FEELINGS IN RESPONSE TO music are often accompanied by measurable bodily reactions such as goose bumps or shivers down the spine, commonly called “chills.” In order to investigate distinct acoustical and musical structural elements related to chill reactions, reported chill reactions and bodily reactions were measured continuously. Chill reactions did not show a simple stimulus-response pattern or depend on personality traits, such as low sensation seeking and high reward dependence. Musical preferences and listening situations also played a role in chill reactions. Participants seemed to react to musical patterns, not to mere acoustical triggers. The entry of a voice and changes in volume were shown to be the most reactive patterns. These results were also confirmed by a retest experiment.

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EMOTIONS INFLUENCE OUR DECISIONS in everyday life, regulate our motivations for actions, and enhance memory formation (Juslin & Sloboda, 2001; Panksepp, 1998; Roth, 2003). Most people listen to music to influence their emotions (Panksepp, 1995). But what power do aesthetic stimuli such as music truly possess to influence and “designate” emotions? Can our moods be manipulated by the “right” music or do we actively construct our feelings using music as a kind of tool? Listening to music appears to be a passive pastime, but is it really that passive?

In 1980, Goldstein (1980) published a study based on questionnaires, which for the first time used “thrills,” or “chills” as the phenomenon was called in later publications, as a parameter for strong emotions in response to music. Except in cases where a cited author used the term “thrill,” from here on we will use the term “chills” according to Panksepp’s discussion of the terms (Panksepp, 1995). Chills are a subtle nervous tremor caused by intense emotion. Goldstein used them as an indicator for strong emotional responses, allowing the combination of psychological self-report with distinct bodily reactions such as “goose bumps” or shivers down the spine. Goldstein applied music as a stimulus in order to test the hypothesis that thrills (chills), as an example of emotional reactions, are mediated by endorphins. He studied the effect of the opiate antagonist naloxone on the frequency, duration, and intensity of thrills and found some evidence that thrills may be attenuated by naloxone. Interestingly, not all participants were susceptible to thrills. Out of the three groups of participants, 10% of the music students, 20% of the medical students, and 47% of the employees of an addiction research center responded in the questionnaire that they had never experienced thrills.

Chills can be a fascinating phenomenon to study strong emotional reactions to aesthetic stimuli since they allow for verification of subjective reports with physiological measurements. They are considered to be distinct events, and therefore, their relationship to the structure of the stimulus can be examined. Several of the following studies have taken advantage of chills as an objective indicator of strong emotions.

Sloboda (1991) used questionnaires to reveal the relationship of thrills (chills) to the structural parts of the music that elicit them. He found that there were distinct musical features that aroused different bodily reactions. When he asked participants about thrills experienced in the five years prior to the study, Sloboda found that up to 90% of the people were susceptible to “shivers down the spine” and 62% to “goose pimples.” Many other phenomena, such as “tears” or “yawning” were summarized under the term thrills, but in a more detailed analysis, only “shivers,” “tears,” and “racing heart” could be associated with distinct musical structures. Shivers were mainly
induced by new or unprepared harmonies and sudden dynamic or textural changes. Altogether, Sloboda's work demonstrated for the first time a relationship between bodily reactions, such as shivers down the spine, and a conscious, aesthetic appreciation of an acoustic stimulus.

Panksepp (1995) studied the chills of undergraduate students by having them listen to 14 pieces of music self-selected by the participants, and four additional pieces chosen by the researcher. According to his results, sad pieces were more effective for arousing chills, and women seemed to be most susceptible to chill reactions. Panksepp's analysis of chills in a time series experiment was novel. The students listened to the three pieces that turned out to be the most effective ones in another part of this study. They raised their hands to indicate when they had perceived a chill. Using this procedure, he discovered that crescendos seemed to somehow be effective, and that a solo instrument emerging from a softer orchestral background was especially influential. In another article, Panksepp & Bernatzky (2002) developed a hypothesis regarding the evolutionary roots of chill reactions. The authors proposed that music might contain acoustic properties of the separation calls of young animals, which stimulate caretakers to exhibit social care and attention. Thus, music may actually activate a separation-distress brain system that provides motivational urgency for social reunion responses.

