Music Perception
Winter 1995, Vol. 13, No. 2, 171–207

The Emotional Sources of "Chills" Induced by Music

JAAK PANKSEPP
The Memorial Foundation for Lost Children & Bowling Green State University

Music modifies moods and emotions by interacting with brain mechanisms that remain to be identified. One powerful emotional effect induced by music is a shivery, gooseflesh type of skin sensation (commonly called "chills" or "thrills"), which may reflect the brain's ability to extract specific kinds of emotional meaning from music. A large survey indicated that college-age students typically prefer to label this phenomenon as "chills" rather than "thrills," but many mistakenly believe that happiness in music is more influential in evoking the response than sadness. A series of correlational studies analyzing the subjective experience of chills in groups of students listening to a variety of musical pieces indicated that chills are related to the perceived emotional content of various selections, with much stronger relations to perceived sadness than happiness. As a group, females report feeling more chills than males do. Because feelings of sadness typically arise from the severance of established social bonds, there may exist basic neurochemical similarities between the chilling emotions evoked by music and those engendered by social loss. Further study of the "chill" response should help clarify how music interacts with a specific emotional process of the normal human brain.

THE ability of music to modify mood is a fact of everyday life (Budd, 1985; Storr, 1992). Adults have no problem identifying the types of emotions conveyed by music, and even young children readily identify compositions that convey joy, sadness, fear, and anger (Dolgin & Adelson, 1990; Terwogt & Van Grinsven, 1988, 1991), which are the four emotions generally regarded as "basic" by all theorists (see Plutchik, 1994). Brain circuits that help mediate those emotions have been provisionally identified in subcortical areas of the brain (Panksepp, 1982, 1986, 1991, 1995, in press). Does music have direct access to such emotional circuits, or are the connections between music and emotions wrought by the complexities of learning? Most likely, both are involved. It is common knowledge that moods

Requests for reprints may be sent to J. Panksepp, Memorial Foundation for Lost Children, 708 East Wooster St., Bowling Green, OH 43402. (e-mail: jpankse@bgnet.bgsu.edu)

are affected most by the music that individuals have learned to love, and a positive correlation has been established between familiarity with and appreciation of music (Cantor & Zillmann, 1973). Investigators have been able to develop effective mood-induction procedures with music (Pignatiello, Camp, & Rasar, 1986), which may be as effective as the few nonmusical alternatives that are available (e.g., Clynes, 1977). Indeed, Clynes (1982) has argued that the dynamic motor forms of emotions and the dynamic acoustic forms that convey emotional meaning in music share basic similarities, and his concepts have yielded algorithms that allow the "living" emotional qualities of the great classical compositions to be truly rendered with feeling by computers (Clynes, 1982, 1995). Just as it is possible to evoke emotional states by certain acoustic forms, it is possible to evoke emotional states by motor reenactment of the dynamic "sentic" forms of the basic emotions (Clynes, 1988). The general assumption of the present work is that musically evoked emotional phenomena emerge initially from presemantic acoustic dynamics, evolved in ancient times, that still interact directly with the intrinsic emotional systems of our brains.

The specific brain mechanisms that music arouses to yield emotional responses remain to be identified, but related neurodynamic issues are beginning to be understood with the tools of modern brain research (Petsche, Lindner, Rappelsberger, & Gruber, 1988; Sergent, 1993). Indeed, happy and sad music have different electroencephalographic (EEG) coherence effects on the brain (Hinrichs & Machleidt, 1992), and sad music also produces more arousal (or alpha blocking) than happy music (Panksepp, Lensing, Klimesch, Schimke, & Vaningan, 1993). Although definitive concepts are not yet available, it is reasonable to assume that the basic emotional systems of the brain are tuned to the auditory environment. This should not be a controversial point, for the sounds of emotions are as distinct as the facial and bodily expressions (Davitz & Davitz, 1959; Pittam & Scherer, 1993). However, analysis of the connections between music and emotion would be facilitated if we had objective bodily and brain indicators for specific types of emotional experiences that can be evoked by music. Various bodily changes do occur in response to music (Landreth & Landreth, 1974), including changes in breathing, heart rate, galvanic skin response (GSR), and skin temperature (McFarland, 1985; Nakamura, 1984; Zimny & Weidenfeller, 1963), as well as within the EEG (Petsche et al., 1988), but none has yet been linked unambiguously to a specific type of emotional experience evoked by music. Indeed, the physiological effects from study to study have typically been quite variable (Dainow, 1977). For the past decade, I have studied the experience of "chills"—the tingly somatosensory feeling that can be evoked by certain kinds of music—with the hope of linking it to our understanding of basic emotional circuits in mammals

(Panksepp, 1981, 1982). My specific hope was to identify a bodily indicator for the emotion of sadness that could then be used in future psychophysiological work.

Considering the largely nonspecific nature of autonomic changes characterizing the basic emotions (but see Ekman, Levenson, & Friesen, 1983), it may seem unlikely that an analysis of bodily responses could ever highlight the specific emotional aesthetics contained in music. However, the provocative and often delightful bodily experiences that deeply moving passages of music arouse in many people may reflect a specific type of emotional process. In this context, the prickly skin response usually called "shivers," "thrills," or "chills" in English has not received the experimental attention it deserves (Sloboda, 1991). This bodily "rush" is commonly described as a spreading gooseflesh, hair-on-end feeling that is common on the back of the neck and head and often moves down the spine, at times spreading across much of the rest of the body. Its causes, diverse manifestations, and psychological meanings remain to be empirically defined. Such an inquiry has, no doubt, been neglected because of the subjective nature of the phenomenon and perhaps, also from the suspicion that chills will turn out to be quite idiosyncratic and variable from individual to individual. Indeed, people rarely discuss the experience, and there is no unambiguous lexical referent for it in English, although the most common labels appear to be "chills" and "thrills." My unabridged *Random House Dictionary of the English Language* does not provide unambiguous guidance on the issue, even though the connotations of "thrill" are certainly closer (e.g., thrill: "7. *a tremor or tingling sensation passing through the body as the result of sudden keen emotion or excitement; A thrill ran down his spine*").

To get a clear idea of the current vernacular usage, I conducted a large survey to see whether any consensus regarding terminology existed among students at our university. To this end, the experience was described without using either the term "chill" or "thrill" to four large introductory psychology classes, several hundred students in size, and 86% of the 828 respondents indicated they have the experience with some regularity. When forced to choose between the above labels, 68.8% thought the appropriate designator was "chills," and 31.2 % reported that they preferred the term "thrills." On the basis of that finding, the term "chills" will be used here to designate the phenomenon. Further, when asked to choose whether happy or sad music more readily produced the phenomenon, 57.2% of the students who experienced the phenomenon believed that happy music was more influential in producing chills than sad music (with no robust sex difference, and surprisingly, no strict relationship to the designator provided in the preceding question). However, the present empirical analysis indicates that sad music is, in fact, more closely related to the response.

Accordingly, I will suggest that the neurobiological roots of this experience are linked more to our human ability to experience social loss than to our ability to experience peaks of happiness. I will argue that such dynamics may reflect the specific nature of emotional systems in our brains, and I will try to relate the findings to our psychobiological work on social bonding, which suggests that attachments among kindred animals are related to brain systems that mediate separation distress (Panksepp, 1981). Thus, the occurrence of chills may be caused by the sudden arousal of such social emotions. That theoretical possibility, as well as the scarcity of empirical data on the topic, has enticed me to pursue empirical work on music-evoked chills for about a decade, and this is the first report of those findings, although they have been presented at several symposia (Panksepp, 1993a, 1994).

There is no question that it is difficult to define and measure chills objectively, although, as discussed more fully later, preliminary work suggests that the experience may be objectively measurable via GSR responses. However, before tackling the topic with technological sophistication, I decided first to characterize it thoroughly at the subjective-experiential level. Here I will summarize a series of systematic observations that consistently suggest that the experience of chills is related more to the perception of sadness in music than happiness. These findings help specify the emotional system that is most closely related to arousal of chills, thereby setting the stage for causal inquiries.

Here I describe results from six studies that sought to clarify the emotional qualities of music that generate chills in college-age adults. The studies were conducted in many small undergraduate psychology classes (typically containing no more than 23 students, except for the first study, which had up to 115 students, and the third, which had up to 42 students per class), during regularly scheduled class periods. All students were advised that participation was voluntary and failure to participate would not affect grades in any way, even though in the smaller lab classes, the exercises did constitute scheduled research projects. In the larger classes, the exercises were always part of course sequences during which emotions were discussed and served to highlight issues covered in class. The data are being shared with the consent of the participants. Only one study was done with each set of students (except for Study 6, which reused a subset of students from Study 3). All studies were conducted toward the end of the semester, when class members felt at ease with each other, and a sensitive and frank mood had been established for conducting such delicate work. Students were requested to systematically monitor their bodily experiences while listening, with eyes closed, to various pieces in a relaxed environment with lights dimmed. They were given no advance knowledge of the specific questions to be asked or the potential theoretical implications of the work, but after completion of each study, the average results were shared and discussed.

The brief survey described above helped characterize the natural history of chills as recalled from memory, and the first study sought to clarify the occurrence of the phenomenon with a longer survey. All subsequent studies analyzed chills in response to specific pieces of music, with the explicit question being whether happy or sad music was more likely to generate chills. The hypothesis generated by the end of the second study—that sadness was more important for the generation of the phenomenon than other emotional experiences—guided the construction of all subsequent studies.

Study 1: Basic Description of the Chill Phenomenon

The first aim was to harvest impressions that people have concerning the characteristics of chills. The respondents were 216 female and 116 male undergraduate students between the ages of 19 and 25 (which reflects the demographics of our University). In a classroom situation, students were presented with a four-item multiple-choice questionnaire, posed one question at a time on an overhead transparency with approximately half a minute to respond to each item. All students recorded their answers on sheets of paper that were collected at the end of the session. The first question concerned the role of music in the lives of these students, the second inquired about the general frequency with which they experience chills, the third about the typical location of chills on their bodies, and the fourth about the type of emotion in music that most commonly produced chills in them. Students were requested to provide the single best answer to each question. Options are presented in Figure 1.

