990), and Levenson et al. (1991) shown in Zajonc and McIntosh's (1992) Table 1. More of the significant differences found in these studies were for the directed facial action task than the relived emotions task. The results of these studies were compared with the physiological averages in Table 1 of this paper. Little correspondence was found with the present results. Considering first heart rate, insofar that these studies found differences, the measure tended to higher for sad and fear than for happy. The inverse order would be predicted for the cardiac interbeat interval measure used here, namely, interbeat interval would be higher for happy than sad and fear. However, the present measure was higher for sad than fear or happy. For finger temperature, the previous studies found no significant differences among sad, fear, and happy. Here, finger temperature was higher for happy than sad and fear excerpts. For skin conductance, the previous data would predict the lowest value for the happy excerpts. The present results found, instead, that the lowest value was for the sad excerpts.

I consider next the cross-cultural data in the study by Levenson, Ekman et al. (1992) in which the directed facial actions task was performed by the Minangkabau of West Sumatra. The results for heart rate and finger temperature were similar to those in the studies just considered, but no consistent differences were found for skin conductance. Again, the patterns did not conform to the present results. Similar non replications were found in other measures. Whereas finger pulse transmission time was longest for happy for the Minangkabau, it was shortest for happy in the present experiment. Finger pulse amplitude was largest for sad, but in the present study it was largest for happy.

However, in both cases it was larger for sad than for fear. Respiration depth was greatest for happy, but here it was least for happy. A partial replication was that in both studies respiration intercycle interval was shortest for fear although in the present study it was also short for happy.

To sum, quite a few of the differences found in these studies, especially in the directed facial actions task, were opposite those found in the present experiment. Possibly, as Boiten (1996) has suggested, the physiological changes in the directed facial actions task may depend more on the difficulty of producing the facial expression than the underlying emotion. More generally, emotion physiology may depend on preparation for overt responses as emphasized by Levenson (1994) and others. Music listening is often not accompanied by overt responses to the music. In this light, it may be noteworthy that the effects of music on a number of physiological measures were similar to the suppressed emotion condition in the study by Gross and Levenson (1993). In that condition, subjects were instructed not to make overt responses while watching a disgust-inducing film. The physiological measures were compared to a control condition with no such instruction. Similar differences as those found here for music obtained for cardiac interbeat interval (IBI), finger pulse amplitude (FPA), finger temperature (TEM), respiration intercycle interval (ICI), and respiration depth (RD). These similarities suggest that suppression of overt action during music listening may also affect physiological measures.

Somewhat more consistency was found with Table 9.2 of Cacioppo et al. (1993). For ease of comparison with their table, the letters in Table 1 labeled the differences as in their table. Ignoring the studies just summarized, I considered only cases in which the reported study and the present study had statistically significant differences on the relevant emotions of fear, sad, and happy. (It should be noted, however, that the majority of the studies surveyed by Cacioppo et al., 1993, did not find significant differences on the physiological measures across conditions.) Of all seven cases with significant differences, the direction of the difference found was the same. For heart rate, the present study agreed with Averill (1969, maximum rise, using film manipulation of emotion) and Tourangeau and Ellsworth (1979, maximum rise, using film manipulation). For finger temperature, skin conductance level, and finger pulse amplitude, the present study agreed with Stemmler (1989, real life manipulation, where fear was induced by a scary radio play and music and unexpected darkness, and happy was induced by a nice experimenter, extra monetary bonus, and a shorter experiment). Finally, both systolic blood pressure and diastolic blood pressure changes in the present experiment agreed with those found by Averill (1969, using a film manipulation). It may be significant that all the manipulations in these studies were extended over time as were the musical excerpts in this experiment.

In conclusion, the present results confirmed and extended the literature on musical emotions in a number of ways. First, emotion adjectives were consistently assigned to the excerpts and these matched the intended emotions. Intersubject correlations were strong and very similar judgments were made of the two excerpts chosen to represent each intended emotion (sad, fear, and happy). The pattern of these judgments fit with the circular representation of emotions proposed for both musical and non-musical emotions. In addition, dynamic ratings of the musical selections clearly differentiated the three excerpt types. These results are consistent with the studies reviewed earlier that find consistent verbal labeling of musical emotions.

Some of the same musical factors as in previous studies were present in these excerpts. The two excerpts chosen to represent sad (Albinoni's *Adagio* in G minor for Strings and Orchestra, and Barber's *Adagio* for Strings) are characterized by very slow tempos, minor harmonies, and fairly constant pitch ranges and dynamics. In contrast, the two excerpts chosen to represent fear (Holst's *Mars — the Bringer of War* from *The Planets*, and Mussorgsky's *Night on Bare Mountain*) have more rapid tempos with accelerandos, dissonant harmonies, rapid changes in dynamics, and large pitch range contrasts. Finally, the two excerpts chosen to represent happy (Vivaldi's *La Primavera* (Spring) from *The Four Seasons*, and Alfven's *Midsommarvaka*) have relatively rapid tempos, dance-like rhythms, major harmonies, and fairly constant pitch ranges and dynamics.