Gabrielson and Lindström (1993, 2003) used an approach to study “peak” emotional experiences in response to music that they termed “SEM’s” (Strong Experiences with Music), but they did not explicitly concentrate on chill reactions, although they belonged to one of the categories they found. They simply asked participants to describe their most intense experiences while listening to music, and categorized participants’ statements. The authors found that all participant responses could be categorized as physical responses, perception, cognition, emotion, transcendental, and existential aspects. The emotion most commonly felt during SEM’s was happiness; whereas negative feelings were seldom evoked by SEM’s.

Blood and Zatorre (2001) used PET to reveal the brain systems associated with chill reactions when listening to music. They found structures such as the nucleus accumbens, the ventral tegmental area, thalamus, insula, and anterior cingulate to be more active during a chill reaction, while activity in the amygdala and ventral medial prefrontal cortex was reduced. This pattern of activity typically has been observed in other brain studies inducing euphoria and/or pleasant emotions (Breiter et al., 1997).

More recent work on chills was done by Craig (2005), who combined physiological measurements of skin conductance level (Galvanic Skin Response, GSR) with the subjective reports of chills made by his participants. The study suggests that chills are associated with discrete physiological events, such that GSRs were significantly higher during chills than before or after chill events. Rickard (2004) found higher levels of both chills and skin conductance in response to music that elicited intense emotions, compared to less emotion-inducing stimuli. Rickard used both chills and skin conductance as indicators of physiological arousal. For a review concerning emotions and physiological reactions, see Cacioppo, Klein, Berntson, & Hatfield (1993), Krumhansl (1997), and Stemmler (1998).

Despite these empirical efforts, limitations remain. First, all of these studies concentrated on singular aspects of chill experiences, such as the underlying brain region or physiological patterns (Blood & Zatorre, 2001; Craig, 2005). Second, the older literature focused on the subjective experience of chills and their relation to musical patterns (Gabrielsson & Lindström, 1993; Panksepp, 1995; Sloboda, 1991). Third, most researchers investigated only a highly selective social and educational group of participants, mostly students.

The purpose of the present experiment was to examine the chill phenomenon through converging psychological, physiological, and psychoacoustical methods, both through inter- and intra-individual comparisons. Since the study of the emotional effects of music is handicapped by a lack of appropriate research paradigms (Scherer, 2004), we tried to overcome this handicap by combining available methods, and using the different facets they reveal, to develop a preliminary hypothesis of how chills may be triggered by music.

The main research questions were: (a) how frequent is the chill response; (b) what are the musical and acoustical features that have the power to arouse such strong emotional responses; and (c) are chills in response to music a general phenomenon or are there specific chill responders that can be characterized by personality, musical education, experience, or preference? In sum, what is induced by music and how does the listener stimulate himself in order to elicit the strong emotions that lead to chills?

Method

In the present experiment, we combined psychological, physiological, and psychoacoustic methods. While listening to music, participants reported the presence of chills by pressing a button. The chills were assessed by
measuring physiological responses and using questionnaires. After the experiment, participants filled in questionnaires regarding their musical experience, preference, memories connected to music, and so on. They also responded to character inventories. The musical events eliciting the strongest emotional reactions were analyzed psychoacoustically.

**Participants**

Thirty-eight participants (mean age = 38, SD = 16, range = 11-72 years; 29 females and nine males; 33 right handed persons and five left handed persons) took part in the experiment. The group included five professional musicians or music students, 20 amateur musicians who still played or once played an instrument, and 13 participants who had never played an instrument. Since we were interested in general reactions to music, we selected a rather heterogeneous group with regards to musical experience and preferences. Three participants even reported not being interested in music at all, and that they only occasionally listened to music on the radio. The group was also heterogeneous pertaining to educational and social backgrounds. To give some examples, there were students, professors, retirees, housewives, veterinarians, and labourers who participated in the experiment. Volunteers were not paid for their participation and were treated in accordance with the “Ethical principles of psychologists and code of conduct” (American Psychological Association, 1992).