The overall percentages of total responses to each option are summarized in Figure 1. The distributions of answers to all questions deviated from chance at the $p < .001$ level by chi-square analysis. In general, the responses of males and females were quite similar, with minor sex variations, such as females believing sad/melancholy music evoked chills more than males, and the reverse for happy/excited music. As is evident from Figure 1, students overwhelmingly claimed that they listen to music primarily for its effect on their emotions and feelings, which is also true for most adolescents (Wells & Hakanen, 1991). The majority experienced chills occasionally, with a small minority having the experience very frequently or never at all. There was a wide distribution of body areas where chills were primarily felt, with the most common report being "all over the body," followed successively by the head, face, neck, and back, with quite a few

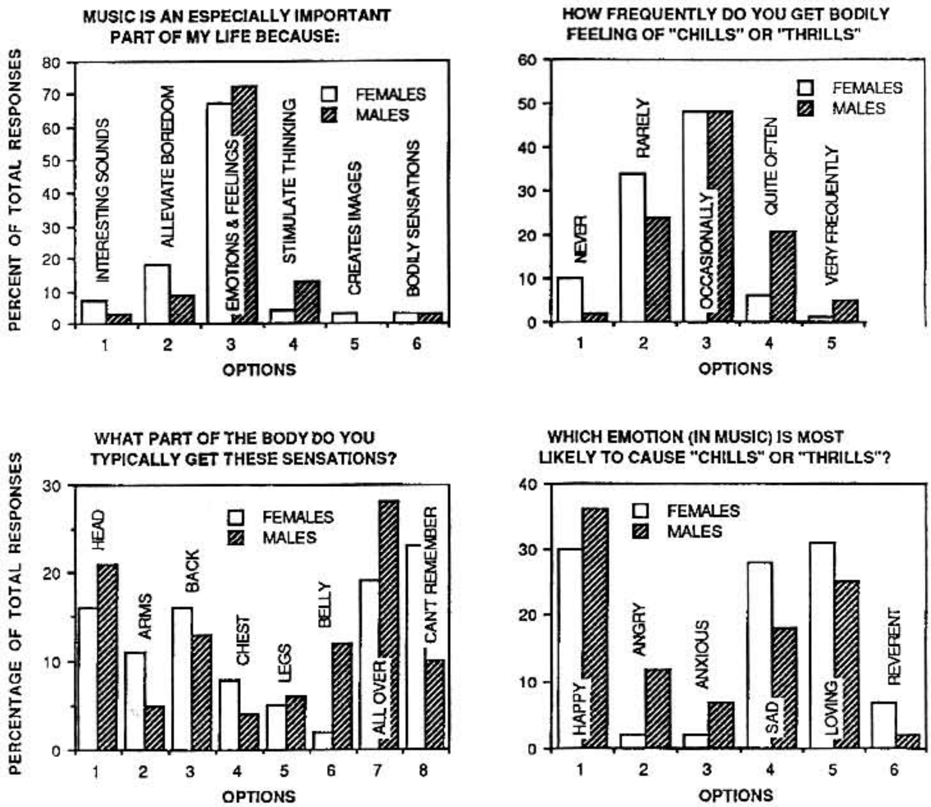

Fig. 1. Percentage of total responses to each of four questions indicated at the top of each graph. The options for the four questions were as follows: First, "music is an especially important part of my life because it"—(1) consists of interesting sounds, (2) alleviates boredom, (3) modifies emotions and feelings, (4) stimulates thinking, (5) creates mental images, (f) causes bodily sensations. Second, "how frequently do you feel chills?"—(1) never, (2) hardly at all, (3) occasionally, (4) quite often, (5) very frequently. Third, "where do you feel chills most?"—(1) head, face, and neck, (2) arms, (3) back, (4) chest, (5) legs, (6) belly/groin, (7) all over, or (8) can't remember. Fourth, "which emotion is most likely to cause chills?"—(1) happy/excited, (2) angry/frustrated, (3) anxious/fearful, (4) sad/melancholy, (5) loving/accepting, (6) peaceful/reverent.

subjects having no distinct memory of location (which largely reflected individuals who only rarely had the experience). Three of the six major emotions that are commonly conveyed by music were chosen evenly by both males and females as the primary types most likely to evoke chills. They included "happy and excited" music, "loving and accepting" music, and "sad and melancholy" music. Angry, anxious, and peaceful music were deemed least likely to evoke the experience. Students were allowed to nominate other feelings in addition to those listed, and only a "thoughtful/nostalgic/bittersweet" category was mentioned at a noteworthy level. Although these responses are opinions, the study did delineate which emotions are deemed most likely to be influential in the generation of chills.

Study 2: The Emotional Basis of Chills

In this study, the types of music that actually produce chills were evaluated empirically. Students were asked to bring in selections that were simply deemed to be "especially emotionally moving" to them, and all selections were rated for their ability to produce chills and to evoke various emotional feelings during the type of group listening situation described here.

METHODS

Participants were 14 undergraduate students (9 female, 5 male between 20 and 24 years old) enrolled in a psychology course on Emotions and Motivations. The students were requested to bring to class a cassette tape of a single musical piece, no longer than 6 min in duration, that was especially emotionally moving to them. The students were simply told that the aim of the experiment was to study emotionality in music, without explicitly stating that an analysis of chills would be involved. During a single 2-hr listening period, the students evaluated all the selected pieces with respect to their ability to evoke various emotional states, and they were also requested to report the frequency of chills. Subjects had been familiarized with the type of questionnaire to be used the day before the listening session, and they were also told at that time that they would be requested to keep a count (on a scratch sheet) of the number of chills they experienced during each piece of music. A description of chills was provided, as based on the descriptive data from Study 1.

APPARATUS AND PROCEDURES

The 14 songs brought in by students, plus 4 additional items provided by the instructor, were dubbed onto a master tape. Testing in this study (as well as all subsequent studies, except Study 4) occurred during a scheduled 2-hr laboratory period (starting at 10:30 A.M.) in a 22 × 30 ft room without windows. The students were requested to sit quietly with eyes closed and to enjoy the music as if they were alone by themselves. They were requested not to talk, and to remain quiet throughout the session, but to feel free to quietly leave the room if they wished for any reason (none did). They were given a simple structured questionnaire form upon which they could record their impressions of each piece during the 1- to 2-min intervals between successive pieces. At the beginning of this listening session (and those in subsequent studies), the lights were gradually dimmed from the normal 450 lux to approximately 20 lux. The music itself was presented with a high-quality stereo system via two 42 × 99 cm EPI Magnus speakers receiving input via a JVC TD W20 cassette deck, run through an ADC "Sound Shaper" Stereo Frequency Equalizer/Spectrum Analyzer set at near midscale for all frequencies. Volume was controlled by a Kenwood KA 880SD Super DLD Stereo Integrated Amplifier. The speakers were situated in adjacent corners at the front of the room. The closest students were seated about 5 feet from the speakers, and the farthest was 18 feet away. Throughout testing, the sound level was monitored with a spot meter at 5 feet equidistant from the speakers, and minor volume adjustments were made to keep the average level at around 85 decibels. The experiment was also conducted on a second set of 16

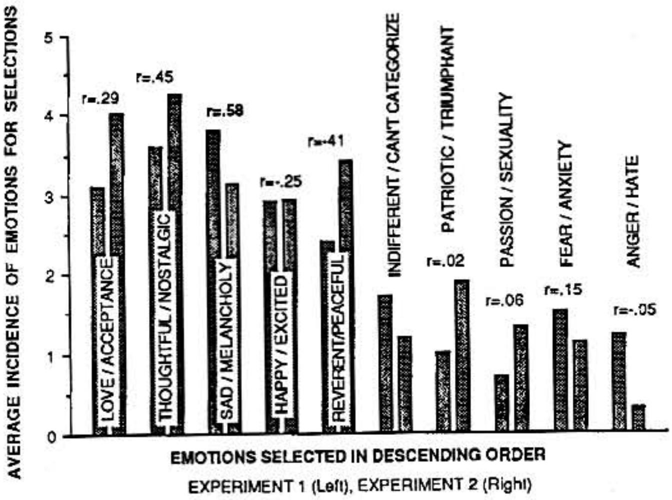

Fig. 2. The incidence of reported emotions contained in emotionally moving selections provided by subjects in Study 2. Adjacent bars are replicate experiments, and correlations between ratings of the various emotions and the incidence of chills across all subjects are indicated above each set of histograms. Sad/melancholy music was most highly correlated with incidence of chills.

students (who did not personally select these musical pieces) to verify that the results were consistent. Because the results proved to be remarkably similar (Figure 2), the overall correlative data have been combined.

The questionnaire that was used contained vertically aligned spaces for each of the 18 pieces of music, and upon the completion of each piece, each student independently indicated the following: (1) The number of chills they had experienced during the piece. (2) The two emotions that best characterized the emotional feelings evoked by each piece. Ten possible emotional responses were provided, including (a) happy/excited, (b) patriotic/triumphant, (c) love/acceptance, (d) anger/hate, (e) fearful/anxious, (f) sad/melancholy, (g) reverent/peaceful, (h) passionate/sexuality, (i) thoughtful/ nostalgic, or (j) indifferent/can't categorize. (3) Each column had a blank to indicate whether the song was recognized. (4) Each song had two 7-point Likert-type scales, one of which asked the listeners to rate the "emotional content" of each piece (with a response of 1 being anchored as "hardly at all," 4 as "quite a bit," and 7 as "moved me a lot") and the other of which asked "how much did you like the piece" (with 1 anchored as "so-so," 4 as "very good," and 7 as "out of sight"). Only key pieces of music are mentioned by name in this and subsequent studies.

RESULTS AND DISCUSSION

All of the selected pieces were reported to yield some chills, with the first class total being 325 chills, ranging from 3 to 26 for the individual pieces. The highest rate of reported chills was 0.5 chills/min/person for the beginning 3-min segment called "Post-War Dream" from Pink Floyd's album *Final Cut* (No. 2 in Figure 3), which, on the average, yielded essentially the same number of chills as one's own song (Figure 3). As familiarity with the selected music proved to be an influential variable in the generation of

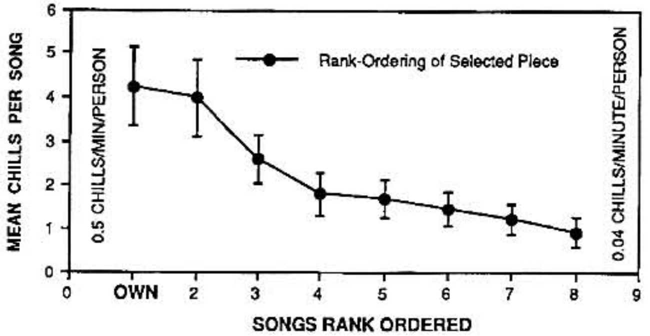

Fig. 3. The average (±SEM) number of chills per song/person for the highest eight selections in Study 2. Selections 2–8 were as follows: (2) Pink Floyd—"Post War Dream," (3) Air Supply—"Making Love Out of Nothing at All," (4) Journey—"Faithfully," (5) Boston—"Peace of Mind," (6) Howard Jones—"No One to Blame," (7) Chris Williamson—"Wild Thing," (8) Bob Marley—"No Woman No Cry."

chills (see Study 3), it is noteworthy that only 36% of the people recognized the Pink Floyd piece. That a novel piece of music would be so effective is rather atypical and hence remarkable. From a subsequent time-series analysis (see Study 6), it was clear that the majority of the chills to this piece occurred in response to the dramatic crescendo at the beginning of the second minute. Quite high levels of chills were also obtained from several other well-known pieces (Nos. 3 & 5, in Figure 3), and so they were used as the familiar pieces in some of the subsequent work (e.g., Study 4). The lowest rate of chills, at 0.04 chills/min/student, was obtained for an odd little selection that no one recognized. Overall, recognizability for the selected pieces ranged from 0% to 100% with a mean of 48%. The average familiarity for each song was modestly related to the average number of chills evoked by these pieces of music ($r = .36$). However, as might be expected (and was found throughout this work), personal meaning had a clear impact on the production of chills. Ten subjects reported having the most chills to their own selections (see Figures 3 & 4). Thus, chill-producing impact is partially derived from the special meaning each person brings to a piece of music he or she knows and enjoys, but other potent variables are also operative, as revealed through a broader analysis of the population results.