Consistent physiological changes occurred between the interval before the music and the interval during the music. The directions of the differences were the same for all excerpt types, suggesting a general set toward musical listening regardless of its emotion quality. In addition, all but one physiological measure differed across excerpt type. These differences were confirmed by correlations with the dynamic emotion ratings, and were aligned with distinct factors corresponding to different physiological systems in a factor analysis. Most of the physiological changes either increased during the musical selection or remained at a fairly constant level over time; only a few measures decreased toward baserate levels.

These results suggest that musical emotions are reflected in psychophysiological measures, and argue against the cognitivist position taken, for example, by Kivy (1990) and, to some extent, Meyer (1956). These psychophysical changes are behavioural indicators that listeners experience emotions when listening to music. Not only do listeners verbally report emotional responses to music with considerable consistency, music also produces physiological changes that correspond with the type of musical emotion. However, in comparing these specific effects with those for non-musical emotions the patterns diverge in some cases. Emotion-specific changes in physiology did not clearly map onto those found in studies of non-musical emotions. Some consistencies were found with previous studies, but the results appear to depend on the emotion-eliciting task. Thus, the question of emotion-specific physiology remains somewhat elusive.

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Sommaire

La littérature philosophique aborde souvent une question importante sur les émotions reliées à la musique: la musique provoque-t-elle des réactions émotives chez ceux qui l'écoutent (la position "émotive") ou exprime-t-elle simplement des émotions que les auditeurs reconnaissent (la position "cognitive"). Pour étudier le phénomène, nous avons enregistré des mesures psychophysiologiques pendant que les sujets écoutaient deux extraits choisis pour représenter trois émotions: la tristesse, (*Adagio* en sol mineur pour orchestre et cordes d'Albinoni et *Adagio* pour cordes de Barber), la peur, (*Mars —le belliqueux*, *Les planètes* de Holst et *Une nuit sur le mont Chauve* de Mussorgsky), et la joie (*Le printemps*, *Les quatre saisons* de Vivaldi et *Midsommarvaka* de Alfven). Les mesures comportaient un spectre assez large de fonctions cardiaques, vasculaires, électrodermales et respiratoires. Certains sujets démontraient des changements dynamiques d'émotions en écoutant la musique reliée à l'une des quatre échelles : la tristesse, la peur, la joie et la tension. Tous les jugements physiologiques et émotionnels étaient faits seconde par seconde. Nous avons de plus recueilli des mesures d'auto-évaluation des émotions.

Les attributs de l'émotion étaient continuellement reliés aux extraits qui eux, étaient associés à l'émotion voulue. Les relations entre les sujets se sont avérées très fortes et plusieurs jugements semblables ont pu être constatés sur les deux extraits choisis pour représenter chacune des émotions (la tristesse, la peur et la joie). Le modèle de ces jugements correspond à la représentation circulaire proposée pour les émotions qui sont reliées à la musique et celles qui ne le sont pas. De plus, les caractéristiques dynamiques des choix musicaux établissaient clairement les trois types d'extraits. Certains facteurs musicaux étaient les mêmes que dans les études précédentes.

Des changements physiologiques constants se sont produits entre l'intervalle avant la musique et l'intervalle pendant la musique. L'orientation des différences était la même pour tous les types d'extraits, ce qui suggère un modèle général d'écoute de la musique, quelle qu'en soit la qualité d'émotion. De plus, toutes les mesures physiologiques, sauf une, différaient d'un type d'extrait à l'autre. Ces différences ont été confirmées par les corrélations avec les caractéristiques musicales de l'émotion et placées par rapport à des facteurs distincts correspondant aux différents systèmes physiologiques pour l'analyse factorielle. La plupart des changements physiologiques augmentaient au cours du choix musical ou demeuraient à un niveau assez constant. Seules quelques mesures se sont abaissées près des niveaux de base.

Les résultats suggèrent que les émotions reliées à la musique sont reflétées dans les mesures psychophysiologiques et vont à l'encontre de la position cognitive. Ces changements psychophysiques sont des indicateurs de comportement montrant que les sujets éprouvent des émotions en écoutant de la musique. Par contre, si l'on compare ces effets spécifiques avec ceux qui sont associés aux émotions non reliées à la musique, les modèles diffèrent dans certains cas. Les changements physiologiques reliés spécifiquement aux émotions ne correspondaient pas clairement à ceux qui ont été constatés lors des études sur les émotions non reliées à la musique. Certaines constantes ont pu être constatées avec les études précédentes, mais les résultats semblent dépendre du test provoquant l'émotion.