**Materials**

**AUDITORY STIMULI**

We chose seven standard pieces for all of the participants in order to be able to compare chill reactions directly (see Table 1). These standard pieces each represented different musical styles. Since strong emotional reactions may depend on a broader context within the music, we decided to play the whole pieces instead of only excerpts. Additionally, every participant brought 5 to 10 pieces that he or she expected would arouse strong emotions. All kinds of musical styles were accepted; participants brought a wide spectrum of musical styles, such as classical, pop, rock, soundtracks, and dance music.

**QUESTIONNAIRES**

Participants completed three standardized personality inventories: (1) Temperament and Character Inventory TCI (Cloninger, Przybeck, Svravkic, & Wetzel, 1999); (2) Sensation Seeking Scale-V SSS-V (Litle & Zuckerman, 1986); and (3) Affective Neuroscience Personality Scale ANPS (Davis, Panksepp & Normansell, 2003; Reuter et al.,

<table>
<thead>
<tr>
<th>Musical piece</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Tuba mirum”—Requiem KV 626</td>
<td>An example of classical vocal music in which all solo voices from bass to soprano as well as a choir enter sequentially without any overlap, enabling study of the effect of different voice registers.</td>
</tr>
<tr>
<td>Wolfgang Amadeus Mozart (Karajan, 1989)</td>
<td>Duration: 251s</td>
</tr>
<tr>
<td>“Toccata BWV 540”</td>
<td>An example of (solo-) instrumental classical music (organ) in which different themes are repeated and developed in a highly ordered manner, enabling study of the effect of repeated parts compared to their first appearance</td>
</tr>
<tr>
<td>Johann Sebastian Bach (Walcha, 1997)</td>
<td>Duration: 496s</td>
</tr>
<tr>
<td>“Making love out of nothing”</td>
<td>An example of pop music previously shown to elicit strong emotional reactions (Panksepp, 1995).</td>
</tr>
<tr>
<td>Air Supply (Air Supply, 1997)</td>
<td>Duration: 340s</td>
</tr>
<tr>
<td>“Main title”—Soundtrack of “Chocolat”</td>
<td>An example of film music, with orchestral instrumentation and a simple structure.</td>
</tr>
<tr>
<td>Rachel Portman (Portman, 2000)</td>
<td>Duration: 186s</td>
</tr>
<tr>
<td>“Coma”</td>
<td>An example of rock music, played by the Cello-Rockband Apocalyptika. “Coma” is a piece that uses “classical” instruments for rock music.</td>
</tr>
<tr>
<td>Apocalyptica (Apocalyptica, 2004)</td>
<td>Duration: 405s</td>
</tr>
<tr>
<td>“Skull full of maggots”</td>
<td>An example of “death metal” music. Even if the piece seems to be nothing but chaotic shouting and crying at the first glance, it has a clear and simple structure.</td>
</tr>
<tr>
<td>Cannibal Corpse (Barnes, 2002)</td>
<td>Duration: 125s</td>
</tr>
<tr>
<td>“Bossa nova”</td>
<td>An example of dance music. The “Bossa nova” expected to elicit strong positive emotions with high activation.</td>
</tr>
<tr>
<td>Quincy Jones (Jones, 1997)</td>
<td>Duration: 161s</td>
</tr>
</tbody>
</table>
The TCI represents a complete character inventory on 30 scales. The values on the 30 scales range between 0 and 100. Higher values represent a stronger molding of the character quality. The SSS-V tests for sensation seeking personalities, and the ANPS evaluates the trait status of individuals for basic emotional tendencies. The ANPS and SSS-V tests result in seven and five scales, respectively, both ranging from 1 to 5. Higher values represent a stronger molding of the character quality.

Additionally, we used two self-developed questionnaires regarding musical preferences, habits, and education. These questionnaires included 7-point Likert scales and open questions.