Across all pieces, the frequency of emotions evoked by the selected pieces (rank ordered from the most to least frequent) were as follows (with correlations to the number of chills per minute indicated in parentheses after each item; the degrees of freedom for each comparison = 16): listeners checked off love/acceptance as the most commonly experienced emotion from the submitted pieces (however, the overall incidence of this emotion was only related to chills at a modest, nonsignificant level of $r = .29$), sad/

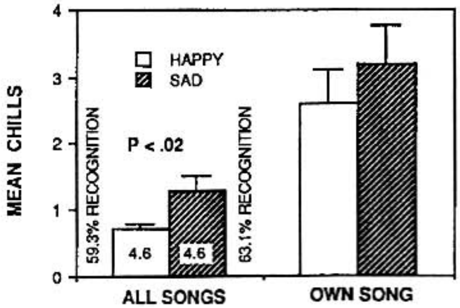

Fig. 4. The mean (±SEM) number of reported chills for all the happy and sad songs provided in Study 3, as contrasted with the number of chills students reported in response to the playing of their own selections.

melancholy came next (with an $r = .58$, $p < .05$), then thoughtful/nostalgic ($r = .45$, $p < .08$), happy/excited ($r = -.25$), reverent/peaceful ($r = -.41$), fearful/anxious ($r = .15$), anger/hate ($r = -.05$), and patriotic/triumphant ($r = .02$), with passionate/sexuality ($r = .06$) coming in last. Although the relationship of sad/melancholy and thoughtful/nostalgic to chills was not reliably different, both were reliably higher than the other emotions ($p < .05$), and it is noteworthy that both happy/excited and reverent/peaceful exhibited negative relationships to chills. In sum, on the basis of such population averages, the two emotions that had the highest relationship to the number of chills were sad/melancholy and thoughtful/nostalgic, with the rest having no positive relationship to chills. The negative relationships to reverent/peaceful and happy/excited tend to rule them out, at least on the face of it, as major positive contributory factors to the chill phenomenon.

The relationship of chills produced by each piece to ratings of "liking" and to "perceived emotional content" were significant ($r = .50$ & $.55$, respectively, with $p < .05$ and $df = 16$), but the relationship between those psychological measures was even higher ($r = .75$, $df = 16$, $p < .01$), suggesting that they were measuring a related psychological dimension. This same high degree of relationship among these variables was observed in each and every one of the listeners at a probability level of less than .01—with the mean of the individual correlations (±*SD*) for chills and emotional content being .70 (±.16), chills and liking being .69 (±.13), and emotional content and liking being .84 (±.10), which suggests they were tapping into a common evaluation system (and that was confirmed by factor analysis in Study 4). More than 90% of these students claimed that they enjoyed the experience. However, contrary to what was claimed in the initial questionnaire (Figure 1), sad/melancholic content of music is more strongly related to production of chills than either happy/excited or love/acceptance dimensions. However, this is not to say that those emotions and others cannot come to be associated with chills through varied personal experiences with music, yielding conditioning effects that might make the more primal unconditional causes obscure. Indeed, as was evident in the next study, the differential relations of happiness and sadness in music to chills are diluted considerably in individuals who have had a considerable amount of personal experience with the music being evaluated. In other words, the learned aspects of chills may yield more evaluative diversity than the unconditional aspects that were of primary interest in the present project.

Study 3: Chills in Response to Happy and Sad Music

The previous study suggests that the experience of chills is related more clearly to sad/melancholy than to excited/happy feelings. If true, that relationship should remain apparent when other methodologies are used. For instance, happy music is not necessarily "excited" and perhaps some might even claim that sad music is not "melancholy," and hence, the previous studies may be intrinsically ambiguous in terms of the types of emotions that are actually related to the chills. In this study, students in a class were requested to simply bring in two pieces of music they especially enjoyed—one being happy and the other sad (with no secondary modifiers such as "excited" or "melancholy"). The surface aim of the study was to determine whether their classmates would also correctly rate the pieces of music as being happy and sad, but the deeper aim was to reevaluate the role of those polar emotions on the genesis of chills. Thus, when the listening session was conducted, all students were not only requested to make affective ratings of sadness and happiness for each piece but to also record the number of times they subjectively experienced chills during each piece.

The general methodology was essentially similar to that of Study 2. Participants were 18 students enrolled in an experimental psychology class. The musical pieces were played under conditions already described, and evaluated with respect to two 7-point Likert scales (as in the preceding study), one for perceived happiness and the other for perceived sadness (with 1 being anchored as "not at all," 4 as "modest," and 7 as "very"). Students were also asked to indicate if they recognized the pieces. Evaluation of the whole series of selected pieces required two 2-hr listening sessions separated by a week.

The two selections for each student were played as successive pairs, with order of sad and happy selections counterbalanced. An independent rating for each piece had been requested for all questions immediately after listening, but, unfortunately, compliance was not consistent. Many students provided only a happiness rating for the obviously happy pieces and only a sadness rating for the obviously sad pieces. This lack of compliance was not intentional; on later questioning, many students explained that it did not make sense to provide both ratings unless the selected items were ambiguous. In general, the students had no problem correctly identifying the happy and sad pieces (they were mostly popular music of the late 1980s), with only two pairs causing some confusion. The average happiness ratings of the happy pieces was 4.6 (±.28), which was no different from the average sadness rating of the sad pieces (4.5 ± .26), but each of those was much higher than the available subset of sadness and happiness ratings for those pieces, which were both less than 2.0. Although the available sadness and happiness ratings for the same pieces were reliably different for each student at $p < .0001$, a desired multiple regression analysis could not be done because of the many missing data points for the nontarget emotions. Critical for the comparison of chills was the fact that the recognizability of the songs did not reliably differ, with the happy pieces being recognized 59.3 (±6.9)% of the time, and the sad pieces 63.1 (±8.2)% of the time. In addition, the average durations of the happy and sad pieces did not reliably differ, so absolute chills were used in the statistical analyses without conversion to chills per minute.

The average chill ratings are summarized in Figure 4. Clearly, subjects reported more chills to their own selections, whether happy or sad, than those selected by others [$F(1,34) = 29.9, p < .0001$]. Overall, sad pieces did produce more chills than the happy ones [$F(1,34) = 6.36, p < .02$], but that difference was not apparent when the chills of only the individuals who had selected the various pairs of pieces were analyzed. This may help explain why people in the initial survey seemed confused whether happy or sad music was more likely to provoke chills. Apparently, as one develops familiar musical favorites, the intrinsic emotional content of the piece may become less important in controlling chills than the experientially conditioned meaning the music has for an individual.

A simple correlational analysis indicated that the reported number of chills was highly related to the sadness ratings of the sad pieces ($r = .76$, $df = 16$, $p < .01$). A more modest positive relationship was also evident for ratings of happiness ($r = .47$, $df = 16$, $p = .05$), but these correlations were not differently related to chills in terms of differential statistical significance as determined by a Z-test for two correlation coefficients. For both the sad and happy pieces, the recognizability of the song was also related to chills: $r = .58$ and .48 ($df = 16$, $p < .05$) for both sad and happy, respectively. Thus, with this set of reasonably familiar music, chills were still significantly related to general emotional content, but the slightly higher relationship to sadness was not sufficiently substantial to yield any clear conclusion that chills are more strongly related to one emotion or the other.

What did seem clear, however, was that differential responsivity was related to familiarity. Specifically, more chills were apparent for sad music only if individuals were not familiar with the pieces, suggesting that conditioning effects could obscure intrinsic responses. The next experiment was designed to evaluate formally whether a differential emotional effect on chills was, in fact, related to lack of familiarity with the music.

Study 4: Chills and The Role of Familiarity with Happy vs. Sad Music

Although the initial survey suggested that happy music is believed to produce chills more readily than sad music, the subsequent empirical analyses more strongly supported the notion that chills are more likely to emerge from sad/melancholic and thoughtful/nostalgic/bittersweet aspects of music than from happy dimensions or loving/accepting ones (Study 2). However, the differential effects of happy and sad music are evident only when individuals do not have strong personal associations to the music (Study 3). It seems reasonable to assume that responses to unfamiliar music are more reflective of the unconditional response tendencies of human emotional systems, whereas responses to familiar pieces are more reflective of the accruing consequences of learning. This, of course, can only be an approximation, for fine pieces of music usually have both the potentials for happiness and sadness interwoven within the musical texture, which may commonly result in greatly varying individual judgments for the same piece of music. In any event, at this point in the analysis, it would seem that many young adults are generally mistaken about the dimension of music that actually provokes their experience of chills. Not only may this arise from the mixed emotional impact of many pieces of music, but also from the vagaries of individual personalities, learning, and the many unique personal associations that gradually come to control one's musical preferences and evaluations.

To determine further how familiar and unfamiliar pieces, both happy and sad, influence chills and to assess whether there are sex differences in these relationships, in the following study, several carefully selected happy and sad items were contrasted with each other. Two distinct pairs of vocal pieces were selected for intensive study. The first included two highly recognizable songs that had produced chills extremely well in Study 2: They were the happiest piece that produced the highest levels of chills ("Peace of Mind" by the group Boston, yielding 3.5 chills/min) and a sad/melancholy piece that also produced many chills ("Making Love Out of Nothing at All" by the group Air Supply, which yielded 4.4 chills/min). I selected the second set of songs to include distinctly happy and sad pieces by the emotionally compelling female vocalist Chris Williamson, from her album *The Changer and the Changed*. On the basis of prescreening data, it was clear that these pieces would probably not be recognized by our undergraduate population. All listening sessions were preceded by a common "warm-up" piece. This was selected to be a moving but emotionally ambiguous instrumental selection (namely, Kitaro's "Auspicious Omen"). Emotional responses and subjectively experienced chills were monitored as already described.

This study was conducted with four separate classes of students. Two were tested in counterbalanced fashion with the well-recognized pair of sad and happy songs (indeed, it turned out that 98% of the people recognized both). The other two groups were exposed in counterbalanced fashion to Chris Williamson's sad song "Wild Thing" and her very upbeat, happy piece entitled "Sing a Song." As anticipated, the recognition score for these pieces proved to be 0%. The Kitaro warm-up piece was also not recognized, except for one male (who, interestingly, reported the highest number of chills of anyone to this piece). The Kitaro selection was always played first, in the hope of establishing a reasonably constant background mood for the vocal pieces that followed.

Just before the listening session, the students were informed that one goal of the study was to measure the number of chills they were going to experience during several pieces of music, and any questions regarding that experience were answered. A questionnaire was passed out, which had a space for giving the number of chills experienced during each piece, a space for identifying the song if it was recognized, and five 7-point Likert scale questions: (1) How much did you like the music?, (2) How would you rate the level of emotional content in this piece? (3) How would you rate the level of sadness/melancholy in this piece? (4) How would you rate the level of happy/excitement in this piece; and (5) how much did this piece affect your mood and feelings? The 7-point scale was anchored at 1 with "not at all," at 4 with "moderate level," and at 7 with "very high." At the end of the session, students were also asked whether or not they enjoyed the chills they had experienced.

The mean ratings for the opening Kitaro selection are summarized as a function of sex at the top of Figure 5. As anticipated, the introductory Kitaro piece was deemed to be emotionally ambiguous: Males and females did not rank the piece differently in either sadness or melancholy, even though females did give it a slightly higher overall emotional ranking than males did [$F(1,112) = 5.45, p < .01$], and also, females reported twice as many chills as males did [$F(1,112) = 6.79, p < .01$]. Females also reported liking the piece somewhat more and reported that their moods had been affected more than males did ($p < .01$). These relationships suggest that females had more chills because they were emotionally moved more by the music, or vice versa.