**Apparatus and Procedure**

Auditory stimuli were presented using closed headphones (Beyerdynamic DT 770 Pro) in combination with a USB soundcard (Audiophile, M-Audio). For the physiological measurements, we used ARBO Ag/AgCl-electrodes with a diameter of 15 mm. Skin Conductance Responses (SCRs) were measured on the middle segments of the index and middle fingers of the nonactive hand. Signals were amplified 100 times with a biosignal amplifier developed by IED (Institut für explorative Datenanalyse) Hamburg. Music, physiological data, and signals from the mouse button were synchronized by the researcher-developed software (Nagel, 2005) based on DT Measure Foundry Data translation. For evaluation and presentation of data, we used Matlab (Version 7.0.4), SPSS (Version 13.0), dB Sonic (Version 4.13), and Adobe Audition (Version 1.0).

During the experiment, participants sat in a comfortable armchair, in a room in which the participant and experimenter were separated by a room divider. Thereby, the contact between participant and researcher was possible when desired, but the researcher could not watch the participant during the experimental session. The experiment was explained in a standardized manner during the placing of the electrodes. Participants could regulate the volume/sound to a pleasant level with the help of a test-tone prior to testing.

Before the experiment began, a 30 s physiological baseline measurement was taken while participants sat in a relaxed manner in the armchair. The experiment then began. Standard pieces four through seven (see Table 1) were presented in order, followed by standard pieces one through three mixed randomly with each participant’s “personal” pieces. Throughout the presentation of these stimuli, participants were asked to press a mouse button whenever they perceived a chill (goose bumps reaction [“Gänsehaut”] or shivers down the spine [“Schauer über den Rücken”]), and to continue to press the button for the duration of the chill. Participants were free to choose the hand with which to make their responses.

After listening to each piece, participants completed a questionnaire regarding their knowledge, liking, and the perceived pleasantness of the piece, as well as bodily reactions to the music such as goose bumps or shivers down the spine. Participants also were asked to describe the musical characteristics of excerpts they perceived as particularly pleasant. When finished, they gave a sign to continue. Following the presentation of auditory stimuli, participants filled in the three character inventories and the questionnaire regarding music preferences, listening habits, and musical education and experience.

To evaluate intra-individual stability of responses, we repeated this experiment seven times with a 24 year-old, right-handed female musician. The experiment was done at the same time (10:30 a.m.) on seven subsequent days with a two-day break for the weekend. We used the same pieces (seven standard pieces plus three personal pieces) in the same order every day.

**Chill Criteria**

Two criteria were required for chill events to be included in analysis. First, since chills are mediated by the sympathetic system (Boucsein, 2001), they also should show an effect on Skin Conductance Response (SCR), the measurements of which are mostly based on sweating reactions and blood flow to the fingers (Boucsein, 2001). These physiological reactions also are mediated by the sympathetic nervous system. Thereby, a reported chill only was included in analysis when a reaction in SCR could be seen during the onset of the chill (i.e., moment when participants pressed the mouse button to report presence of a chill). Second, in the questionnaire administered after each piece, participants indicated their perceived bodily reactions to the music. Only chill events for which participants reported experiencing “goose bumps” and/or “shivers down the spine” were included in analysis.

It should be noted that a chill may also be understood as a mere subjective feeling that does not necessarily occur together with a physiological response; however, in order to have objective control for the reported chills, we defined chills as a reported feeling combined with a measurable physiological response. Chills in reaction to standard pieces could be used for direct comparison since all participants listened to these pieces under the same conditions. Thus, the analysis of character inventories, music questionnaires, and the musicological analysis was based on the seven standard pieces. Chills from personal pieces were used to perform a more detailed
analysis of the chill phenomena. We compared participants’ statements regarding pleasant musical events for chill and nonchill pieces. Additionally, excerpts from the personal pieces were analyzed psychoacoustically.

Analysis of Standard Pieces

CHARACTER INVENTORIES AND MUSIC QUESTIONNAIRES
To check for differences in character and musical experience between chill responders and nonchill responders, we divided the two groups according to the number of chills they perceived in response to the standard pieces. Here the conditions for all listeners were the same. We divided the participants into two categories: the upper quarter (25%), i.e., participants who perceived up to 17 chills in response to the standard pieces, and the lower quarter (25%), i.e., participants who perceived no chills at all. Both groups consisted of three men and seven women. Since we found a similar distribution between genders in both groups, which also reflects the distribution of the whole group, we could not detect any gender difference in chill response. Since we were working with volunteer participants the gender bias reflects the gender distribution that characterizes volunteers. Mann-Whitney U tests were used to calculate the differences between these two categories.

COMPARISON OF CHILL ONSETS IN TIME
The relationship between music and chill onsets was studied via musicological structural analysis. This was done for the seven standard pieces.

Analysis of Personal Pieces

PARTICIPANTS’ STATEMENTS REGARDING THE CHILL PIECES
Since chills were expected to be pleasant emotional reactions, we asked two questions regarding pleasantness in the questionnaire after each piece: “How would you rate the piece of music according to pleasantness?” (“Als wie angenehm haben Sie das Stück empfunden?”), and, as an open question: “If you find a section of the piece particularly pleasant, could you please describe its characteristics?” (“Falls es einen Abschnitt im Stück gibt, den Sie als besonders angenehm empfunden haben, können Sie die Merkmale dieses Abschnitts beschreiben?”).

The first question was used to control whether there really is a relationship between chills and pleasantness, assessed using a Spearman correlation between the number of reported chills and the rating of pleasantness for the “personal” pieces. If this was the case, the second question was used to reveal, in an indirect manner, what structural parts of the music were perceived consciously and attentively as pleasant, thereby revealing possible structural parts of the personal pieces that show a relationship to the chill experiences. We decided not to ask directly “what do you think triggered the chill?” in order to avoid confusion of the participants’ chill hypotheses and opinions of the actual structural parts to which they reacted. Asking directly for the cause of chill could have resulted in participants concentrating on the previously named structural parts in the subsequent pieces, to see whether or not they triggered chills again that could have led to self-fulfilling prophecies regarding the causes of chills. We used the musicological analysis of the standard pieces for a direct analysis of the musical structural parts, to which the participants had chill reactions.

The analysis of chill-reaction patterns to the standard pieces revealed a set of basic musical structures that seem to be related to chills. We used these results to categorize the statements of the participants according to the following musical structures: (a) beginning of a piece; (b) entry of instrumental or human voice(s); (b) volume or changes in volume (e.g., fortissimo, pianissimo, crescendo, diminuendo); (c) melody, theme or motive; (d) tempo, rhythm; (e) contrast of two voices; (f) harmony; and (g) others.

We compared the number of statements (all statements and statements in different categories) for three groups: (a) chill responders regarding chill pieces; (b) chill responders regarding nonchill pieces; and (c) chill non-responders regarding nonchill pieces.

MEANS OF PSYCHOACOUSTICAL TIME-SERIES
The chills from the personal pieces were analyzed psychoacoustically. The hypothesis was that chills occur in response to distinct acoustical patterns in a reflex-like manner. We collected 190 musical excerpts 20 seconds in length, each beginning 10 seconds before a chill onset and ending 10 seconds after. The excerpts were analysed psychoacoustically using dBSonic software, focusing on loudness, sharpness, roughness, and fluctuation for each excerpt (Zwicker & Fastl, 1999). The measure for loudness was “sone,” where “the level of 40 dB of a 1-kHz tone was proposed to give the reference for loudness sensation, i.e., 1 sone” (p. 205). Sharpness was measured in “acum,” where “the reference sound producing 1 acum is a narrow band noise one critical-band wide at a centre frequency of 1 kHz having a level of 60 dB” (p. 239). “Asper” was the measure for roughness, where one asper is defined as “the 60-dB, 1kHz tone that is 100% modulated in amplitude at a modulation frequency of 70 Hz” (p. 257). Finally, fluctuation is described in “vacil,” where “a fixed point is therefore defined for a 60-dB, 1 kHz 100% amplitude-modulated at 4 Hz, as producing 1 vacil” (p. 247).
In order to check for a general common pattern in all chill excerpts, the means of all the time series were calculated separately for each parameter. We were especially interested in peaks in relation to chills. As a criterion for the significant peaks in means of the psychoacoustical time series, we decided on the mean upper 10% (percentile) of all individual time series, i.e., the value of the 90th percentile of the 190 individual time series was calculated. The mean of the resulting 190 values was used as the level of significance.