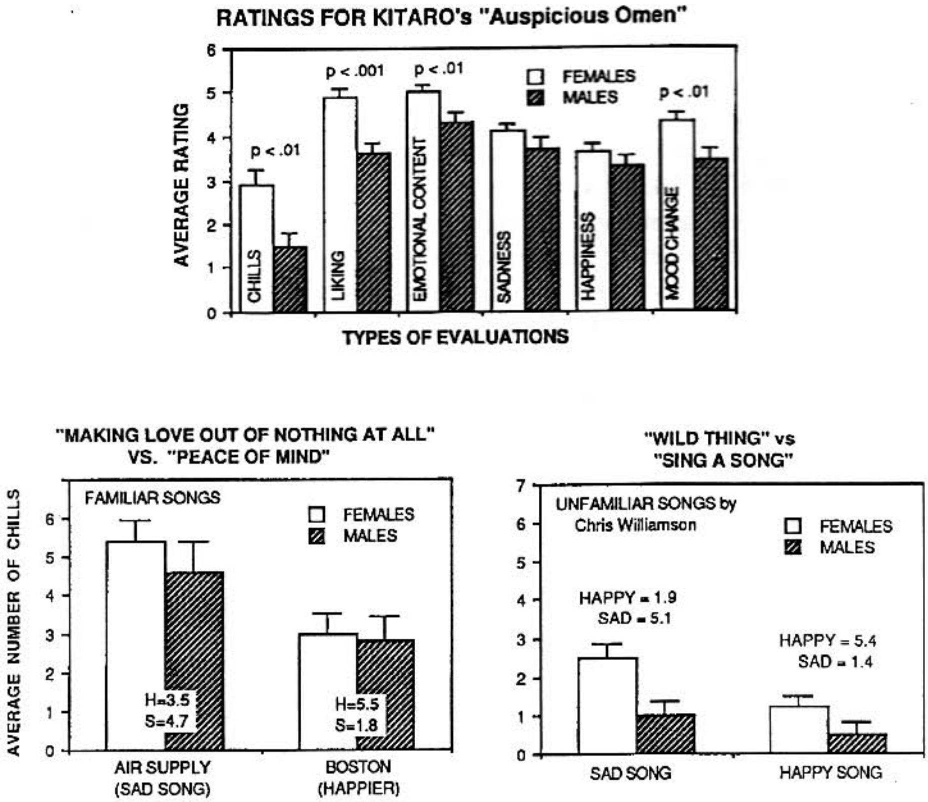

Fig. 5. The mean (±SEM) incidence of chills and responses to the various rating scales as a function of sex in Study 4 for the Kitaro piece played first for all subjects (top), and the subset of subjects that received happy and sad familiar pieces of music (lower left) and happy and sad unfamiliar pieces of music (lower right). The numbers within the lower histograms summarize the happiness and sadness ratings for each piece (H = happy; S = sad).

As summarized at the bottom of Figure 5 (left side), the specific emotional judgments made of the two familiar pieces did indicate that the Air Supply rendition of "Making Love Out of Nothing at All" was deemed to contain significantly more sadness (mean, 4.7) than happiness (mean, 3.5), whereas the Boston rendition of "Peace of Mind" was deemed to contain considerably more happiness (mean, 5.5) than sadness (mean, 1.8). This differential judgment was slightly clearer in females, as indicated by a marginal sex by emotion interaction [$F(1,60) = 3.08, p < .09$]. Although males and females did not exhibit a reliable difference in chills to either piece, overall the sadder piece generated reliably more chills than the happier piece in both males and females [$F(1,60) = 16.1, p < .001$]. There were no sex differences in the affective ratings given to the Boston piece, but females liked the Air Supply piece more than males did, and their mood was also modified more, just as had been the case with the Kitaro piece ($p <$ .05). This suggests that females may be slightly more attuned to expressions of sadness in "love music."

Responses to the two unfamiliar pieces yielded clear differential emotional judgments in both males and females [for mean values, see Fig. 5: sad song, $F(1,50) = 84.1, p < .0001$; happy song $F(1,50) = 212.9, p < .0001$]. Although there was no sex difference in the sadness ratings for the sad piece, females did rate the happy piece as happier [$F(1,50) = 7.96, p < .01$]. As with the other pieces, females also liked the sad piece more than males did, gave it higher emotional ratings, and reported their mood to be affected more ($p < .05$). The happy piece only yielded a comparable sex effect for the mood question. With respect to the subjective experience of chills, the sad piece produced more reported incidents than the happy piece did [$F(1,50) = 14.38, p < .001$], but this effect was only clear in females ($p <$ .001) as the similar trend was not statistically significant in males. Unfortunately, the other differential judgments between sexes make it difficult to specify a potential cause of the differential chill reports between males and females. It is not certain whether the specific emotional effect (happiness and sadness) or the general emotional effects (mood, liking, and emotional content) are more influential.

Accordingly, the intercorrelations among ratings for each piece of music were subjected to unrotated factor analysis. Every piece yielded two reliable factors, one of which (accounting for about half of the variance) might be termed a general "affective dimension," as ratings for liking, emotional content, and mood change were highly related for every piece. The number of chills loaded highly on this factor at .62 for the familiar songs, and at .65 for the unfamiliar songs. Sadness loaded at .54 and .68 for these pairs of songs, respectively, whereas happiness did not relate to it positively (with –.08 and –.43 loadings on this factor). The other factor (accounting for about a fifth of the total variance) was related more specifically to "positive emotionality": The happiness question loaded at .92 for the first pair of songs and at .85 for the second pair. As might be expected, the sadness ratings loaded inversely on this second factor at –.75 and –.66. It should be noted that these loadings were apparent only when the data for the respective pairs of songs were taken together. When each was considered separately, the variances of the sadness and happiness ratings were so constricted that such relationships were not evident for the individual pieces considered separately. However, the remaining ratings, which also contributed to the first factor, were clearly evident in the factor analyses of each of the five individual pieces. In sum, it is especially noteworthy that, at least for these individual musical selections, most people seemed to relate the concepts of "liking," "emotional content," and "mood changes" much more to sad, rather than to happy, dimensions of the music.

Several additional observations were noteworthy. The tendency to report chills seemed to be a stronger and more stable characteristic in females than in males. Thus, the average test-retest correlation for females listening to the three pieces of music in this first set of selections was $r = .48$ ($df = 34$) and in the second set it was $r = .51$ ($df = 27$), both being significant at $p <$ .001. For males, these respective correlations were $r = .24$ ($df = 24$) and $r =$ .31 ($df = 21$), which were not significant. These correlative relationships were reliably higher in females than males ($p < .01$). Finally, 82% of the females and 75% of the males reported that they liked the chills, whereas 18% and 25% were either neutral or not sure, with those who disliked chills constituting less than 6% of those subgroups.

Overall, these data again support the thesis that sadness or melancholy is an emotional dimension more significantly related to the production of chills than is happiness. In each pair of songs, the sadder piece produced more chills than the happier one, and the sex differential in this relationship was evident only for the three unfamiliar pieces. The factor-analytic data provide further support for the relationship between chills and sadness. When the respective pairs of songs were considered together, both sadness/melancholy and the frequency of chills loaded on a single "affective dimension" (which reflected overall liking, perceived emotional content, and ability of the song to modify moods). Surprisingly, the ratings of happiness did not load on this factor at all. This is not to claim that some other happy pieces might not exhibit such a loading, but that was not the case in the present selections. I would note that I have also conducted comparable work with a third pair of happy vs. sad songs performed by Leonard Cohen, a male artist whose work, like Chris Williamson's, was not recognized by our students. Even though chills were much less frequent than in the above-named pieces, the same essential pattern of significant relationships described above was evident once more.

In sum, everything else being equal, sad songs seem to be more capable of evoking chills than happy songs, especially in females, but this effect of sex is clearly evident only for unfamiliar pieces. Of course, this is not to say that happy music cannot produce chills, for both of the happier selections used in this study did produce a substantial number of chills (and there was also a sex effect for the unfamiliar song). However, time and again, we have now seen that the happier selections are not as effective as the sadder ones in evoking reports of the phenomenon. Indeed, it remains possible that thoroughly happy music has very little capacity to provoke chills. Although not addressed here, it will be worth considering whether the chills provoked during happy music are caused by segments where happiness and sadness are inextricable entwined in bittersweet feelings. Indeed, perhaps the acoustic structure of sadness is often added to happy music to generate more affective impact.

Study 5: Evocation of Chills and Emotional Ratings of Music

The previous two studies clearly suggest that emotional pieces that contain considerable sadness are more capable of evoking chills than pieces that contain primarily happiness. This pattern has now been observed with a large variety of songs selected by the participating students (Study 3), or by the investigator (Study 4), as well as in a general set of pieces selected by students to simply be high in emotional content (Study 2). Could these patterns be demonstrated the other way around, that is, if we simply asked students to bring in pieces that provoked chills? Would sadder ratings be given to the pieces that were effective in producing chills? In this study, each student in a small laboratory class on Emotions and Motivations was requested to share a single piece of music that was especially effective in evoking chills in them (with no stipulation that the pieces contain any specific feeling). All submitted pieces were played in the classroom as previously described, and they were rated, at the end of each presentation, for the presence or absence of chills and the level of sadness or happiness expressed in the piece. In this way, it could be determined if those pieces of music that are deemed effective in producing chills are also rated higher on sadness than those that are not.

Twenty-three students participated (all, except one 33-year-old, being 19–24 years old). Fifteen were female and eight were male. In addition to reporting whether they experienced any chills during the music and whether they recognized the pieces, all were asked to rate the levels of sadness and happiness for each piece on the seven-point graded scale used in the previous study. Evaluation of the whole series of selected pieces required two 2-hour listening sessions separated by a week.

The emotional ratings of each piece were tabulated with reference to whether a song had been reported to produce any chills or not (the actual number of chills was not requested). In other words, the emotional ratings for any one song could fall into the category of those that produced chills or those that did not. Two subjects were discarded from the analysis; one because he experienced no chills during the course of the study, and another who reported abnormally high numbers—twice the level of the next highest—and on later inquiry indicated that she had also been responding to the felt vibration of the bass (she was sitting closest to a speaker). No such problem had been detected before.

To determine whether happiness and sadness ratings differentiated among songs that produced chills, the data were subjected to three-way analysis of variance with the factors being sex, presence/absence of chills, and happiness-sadness dimensions of each song. The results (means are summarized in Figure 6) yielded a reliable three-way interaction [$F(1,19) = 4.55$, $p <$

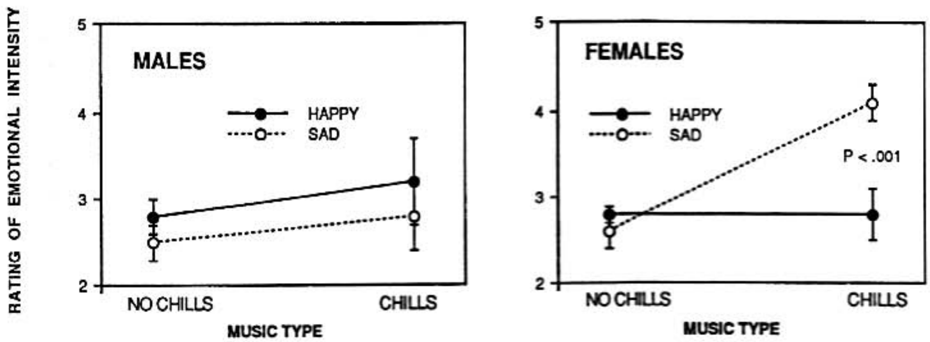

Fig. 6. The average (±SEM) ratings of happy and sad emotional content for musical selections that produced chills versus those that did not in males (left) and females (right) for Study 5.

.05], indicating that songs that produced chills were rated sadder by females than songs that produced no chills [$F(1,19) = 4.55$, $p < .05$], but no such two-way interaction was evident for the males. The sex by emotion interaction was almost reliable [$F(1,19) = 3.91$, $p = .063$], suggesting that females generally rated chill-evoking songs as sadder than males did. Finally, even though the overall simple main effects of sex and emotion were not reliable, the effect of chills was, indicating that songs that provoked chills generally gave higher emotional ratings than songs that did not produce chills [$F(1,19) = 11.23$, $p < .005$].

Comparisons were also run analyzing sex and the number of songs that produced chills, the percentage of songs recognized, and the percentage of recognized songs with chills. Females identified marginally more songs as producing chills than did males (8.8 vs. 5.9), a difference that was not statistically reliable. The percentage of songs recognized was 49–50% in both sexes. The percentage of recognized songs with chills was 48% in females and 24% in males [$t(19) = 2.55$, $p < .02$]. As in all the previous studies, individuals were very likely to report chills for the piece of music they themselves submitted (>90%) whereas they reported chills for only a third of the songs selected by others.