Additionally excerpts were categorized according to: (1) individual participants, i.e., the chill-excerpts of every individual were summarized in one category to test for differences between participants; (2) musical experts (5), musical amateurs (20), nonmusicians (13); (3) whether the chill consisted of goose bumps and shivers down the spine, or just goose bumps, or just shivers; (4) whether positive, negative, or no memories were associated with the piece of music that aroused the chills; and (5) whether the piece was rated as very intense or not very intense. Means and medians of the categories were calculated.

**FREQUENCY OF PEAKS IN PSYCHOACOUSTICAL PARAMETERS RELATED TO CHILLS**

We collected and counted excerpts that showed a significant peak in loudness, sharpness, roughness, or fluctuation at the chill onset. A peak was rated as significant when it was higher than 90% of the entire curve (see Figure 1 for an example of a peak rated significant). In the same way, we collected and counted excerpts that showed significant peaks one, two, three, and four seconds before the chill onset, since the chill can occur with a delay.

Additionally, we calculated the differentiation of all values in one-second intervals. The absolute values of the differentiation show changes in the psychoacoustical parameters. A high value in the differentiation reveals a strong change in the parameters independent of direction. We repeated the peak analysis for the differentiation of all named parameters.

Then we compared the results to 190 excerpts analyzed in the same manner that were collected from:

1. The same chill pieces, i.e., musical pieces that aroused chills, but from points in time that showed no chill reaction (nonchill excerpts from chill pieces). When possible, the same numbers of nonchill and chill excerpts were collected from the same piece.

2. An additional 190 excerpts were collected from pieces that chill-responders listened to without perceiving any chills (nonchill excerpts from nonchill pieces).

Finally, we compared the number of collected peaks in loudness, sharpness, roughness, and fluctuation as well as in their differentiation for chill excerpts, nonchill excerpts from chill pieces, and nonchill excerpts from nonchill pieces, by performing chi-square tests.
Results

Only 21 of the 38 participants reported chills during the experiment. Chill responders had a mean age of 40 years (range = 11-72), and included two professional musicians, eleven amateur musicians, and eight non-musicians. The 17 chill nonresponders had a mean age of 35 years (range = 19-64) and included three professional musicians, nine amateur musicians, and five nonmusicians. Each group included academics as well as nonacademics.

Of the 21 chill responders a total of 399 chill events were reported. Of these 399 reported chills, 108 did not correspond to a visible SCR and thus were excluded from the analysis. Of the remaining 291 chill events, 79 occurred in reaction to the standard pieces, 212 during the personal pieces.

Case study: Bach “Toccata BWV 540”

Figure 2 illustrates the results of the chill analysis for J.S. Bach’s “Toccata BWV 540.” This music is an interesting example of chill reactions to music, because it consists of six general structural parts that are repeated and varied several times throughout the piece. The top section of Figure 2 shows the acoustic envelope of the piece with the six excerpts within the score marked (along the top of the waveform) and then shown in notation below (along with structural element description and chill response data). The chill responses of the four participants (P27, P12, P05, P11) who reported chills in response to the Toccata are indicated below the waveform. Although of the seven standard pieces the “Tuba mirum” elicited the most chills (a total of 40 chills from 8 participants), the “Toccata BWV 540” (which elicited the second highest number of chills; a total of 22 chills from 4 participants) is presented for case study because chills are more equally distributed between participants and the six structural excerpts are repeated several times within the piece.

The top section of Figure 2 illustrates that chills do not show a simple stimulus-response pattern; there is no point in time where all four participants react simultaneously in response to the toccata. The only example of participants reacting relatively closely in time can be found at 8:01 min (participant 12) and 8:03 min (participant 11) at the end of the toccata.