These results affirm the previous pattern of observations in that sadness and chills go together more clearly than happiness and chills. Again, there was a noteworthy sex difference, resembling that observed in Study 4, which suggests that the relationship between sadness and chills is more evident in females. Indeed, overall, males rated the selected pieces less sad than did females in this study. This again suggests either that females are emotionally more responsive or perceptually attuned to sadness in music than males, or that males are more selectively attuned to happiness in music than are females. Such differences may help explain why females reported more chills to the same music than males: They are more emotionally moved by such music, and their increased level of emotional responsiveness may increase the incidence of chills. However, it is also important to emphasize that the measure of "emotional content" is not independent of the chill experience. As the factor analysis in the preceding study suggested, they may both reflect a similar underlying construct, whereas happiness is related to a different factor.

Study 6: A Time-Series Analysis of Chills

Obviously, a great many ambiguities exist in the interpretation of the foregoing correlative data. Not only are there ambiguities in the words used to describe emotional and musical experiences, but also in the effective stimuli within the music and the temperamental characteristics of individuals. Even less is understood of the underlying physiological and psychoneurological processes. Future research will need to address these issues, and an essential need will be the identification of the acoustic patterns in music that help trigger the feeling of chills. I believe the preceding correlative data strongly suggest that the basic sound structures that convey feelings of sadness are a key ingredient in the complex of stimuli that provokes chills. However, to evaluate such specific hypotheses, we will need to identify the exact features of individual musical pieces that evoke chills. To evaluate whether that can be achieved empirically as opposed to simply retrospectively (e.g., Sloboda, 1991), in the following exploratory study, I sought to determine approximately when chills actually occurred in response to three top chill-producing pieces identified in Study 2, one of which also served as a familiar piece in Study 4.

The subjects were 10 students who exhibited the highest levels of chills in Study 2. The three pieces were played as before, and the students were simply asked to slowly raise their hands for a moment whenever they experienced chills. Because the lights were dimmed and the students were asked to keep their eyes closed, they presumably could not have cued each other. The investigator kept tabs on the number of hands raised during each successive 20-sec period, starting from the onset of each piece. The pattern of results is summarized in Figure 7. The overall incidence of chills clearly peaked once for the short Pink Floyd piece and several times during the two longer selections. These distributions deviated from chance expectation (i.e., flat/even distributions) by chi-square analysis for all three pieces ($p < .01$). All of the peaks corresponded to the most intense and dramatic

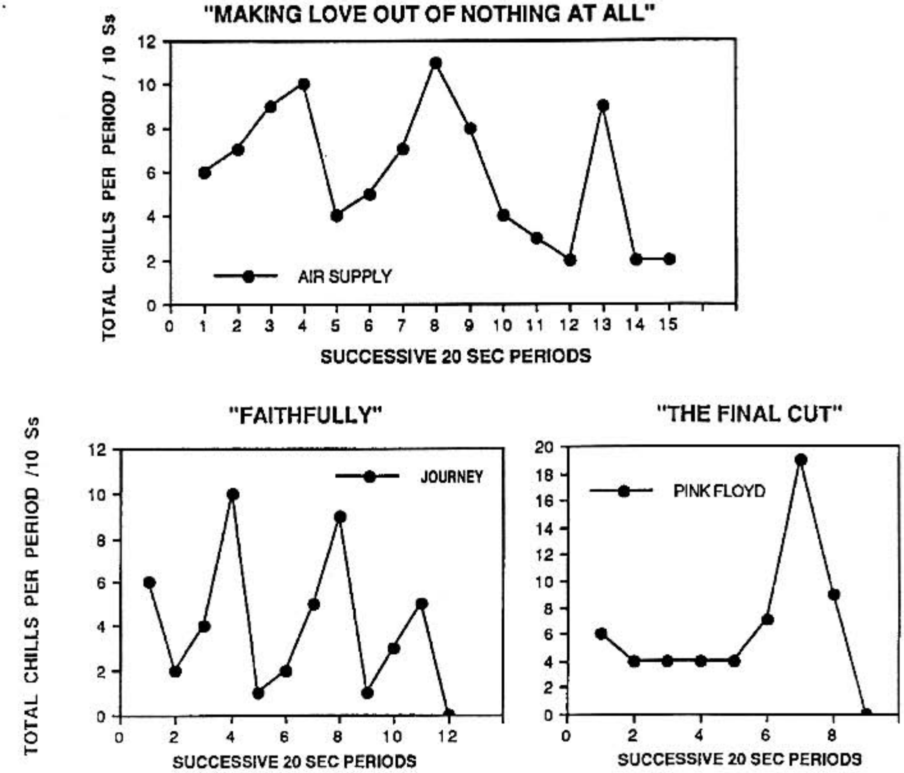

Fig. 7. A time-series analysis in 20-s blocks of chills experienced during the three most effective pieces from Study 2.

crescendos, which agrees with the impressions of most observers I have queried.

This is not to say that other components in music, including conditioned ones, cannot evoke chills, but to affirm that one unconditional characteristic is probably especially efficacious in promoting the feeling. Future work should seek to characterize more accurately the precise acoustic structures in the context of specific background moods as well as the physiological responses that mediate this aesthetic/emotional event. To do this empirically, investigators will need to measure the various components of the experience objectively using real-time monitoring of all relevant responses (both cognitive/somatic and emotional/autonomic ones, both at peripheral and central levels). Only in that way can the nature of this intriguing phenomenon be understood. Interpretation of the present results is obviously impeded by all the methodological weaknesses that are intrinsic to reports of subjective experience. Future work must seek to use more objective measures to analyze the phenomenon.

General Discussion

These studies show that the phenomenon of "chills" can be studied reasonably well using subjective self-reports, but there is presently a clear need for more objective measures in this new field of research. Without additional work along those lines, we cannot be certain that we are dealing with a single entity (see Sloboda, 1991, for the many physiological changes induced by music). It remains possible that several phenomena of this kind actually exist. Only objective indicators can discriminate such issues. In preliminary work, I have concurrently harvested GSR responses and the feelings of chills (as indicated by button pushes) from three volunteers who frequently experienced chills to music. In each case, the incidence of button pushes corresponded almost perfectly to changes in fingertip GSR. However, we cannot conclude much from that correlation, because it would be essential to exclude the possibility that the simple act of pushing a button in the midst of a strong emotional experience might produce comparable arousal of the GSR. In addition to the many other issues that still need to be addressed, we must, of course, remain wary of deriving causal interpretations from correlative work. Manipulative experiments that modify background mood in other ways will be needed to identify causal relations.

However, because the impetus for these studies was my interest in the neurological foundations of basic emotions (Panksepp, 1982), especially the biological nature of emotions related to social bonding and social loss (Panksepp, 1981), I will share some thoughts concerning the potential evolutionary and neurological sources of chills. Because the present data relate to those issues only inferentially, I will divide this discussion into two sections. The first half will be concerned directly with the specific empirical observations of these studies, and the rest will be devoted to neural and conceptual issues that may be essential for future disentanglement of the underlying causal issues.

EMPIRICAL DISCUSSION

These studies yielded rather clear evidence about the general emotional characteristics of music that are related to the phenomenon of musically induced chills. More than anything, it is probably due to the intensification of bittersweet sadness in music, in conjunction with a thoughtful/nostalgic, perhaps wistful, mood that is evoked by certain pieces, which in the vocal form often focuses on the drama of lost love. This relationship between intensifying feelings of sadness and chills is more evident in females than males, but the relationship is also present in males, especially when the biasing effect of past learning and familiarity is minimized (as in Study 4). Of course, whether chills cause the emotional feelings or the emotional feelings cause chills cannot be resolved by correlative work such as this. I personally prefer the latter option and will discuss the phenomenon in those terms later, but such causal issues will require additional empirical clarification.

To understand the phenomenon of chills, we will have to address both conditional and unconditional factors. What is the intrinsic message in music that first provokes chills, and how does the phenomenon become individualized through personal experience with certain types of music? Unfortunately, the present data set, descriptive as it is, does not relate unambiguously to those important issues. Accordingly, most of my remarks must remain speculative.

It seems likely, on the basis of Study 6, that some acoustic feature carrying a special form of emotional meaning is an important ingredient in triggering chills. The time-series analysis of several songs suggested that crescendos, where emotional intensity obviously peaks, are an optimal stimulus for generation of the effect (Figure 7). Presumably, the intensification of emotional feeling could also be achieved in other ways, for instance, through the piercing simplicity of certain solo pieces that emerge from a richer orchestral background, or as Sloboda (1991) found, via the sudden introduction of a "new or unprepared harmony" or "sudden dynamic or textural change" (p. 114). However, it is unlikely that such periods of emotional intensification could have a sufficiently powerful effect to produce chills were it not for the background mood of nostalgic sadness established by the rest of the piece. Because it is well established that the major/minor distinction in music is important for the generation of happiness/sadness in music (Crowder, 1984; Kostner & Crowder, 1990), future work should determine whether such variables will differentially modify the expression of chills. For instance, in Study 4, the happy and sad piece by Chris Williamson clearly followed the major and minor distinction, but that was not the case for the two familiar songs. Obviously, sadness/grief can also be conveyed in the major key, but that may typically require semantic enhancement. Although the data from the present work consistently indicated that feelings related to sadness (and hence, presumably, impending loss) were experienced in musical pieces that generated the most chills, they were not the only ones. Apparently, under certain conditions, which need to be defined more precisely, unfamiliar but quite happy music could also produce chills (e.g., "Sing a Song" by Chris Williamson, which does contain quite a few crescendos). However, it remains possible that the shivery feeling induced by happy music is, in fact, different from that induced by sad music, but that possibility will require more research. There are also nonmusical circumstances that produce similar responses (see Goldstein, 1980, for an empirically based list).

Because of the pervasive influences of learning, the acoustic features that tend to be highly effective in evoking chills may not be absolutely essential for the generation of this experiential phenomenon. Clearly, the tendency to have this feeling undergoes some type of conditioning as a function of experience. This is indicated by both the power of familiarity to promote the phenomenon, and common anecdotal observations of many people, including myself, of having this response simply as a function of remembrance of past emotional experiences. For instance, I commonly experience chills when I recall the deep feeling of grief and pain from the premature loss of a loved one (e.g., see dedication at end of this paper). In addition, it is well established that there are developmental changes in the appreciation of affect in music (Cunningham & Sterling, 1988; Dolgin & Adelson, 1990) as well as diverse affective effects of musical competence (Nilsonne & Sundberg, 1985; Sloboda, 1991), which contribute many additional dimensions that will eventually need to be empirically considered before definitive knowledge will be available in this field.

Only two other substantive reports concerning this phenomenon exist in the literature (Goldstein, 1980; Sloboda, 1991), so our empirical knowledge remains necessarily modest. This important emotional response may have been neglected because many suspect that it is idiosyncratic, with a great deal of variability among different individuals, as well as the fact that critical aspects of the phenomenon arise from relatively inaccessible subjective reaches of the mind/brain, which many individuals may wish to keep private. Another may be that most people who have given it thought have developed strong convictions as to the personal meaning of the feeling. If so, the present work does suggest that many individuals are mistaken about the prevailing emotional characteristics of the response. Indeed, Goldstein (1980) chose to call the phenomenon "thrills," and subsequently, he has affirmed (personal communication, Annual Neuroscience Society Convention, St. Louis, 1990) that happy music is certainly more influential in inducing the effect than sad music. Indeed, dictionary definitions of the two terms support Goldstein's view, but in fact, most people, at least on our campus in Northwest Ohio, tend to prefer the label "chills" while concurrently sharing Goldstein's apparently mistaken belief that happy music is more influential than sad music in creating the phenomenon. However, it is also noteworthy that there was a sex bias in this belief. Males are slightly more prone than females to believe that happy/excited music is more influential in the production of chills than sad/melancholy music. However, when their assumption was put to a reasonably rigorous test (Study 4), males do, in fact, report that sad music produces more chills than happy music. Of course, it remains possible that those who have the strongest conviction that happy/excited music produces more chills than sad music may actually exhibit that trend if evaluated as a distinct cohort. However, for the population at large, sad music is certainly more efficacious in producing chills than is happy music.

Because of the powerful effects of learning, there are bound to be substantial individual differences in the actual variables that control the phenomenon. Indeed, throughout this work, it was clear that personal preferences and associations are remarkably influential in the generation of chills. This was reflected in several ways: Individuals were more likely to have chills to a piece of music they themselves selected than to pieces that others had chosen to share. Also, more chills routinely occurred in response to familiar than unfamiliar music. Presumably this familiarity effect arises from the rich personal associations that individuals have developed to "their own" music, so it is clear that people are most likely to have chills to music that has moved them in the past (i.e., music to which they are "attached").

However, since unfamiliar sad music was more likely to provoke chills than unfamiliar happy music, the evidence suggests that there are more primitive instinctual neuropsychic components that underlie the phenomenon. Of course, in entertaining such an possibility, it is impossible to exclude the influences of generalization from past learning. Even if one were to evaluate the matter in very different cultures with vastly different musical/emotional traditions, the results could not be definitive, because the necessary generalizations could emerge from past experience with unique prosodic dimensions of affective intonation that may be a shared heritage in humans (Davitz & Davitz, 1959). Indeed, in the ensuing "theoretical discussion," I will suggest that the unconditional components of the chill response may arise from a special type of auditory responsivity to certain forms of presemantic communication (see MacLean, 1981, for a discussion of the neurology of such preverbal communication systems). I will argue that the chill ultimately reflects a property of ingrained neural systems of our old mammalian brain that monitor emotions related to social proximity and separation.

Although this is bound to be a controversial suggestion, it is clear that a powerful "chill" phenomenon remains when the issue of personal learning has been minimized through the use of unfamiliar pieces of sad music. This is not to say that every sad piece of music can generate this autonomic-emotional response. A certain kind of acoustic dynamic, with intrinsic emotion-activating properties (e.g., "piercing" crescendos such as those that cause peaks in Study 6), may be essential for the phenomenon to be triggered, but a background mood of bittersweet, melancholy, and sadness may also be important for the responses to occur with any consistency. It also seems evident that certain types of sustained high-frequency notes, often presented by a solo performer, are an optimal stimulus for activating the response. In my experience, the a cappella soprano voice, as well as string instruments such as violins and cellos, when rendered with an insistent piercing quality that is often best achieved with little accompaniment, is ideal for generating chills, but a broad-scale empirical evaluation of that hypothesis is needed. Some anecdotal support for the idea comes from an informal competition I have held for several years to see which recent popular song produces the most chills: In 1994 Whitney Houston's very popular rendition of "I Will Always Love You" was far and away the most effective stimulus for producing chills among my students, and that piece has many of the characteristics described above, as did the most effective songs of Study 2. As an example of a male performance that topped my "chill chart" of 1992, the winner was "For Crying Out Loud, You Know I Love You" by Meat Loaf. A time-series analysis of those pieces should indicate that the peaks of chills occur during the crescendos, for instance, toward the end of the fifth minute of "For Crying Out Loud...."

It is also noteworthy that on a semantic level all of these songs deal with loss or the impending potential for loss, most commonly in the context of unrequited or fragmenting love experiences. Such events, of course, are essential ingredients for the induction of sadness. Indeed, perhaps the interplay between potential loss and redemption is an essential cognitive ingredient for evocation of chills. This is probably a primal psychodynamic process expressed within the brain circuits that elaborate social feelings of attachment and loss through the interplay of potentials for happiness and sadness—the possibility of being lost forever mixed with the possibility of reunion. Considering the complexity that such social feelings can attain as a function of personal experiences, it is easy to understand why people would be confused about the sources of chills within the music they love. Further, considering the power of generalization within all learning systems, it is easy to understand how the phenomenon may come to be associated with the many emotions that are often aroused by a single musical piece. Most music capable of producing chills blends several affective messages—often with mixtures of happy, sad, and other components. The Kitaro selection used in Study 4 is a fine example of a piece in which feelings are so blended that people disagree markedly about the main affective message.

This rich tapestry of underlying emotional influence and counterinfluence, as well as its underlying physiological nature (which, presumably can be objectively analyzed), makes the chill an especially auspicious target phenomenon for an empirical analysis of one type of esthetic/emotional experience in humans. There could also be many applications of such knowledge, ranging from more sophisticated monitoring of psychiatric disorders to personality and emotional assessments, as well as potential outcome measures in new forms of emotional education. A general purpose, multiuser, time-event and physiological monitoring system to evaluate the occurrence of such internal events in real-life situations, would, of course, be a blessing for further work in the area.

Although the cognitive meaning of chills, indeed music in general, remains a rich and relatively unexplored field (Howell, Cross, & West, 1985), I will delve no further into those matters here, but would briefly share a few thoughts on the personality features that may be related to this experience. On the basis of the fact that the experience of chills was always related to high ratings of mood changes and induction of emotional effects, I would hypothesize that people who exhibit the most chills will tend to be individuals of high emotional responsivity and sensitivity. As a consequence, it might be anticipated that they would have highly nurturant and socially agreeable personalities. Such possibilities can be empirically evaluated because the present work indicated that the capacity to experience chills is probably a trait characteristic—some people consistently reported many chills, whereas others consistently reported few in response to a large range of musical stimuli.

In this context, it is worth noting that modern personality research has unambiguously indicated that about half of human personality is guided by evolutionary/genetic dictates (Bouchard, 1994; Goldsmith, 1993), which no doubt is due in large part to the heritability of emotional responsivity. This phenomenon is especially well documented in animals (McGuire, 1993) and may arise from the differential sensitivities of various emotional circuits within the brain (Panksepp, 1991). Among the basic emotional circuits that all mammals possess are those for anger, fear, separation distress, play, desire, and perhaps social nurturance and dominance (Panksepp, 1982, 1991, in press). Chills presumably arise from emotional circuits such as these. As sadness always appeared to be the preeminent emotion related to chills, I would outline a neurophysiological and evolutionary scenario whereby chills may emerge from the brain dynamics that arise from the perception of social loss.

A THEORETICAL PSYCHOBIOLOGICAL DISCUSSION

The fact that sadness can provoke chills seems outwardly perplexing from the perspective that most people find the experience to be positive emotionally. No doubt, this is only a superficial paradox that disappears when we consider the deeper aspects of human emotionality. There can be no happiness (and love) without sadness, nor can there be sadness without happiness. As neurological evidence indicates, the basic output circuitries of grief and joy (as indexed by crying and laughter) are intertwined in the human brain (Poeck, 1969). These powerful emotions, which emerged early in mammalian evolution (MacLean, 1990), were designed to solidify and elaborate the mandates and possibilities of social bonds (Panksepp, in press): The early developmental manifestations of happiness and joyfulness are most evident in the course of vigorous social play (Panksepp, Siviy, & Normansell, 1984) and the manifestations of sadness probably emerge from separation distress that can be evoked in all mammals, especially young ones, by social isolation (Panksepp, Newman, & Insel, 1992). Indeed, both processes are modulated, in opposite directions, by the same neurochemistries (Panksepp, in press).

Of course, happiness and sadness work together, and the most moving music allows the two processes to be blended in such a way as to magnify our sense of ourselves as deeply feeling creatures who are conscious inheritors of the tragic view—the ability to see hope and grace in the midst of despair. It may be that the physiological possibility for the experience of chills is established when music joins our deepest opposing emotional potentials within the cradle of consciousness. Considering the differential social motivational sensitivities and responsivities of the two sexes, it should not be surprising that there may also be sex differences in the sensitivities of the underlying neuroemotional systems. In general, at least on the basis of animal data, females have more robust social-emotional systems related to sorrow and nurturance than do males (Panksepp, in press). Thus, it would be reasonable that the musical juxtaposition of joyous hope and despair would be less likely to take the emotional consciousness of males toward the intense emotional response of chills than that of females. Then again, it remains possible that the sex differences observed in this work were due to differential response biases and other measurement problems rather than to any substantive differences in the underlying neurodynamics: For instance, females may be more likely to focus on small physiological events and report them as chills, whereas males may be more prone to consider chills to be the bodily consequences of anger and anxiety (see Figure 1). Of course, these issues are difficult to evaluate scientifically, and they take us, as does music itself, to the very edge of our knowledge about ourselves. But there is a more prosaic way to discuss these issues.

As noted above, the brain circuits that mediate crying and laughter are inextricably entwined within primitive subcortical areas of the brain (Poeck, 1969). To the best of our knowledge, these circuits are critically linked, in presently unfathomed ways, to our subjective experience of joy and sorrow, which can now be monitored using modern brain-imaging technologies (George, Ketter, Parekh, Horwitz, Herscovitsch, & Post, 1995). Unfortunately, those techniques cannot tell us much about the finer details of the underlying neural circuits. In order to plumb those depths, animal brain research remains essential: Indeed, we presently know a great deal about the neural circuits for separation distress that lead young animals to cry out when they are lonely and lost (Panksepp, Normansell, Herman, Bishop, & Crepeau, 1988). Separation calls inform parents of the whereabouts of offspring that have become lost, and such calls arouse powerful care-giving motivations in parents, especially the mothers (Pettijohn, 1979), who typically have more powerful brain circuits for nurturance than do fathers (Pedersen, Caldwell, Jirikowski, & Insel, 1992). Internal feeling of coldness and chills when parents hear separation calls may provide increased motivation for social reunion. Thus the separation call may have been designed, during the evolutionary construction of the brain's emotional systems, to acoustically activate a thermally based need for social contact, most especially in parents who suddenly hear the wail of their own lost infants. This may also help explain the learning/familiarity effects observed with chills, because social attachments in mammals are learned (Nelson & Panksepp, 1996). To put it another way, perhaps the "chill" that we experience especially intensely during sad and bittersweet songs, occurs because that type of music resonates with the ancient emotional circuits that establish internal social values. Sad music may achieve its beauty and its chilling effect by juxtaposing a symbolic rendition of the separation call (a high-pitched crescendo or a solo instrument emerging from the background) in the emotional context of potential reunion and redemption. This principle could explain much of the data harvested in the above studies.

But why would social loss generate an autonomic response characterized subjectively as chills? Our theoretical view of the underlying evolutionary matters is that the mammalian brain mechanisms for social bonding and feelings of separation distress arose from more ancient, preexisting mechanisms such as those that mediate place attachment, pain perception, and thermoregulatory influences (Nelson & Panksepp, in press; Panksepp, Knutson, & Pruitt, in press). It is the latter antecedent that may explain the "chill" phenomenon. Social motivation may partially operate through the internal representation of thermal feelings—with social contact giving one the subjective experience of being warmer, whereas social isolation makes one feel colder. Obviously, such controls could be more than metaphoric, because physical contact obviously promotes physical thermoregulation in the cold, but the evolution of such neurosymbolic mechanisms could have also provided an affective motivational substrate for promoting the types of close interactional patterns that we call social bonds in the absence of direct thermoregulatory stressors. When a mother and infant are suddenly separated, it is easy to understand that a chilly feeling in both could help promote reunion. Indeed, it should not escape our attention that, to an impressive degree, the semantics of social closeness and social loss still use thermoregulatory terms (Alberts & Decsy, 1990). We speak of "warm people" and "cold people" and we feel "warm" when we are with those we love and have a feeling of "coldness" when we are with those who do not seem to care about us.

Because the separation call is an evolutionary design feature in the mammalian brain that promotes contact seeking (see Panksepp, 1981; Nelson & Panksepp, in press), it is reasonable that its unconditional acoustic characteristics might elicit chills so as to promote the seeking of reunion. In this context, it is worth noting that the human separation call is a prolonged wail with a fundamental frequency of around 500 Hz and with successive harmonics up to 4500 Hz (Bryan & Newman, 1988; Lester, Corwin, & Golub, 1988), and I would predict that this acoustic property along with the resonant formants, especially in the context of real-life moods or those evoked by music, would be the ideal conditions for the evocation of chills. This prediction is consistent with the preliminary data provided in Figure 7. Furthermore, in other unpublished work, we have been able to evoke chills in adults during playback of their infant's cries. Parenthetically, females again exhibited more responses to such stimuli than did males. Such findings would suggest that the human brain is attuned to certain emotional sounds and that the penetration of such sounds into the underlying emotional circuits is more intense in females than in males. Thus, it may be that the experience of chills is largely a central nervous system phenomenon, arising from brain areas that elaborate somatosensory representations of the body that interact with emotional circuits, with perhaps only secondary interaction with the periphery. Presumably the role of peripheral skin sensations in the phenomenon could be evaluated in quadriplegic individuals. If the feeling of chills is simply due to either peripheral autonomic output or pulsatile release of pituitary or adrenal hormones onto peripheral nerve receptors, then the chill effect, at least on the body surface, should be absent after high spinal cord trauma. If it has a strong central component, it should remain intact to some extent.

In any event, the chill feels as if a fountain of neurochemicals has been released in brain areas that control our bodily feelings, and considering the importance of neuropeptides in the control of emotions (Panksepp, 1993b), it may well be that chills are the direct result of social neuropeptides being released in the brain. To the extent that chills are a central brain phenomenon, there are bound to be specific neurochemical features in the human brain that precipitate this response to music, and considering the potential evolutionary sources discussed above, it remains possible that homologous features would still exist in other animals. On the basis of our animal work on central socioemotional processes, we would predict that brain oxytocin, prolactin, and opioid systems may be major players in the production and control of chills. These circuits are especially important in the control of separation distress and maternal and other social processes (Panksepp, 1991, 1992; Nelson & Panksepp, in press). For instance, there is abundant anecdotal evidence that the cry of infants can lead to milk letdown, and this reflex is known to be triggered by oxytocin release (Newton & Newton, 1948). Although no one can adequately evaluate the possible roles of oxytocin or prolactin at the present time (because pharmacological tools appropriate for human use are not available), the opioid hypothesis can be addressed, because many opiate receptor agonists and antagonists are available.

Indeed, Goldstein (1980) monitored the experience of music-induced chills (or "thrills," as he called them) before and after the intravenous administration of the potent opiate receptor antagonist naloxone. He found that naloxone markedly attenuated chills in a third of his subjects. Although this result can be used to argue that chills are provoked by release of endogenous opioids in the body (as Goldstein did), it can also be used to argue the opposite hypothesis, that a reduction of opioids in the brain normally causes the chills. Obviously, tonic receptor blockade would diminish the psychological impact of both sudden increases and decreases of opioid activity. I believe the latter is the more likely vector: Opioid release *in the brain* appears to contribute to the pleasures derived from social activities (Keverne, Martensz, & Tuite, 1989; Panksepp & Bishop, 1981), whereas opiate antagonists increase feelings of social need (Panksepp, 1981; Panksepp, Herman, Vilberg, Bishop, & DeEskinazi, 1980). In this context, please note that in human opiate addicts, injection of narcotics tends to lead to a feeling of warmth, whereas the antiopiate state promotes feelings of coldness and gooseflesh (the so-called experience of "cold turkey") (Kurland, 1978). Such a feeling of coldness can be produced precipitously by a single dose of an opiate antagonist given to nonaddicted individuals who have recently been exposed to a single priming dose of morphine (Jones, 1979).

Accordingly, it seems reasonable to propose that a neurochemical condition activated by social loss, for instance, a reduction of opioid tone, may promote the experience of chills. One reasonable place this could transpire is in the midbrain, in primitive auditory waystations such as the inferior colliculus and medial geniculate body, which are rich in opiate receptors (Panksepp & Bishop, 1981) and are anatomically interrelated with somatosensory representation within deep collicular and thalamic areas (Brodal, 1981). Indeed, such brain zones are rather close to separation-distress circuits, as characterized by brain stimulation in other animals (Panksepp et al., 1988). In addition, opioids are known to participate in the creation of social bonds (Panksepp, in press), playful moods (Panksepp, 1981), and sexual pleasures (Ågmo & Gomez, 1993) within primitive subcortical brain zones such as the preoptic area, which have long been known to participate in thermoregulatory processes (Myers, 1974). Thus, it is easy to envision many ways in which opioids may modulate the somatosensory-chill phenomenon through changing brain chemistries associated with socioemotional dynamics. An intriguing corollary of this analysis would be that certain types of music may be especially effective in activating endogenous opioid systems of the brain, and this may help explain why music can be "addictive," and why people become attached to performers who create the music they love. Indeed, the possibility that people bond to music because it is capable of activating certain neurochemical systems, such as opioid ones, may help explain why familiarity is so important for the induction of chills: If we have become "bonded" to music, then it should be able to evoke social emotions more readily.

As subjective emotional issues are difficult to study in humans, it will be of considerable interest to determine whether EEG and other brain imaging procedures can detect objective brain changes that occur during music, especially during those special emotional moments when we experience chills. Some recent progress along these lines has been made (Petsche et al., 1988), and we believe that the event-related desynchronization (ERD) technique of Pfurtscheller (1991, 1992) may be especially promising in analyzing the brain changes related to emotionality (Davidson, 1993; Panksepp, 1995) as well as the affective states evoked by music (Panksepp et al., 1993; Vaningan & Panksepp, 1995). Obviously, more sophisticated measures such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) (Sergent, 1993) will add other important dimensions to such analyses. Such measures may eventually allow us to directly monitor individuals' social-emotional responsivity, which should help clarify the biological substrates of personality as well as the manner in which subjective experiences are elaborated by the brain. Only when we begin to harvest such objective brain indicators of internal affective states will we be in a position to understand how mere sound helps recreate the evolutionarily derived world of affectively tinged musical experience within the human brain (Clynes, 1982; Wallin, 1991).

SOME ADDITIONAL PREDICTIONS AND CONCEPTUAL/TERMINOLOGICAL ISSUES

Although some of the lines of reasoning shared in this discussion have seemingly strayed far from the primary phenomenon of musically induced chills, they do lead to a variety of testable propositions. For instance, acoustic filtering of music so as to eliminate the primary characteristics of the separation call should diminish the experience of "chills." This should also hold for modification of critical note durations and sequence characteristics. Socioemotional changes, artificially or naturally produced, should modulate the expression of this phenomenon. For instance, according to the present analysis, evocation of mild sadness in individuals before testing should increase chills more than the induction of happiness. Of course, the meaning of such emotional terms remains ambiguous, and this is an especially large problem for the concept of happiness. There may be several forms, ranging from energized playfulness to the more quiet satisfactions derived from material or psychological resources. Indeed, I would not be surprised if the most profound forms of happiness ultimately emerge from people working through experiences of sorrow, which may tend to chronically reduce the threshold for chills. Just as the greatness of music resides in its ability to arouse sequences of powerful but often opposing emotional forces in the brain/mind, so also, the most profound forms of happiness may arise from the interplay of polar dualities within the higher brain dynamics of human emotions. I hope the present studies will encourage more empirical work on such important and fascinating issues. Toward that end, we may eventually need to establish a standard scientific term for "chills" and its potential variants.

From that perspective, I would note that in several symposium presentations of this work (Panksepp, 1993a, 1994), I chose to label the chill phenomenon as a "skin orgasm" on the basis of the assumption that there are underlying neurochemical similarities between the two phenomena. Although on the surface this may seem unrealistic and sensationalistic, I do wish to indicate that many of the neurochemistries that underlie sexuality are the same as those that mediate other social processes (for review see Nelson & Panksepp, in press; Panksepp, in press; Pedersen et al., 1992). Thus, if we wish to generate a scientific term for the chill phenomenon, the *skin orgasm* designation may have some merit. An alternative may be the specific Russian idiom for the sensation anglicized as "*murashki begaiut po telu*," which translates to "ants running up and down your skin." I personally prefer the "skin orgasm" term. In any event, if future work shows that physiological relationships between sexual orgasms and skin orgasms do exist within the brain, I would suggest that it is likely to be an "opponent process" type of relationship: The two emotional responses may operate more in reciprocal interaction rather than synergistic interaction with each other. If so, it may be quite difficult to generate musically induced skin orgasms after sexual orgasm; it might be quite a bit easier to evoke skin orgasms during prolonged abstinence, especially when individuals are thinking of loved ones they have not been with for a long time. Thus, with no sensationalism intended, I would commend the term *skin orgasm* (originally suggested to me by Dr. Gunther Bernatzky of the University of Salzburg) as a potential scientific designator for the experience that has been called *chills* in this paper. Of course, all words we must use to explicate this phenomenon pale before the emotional mystery that music can evoke within our brain's mind.[1-3]

References

Ågmo, A., & Gomez, M. (1993). Sexual reinforcement is blocked by infusion of naloxone into the medial preoptic area. *Behavioral Neuroscience, 107,* 812–818.

Alberts, J. R., & Decsy, G. J. (1990). Terms of endearment. *Developmental Psychobiology, 23,* 569–584.

Bouchard, T. J. (1994). Genes, environment, and personality. *Science, 264,* 1700–1701.

Brodal, A. (1981). *Neurological anatomy in relation to clinical medicine* (3rd ed.). New York: Oxford University Press.

Bryan, Y. E., & Newman, J. D. (1988). Influence of infant cry structure on the heart rate of the listener. In J. D. Newman, (Ed.), *The physiological control of mammalian vocalization* (pp. 413–432). New York: Plenum Press.

Budd, M. (1985). *Music and the emotions.* London: Routledge & Kegan.

Cantor, J. R., & Zillmann, D. (1973). The effect of affective state and emotional arousal on music appreciation. *The Journal of General Psychology, 89,* 97–108.

Clynes, M. (1977). *Sentics: The touch of emotions.* New York: Doubleday/Anchor.

Clynes, M. (1982). *Music, mind and brain: The neuropsychology of music.* New York: Plenum Press.

Clynes, M. (1988). Generalized emotion: How it may be produced, and sentic cycle theory. In M. Clynes & J. Panksepp (Eds.), *Emotions and psychopathology* (pp. 107–170). New York: Plenum Press.

Clynes, M. (1995). Microstructural musical linguistics: composers' pulses are liked most by the best musicians. *Cognition, 55,* 269–310.

Crowder, R. G. (1984). Perception of the major/minor distinction: I. Historical and theoretical foundations. *Psychomusicology, 4,* 3–12.

Cunningham, J. H., & Sterling, R. (1988). Developmental change in the understanding of affective meaning in music. *Motivation and Emotion, 12,* 399–413.

Dainow, E. (1977). Physical effects and motor responses to music. *Journal of Research in Music Education, 25,* 211–221.

Davidson, R. (1993). The neuropsychology of emotional and affective style. In M. Lewis & J. M. Haviland (Eds.), *Handbook of emotions* (pp. 143–154). New York: Guilford Press.

---

1. One real-life memory produces chills more readily for me than any other—the remembrance of my precious daughter, Tiina Alexandra, when her ghostly memory passes through my mind. I dedicate this paper to lost children like her, whose lives have been taken prematurely. Tiina was killed in her sixteenth year, along with three friends, by a careless, drunken man on the evening of March 29, 1991. Several memorial poems related to this tragedy that evoke chills in me, most especially Good Friday (1991), can be found in Miller (1995). I also dedicate this work to Dr. Justine Sergent of McGill University, whose life, and pioneering work on brain responses to music, was cut short by the frustrations of having to struggle against great odds.

2. The present work was supported by Wright-Patterson Contract #F336019 MU146 & MT702 and The Memorial Foundation for Lost Children, a legacy of the above tragedy, which is devoted to promoting work on the brain mechanisms of emotionality with the aim of helping children with neuropsychiatric disorders. I appreciate the assistance of Dr. Loring Crepeau during early phases of this work and the insightful editorial comments of Dr. Anesa Miller, two anonymous reviewers, and the editor of this journal.

3. These results have been presented at the American Association for the Advancement of Science Convention, Boston, MA, in January 1993 and the Karajan Symposium on Brain and Music, Vienna, Austria, in June 1994.

Davitz, J. R., & Davitz, L. J. (1959). The communication of feelings by content-free speech. *Journal of Communication, 9,* 6–13.
Dolgin, K. G., & Adelson, E. H. (1990). Age changes in the ability to interpret affect in sung and instrumentally-presented melodies. *Psychology of Music, 18,* 87–98.
Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science, 221,* 1208–1210.
George, M. S., Ketter, T. A., Parekh, P. I., Horwitz, B., Herscovitsch, P., & Post, R. M. (1995). Brain activity during transient sadness and happiness in healthy women. *American Journal of Psychiatry, 152,* 341–351.
Goldsmith, H. H. (1993). Temperament: Variability in developing emotion systems. In M. Lewis & J. M. Haviland (Eds.), *Handbook of emotions* (pp. 353–364). New York: Guilford Press.
Goldstein, A. (1980). Thrills in response to music and other stimuli. *Physiological Psychology, 3,* 126–129.
Hinrichs, H., & Machleidt, W. (1992). Basic emotions reflected in EEG-coherences. *International Journal of Psychophysiology, 13,* 225–232.
Howell, P., Cross, I., & West, R. (Eds.). (1985). *Musical structure and cognition.* London: Academic Press.
Jones, R. T. (1979). Dependence in non-addict humans after a single dose of morphine. In E. L. Way (Ed.), *Endogenous and exogenous opiate agonists and antagonists* (pp. 557–560). New York: Pergamon Press.
Keverne, E. B., Martensz, N., & Tuite, B. (1989). ß-endorphin concentrations in CSF of monkeys are influenced by grooming relationships. *Psychoneuroendocrinology, 14,* 155–161.
Kostner, M. P., & Crowder, R. G. (1990). Perception of the major/minor distinction. IV. Emotional connotations in young children. *Music Perception, 8,* 189–202.
Kurland, A. A. (1978). *Psychiatric aspects of opiate dependence.* West Palm Beach, FL: CRC Press, Inc.
Landreth, H., & Landreth, J. (1974). Effects of music on physiological response. *Journal of Research in Music Education, 22,* 4–12.
Lester, B. M., Corwin, M., & Golub, H. (1988). Early detection of the infant at risk through cry analysis. In J. D. Newman, (Ed.) *The physiological control of mammalian vocalization* (pp. 395–411). New York: Plenum Press.
MacLean, P. D. (1981). Role of transhypothalamic pathways in social communication. In P. J. Morgane & J. Panksepp (Eds.), *Handbook of the hypothalamus: Vol. 3. Part B. Behavioral studies of the hypothalamus* (pp. 259–287). New York: Marcel Dekker.
MacLean, P. D. (1990). *The triune brain in evolution: Role in paleocerebral functions.* New York: Plenum Press.
McFarland, R. (1985). Relationship of skin temperature changes to the emotions accompanying music. *Biofeedback and Self Regulation, 10,* 255–267.
McGuire, T. R. (1993). Emotional and behavior genetics in vertebrates and invertebrates. In M. Lewis & J. M. Haviland (Eds.), *Handbook of emotions* (pp. 155–166). New York: Guilford Press.
Miller, A. (1995). *A road beyond loss: Three cycles of poems & epilogue.* Bowling Green, OH: The Memorial Foundation for Lost Children.
Myers, R. D. (1974). *Handbook of drug and chemical stimulation of the brain.* New York: Van Nostrand Reinhold, Co.
Nakamura, H. (1984). Effects of musical emotionality upon GSR and respiration rate. *Japanese Journal of Psychology, 55,* 47–50.
Nelson, E., & Panksepp, J. (in press). Brain substrates of infant-mother attachment in mammals. *Psychological Bulletin.*
Newton, N., & Newton, N. (1948). The let-down reflex in human lactation. *Journal of Pediatrics, 33,* 698–704.
Nilsonne, Å., & Sundberg, J. (1985). Differences in ability of musicians and nonmusicians to judge emotional state from the fundamental frequency of voice samples. *Music Perception, 2,* 501–516.

Panksepp, J. (1981). Brain opioids: A neurochemical substrate for narcotic and social dependence. In S. Cooper (Ed.), *Progress in theory in psychopharmacology* (pp. 149–175). London: Academic Press.

Panksepp, J. (1982) Toward a general psychobiological theory of emotions. *The Behavioral and Brain Sciences, 5,* 407–468.

Panksepp, J. (1986). The anatomy of emotions. In R. Plutchik (Ed.), *Emotion: Theory, research and experience: Vol. III. Biological foundations of emotions* (pp. 91–124). Orlando, FL: Academic Press.

Panksepp, J. (1991). Affective neuroscience: A conceptual framework for the neurobiological study of emotions. In K. Strongman (Ed.), *International reviews of emotion research* (Vol. 1, pp. 59–99). Chichester: Wiley.

Panksepp, J. (1992). Oxytocin effects on emotional processes: Separation distress, social bonding, and relations to psychiatric disorders. *Annals of New York Academy of Sciences, 652,* 243–252.

Panksepp, J. (1993a, January). *Music and brain mechanisms of emotionality.* Paper presented at the meeting of the American Association for the Advancement of Science, Boston.

Panksepp, J. (1993b). Neurochemical control of moods and emotions: Amino acids to neuropeptides. In M. Lewis & J. M. Haviland (Eds.), *Handbook of emotions* (pp. 87–108). New York: Guilford Press.

Panksepp, J. (1994, June). *The emotional basis of skin orgasms induced by music.* Paper presented at the meeting of the Karajan Symposium on Brain and Music, Vienna.

Panksepp, J. (1995). Affective neuroscience: A paradigm to study the animate circuits for human emotions. In R. D. Kavanaugh,B. Zimmerberg, & S. Fein (Eds.), *Emotions: An interdisciplinary approach* (pp. 29–60). Hillsdale, NJ: Lawrence Erlbaum.

Panksepp, J. (in press). *Affective neuroscience: The foundations of human and animal emotions.* New York: Oxford University Press.

Panksepp, J., & Bishop, P. (1981). An autoradiographic map of (3H) diprenorphine binding in rat brain: Effects of social interaction. *Brain Research Bulletin, 7,* 408–410.

Panksepp, J. , Herman, B. H. , Vilberg, T. , Bishop, P., & DeEskinazi, F. G. (1980). Endogenous opioids and social behavior. *Neuroscience and Biobehavioral Reviews, 4,* 473–487.

Panksepp, J., Knutson, B., & Pruitt, D. L. (in press). Toward a neuroscience of emotion: The epigenetic foundations of emotional development. In M. F. Mascolo & S. Griffin (Eds.), *What develops in emotional development?* New York: Plenum Press.

Panksepp, J., Lensing, P., Klimesch, W., Schimke, H., & Vaningan, M. (1993). Event related desynchronization (ERD) analysis of rhythmic brain functions in normal and autistic people. *Neuroscience Abstracts, 19,* 1885.

Panksepp, J. D., Newman, J., & Insel, T. R. (1992). Critical conceptual issues in the analysis of separation-distress systems of the brain. In K. Strongman (Ed.), *International reviews of emotion research* (Vol. 2, pp. 51–72). Chichester: Wiley.

Panksepp, J. , Normansell, L. , Herman, B. , Bishop, P. & Crepeau, L. (1988) . Neural and neurochemical control of the separation distress call. In. J. D. Newman (Ed.), *The physiological control of mammalian vocalizations* (pp. 263–300). New York: Plenum Press.

Panksepp, J. , Siviy, S., & Normansell, L. (1984). The psychobiology of play: Theoretical and methodological perspectives. *Neuroscience and Biobehavioral Reviews, 8,* 465–492.

Pedersen, C. A., Caldwell, J. D., Jirikowski, G., & Insel, T. R. (Eds.) (1992). *Annals of the New York Academy of Sciences: Vol. 652. Oxytocin in maternal, sexual and social behaviors.* New York: New York Academy of Sciences.

Petsche, H., Lindner, K., Rappelsberger, P., & Gruber, G. (1988). The EEG: An adequate method to concretize brain processes elicited by music. *Music Perception, 6,* 133–160.

Pettijohn, T. F. (1979). Attachment and separation distress in the infant guinea pig. *Developmental Psychobiology, 12,* 73–81.

Pfurtscheller, G. (1991). EEG rhythm—event-related desynchronization and synchronization. In. H. Haken & H. P. Koepchen, *Rhythms in physiological systems* (pp. 289–296). Berlin: Springer-Verlag.

Pfurtscheller, G. (1992). Event-related synchronization (ERS): An electrophysiological correlate of cortical areas at rest. *Electroencephalography and Clinical Neurophysiology, 83*, 62–69.

Pignatiello, M. F., Camp, C. J., & Rasar, L. A. (1986). Musical mood induction: An alternative to the Velten technique. *Journal of Abnormal Psychology, 95*, 295–297.

Pittam, J., & Scherer, K. R. (1993). Vocal expression and communication of emotion. In M. Lewis & J. M. Haviland (Eds.), *Handbook of emotions* (pp. 185–197). New York: Guilford Press.

Plutchik, R. (1994). *The psychology and biology of emotions*. New York: Harper Collins.

Poeck, K. (1969). Pathophysiology of emotional disorders associated with brain damage. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology, Vol. 3, Disorders of higher nervous activity* (pp. 343–367). Amsterdam: North-Holland Publishing Co.

Sergent, J. (1993). Mapping the musician brain. *Human Brain Mapping, 1*, 20–38.

Sloboda, J. (1991). Music structure and emotional response: Some empirical findings. *Psychology of Music, 19*, 110–120.

Storr, A. (1992). *Music and the mind*. New York: Ballantine Books.

Terwogt, M. M., & Van Grinsven, F. (1988). Recognition of emotions in music by children and adults. *Perceptual and Motor Skills, 67*, 697–698.

Terwogt, M. M., & Van Grinsven, F. (1991). Musical expression of mood states. *Psychology of Music, 19*, 99–109.

Vaningan, M., & Panksepp, J. (1995). Cortical arousal patterns in response to emotional and neutral auditory stimuli. *Abstracts for the Society for Neuroscience, 21*, 951.

Wallin, N. (1991). *Biomusicology: Neurophysiological, neuropsychological, and evolutionary perspectives on the origins and purposes of music*. Stuyvesant, NY: Pergamon Press.

Wells, A., & Hakanen, E. A. (1991). The emotional use of popular music by adolescents. *Journalism Quarterly, 68*, 445–454.

Zimny, G., & Weidenfeller, W. (1963). Effects of music upon GSR and heart rate. *American Journal of Psychology, 76*, 311–314.