However, the data appear to cluster when categorizing the chills based on the structural parts. The main theme (part 4) elicited chills from all four participants; nine of the total 22 chills (41%) occurred when this main theme was played. Part 5, a chord sequence combined with an ascending figure, elicited the second highest number of chills; from three participants eight of the total 22 chills (36%) occurred during this part. None of the four remaining parts (1, 2, 3, 6) elicited chills in more than one participant, resulting in just one or two chills during the piece. Thus, sections 4 and 5, which made up 36% of the duration of the “Toccata,” elicited 77% of chills for this piece.

Retest Experiment

To evaluate response reliability, we repeated this experiment seven times with a 24 year-old, right-handed female musician. Here we present two examples: Figures 3 and 4 illustrate chill responses to the “Tuba mirum” (standard piece) and Strauss’ “Breit über mein Haupt” (personal piece) across the seven days of testing.

As for all other participants, of the seven standard pieces the “Tuba mirum” elicited the largest number of chills from this participant. Across days 1 through 5, at two points in time, chill responses were the most stable at 2:12 min (days 1 through 5), at which point the alto voice enters, and at 2:35 min (days 1 through 4), at which point the soprano voice enters. It is noteworthy to mention that the participant in this retest experiment was a singer (soprano). On days 6 and 7 no chills were elicited.

On four days (days 4 through 7), the participant commented on what was particularly pleasant about this piece. On days 4, 5, and 7 she named the “entry of the alto,” which occurs at 2:35 min; on days 3 and 7 she named the “entry of the quartet,” which occurs at 3:20 min.

Figure 4 shows one point in time where chill response was stable for the personal piece “Breit über mein Haupt.” At 1:00 min, a chill occurred within a range of four seconds on six of seven days (days 1 through 6). The psychoacoustical analysis showed that the piece reached its climax in loudness at this time. Another peak in loudness at 0:50 min could be associated with a chill occurring on two days. Another peak at 0:28 min may be associated with a chill occurring on three days. It must also be mentioned though that in this case the participant pressed the button before the peak of loudness was reached.

When asked what was particularly pleasant about this piece, the participant named the text passages “Nacht” on day 1, “nur deiner Locken Nacht” on day 4, and “deiner Locken Nacht” on day 5. Those were the only statements regarding this piece throughout the experiment. The passage “nur deiner Locken Nacht” lasts from 0:56 min to 1:07 min.
FIGURE 2. Case study of Bach’s “Toccata BWV 540.” The top section shows the acoustic envelope of the piece with the six excerpts within the score marked (along the top of the waveform) and then shown in notation below (along with structural element description and chill response data). The chill responses of four participants (P27, P12, P05, P11) are indicated below the waveform.
Frequency of Chills

Figure 5 shows the frequency of chill responses for all participants for the standard pieces. It is apparent that chills are relatively rare events and are not regularly distributed between participants or pieces. While some participants perceive up to 15 chills in one piece, others do not perceive any chills at all. Further, while Mozart’s “Tuba mirum” and the Bach “Toccata” aroused many chills, “Skull full of maggots” and the “Bossa nova” did not result in chill responses.

Questionnaires

Participants completed three character inventories: the Temperament and Character Inventory TCI (Cloninger, Przybeck, Svrakic, & Wetzel, 1999), the Sensation Seeking Scale SSS-V (Litle & Zuckerman, 1986) and the Affective Neuroscience Personality Scales ANPS (Davis, Panksepp, & Normansell, 2003; Reuter et al., 2005). We compared responses from chill nonresponders and chill responders using a Mann-Whitney U test; two significant differences between the two groups were revealed. First, chill responders were less thrill and adventure seeking (SSS-V). On a 7-point Likert scale, chill responders rated 3.3 on average ($SD = 1.6$), whereas chill nonresponders rated 6.0 ($SD = 2.0$; one missing value). This difference was significant, $U = 12.5$, $p < .01$, two-tailed.

Second, chill responders were more reward dependent (TCI). On a 0-100 scale, chill responders rated 57.5 on average ($SD = 4.9$; two missing values), whereas chill nonresponders rated 49.1 ($SD = 9.4$; two missing values). The difference was significant, $U = 13.0$, $p < .05$, two-tailed.
FIGURE 4. Chill response data (top panel) for one participant across seven days in response to Strauss’ “Breit über mein Haupt” with accompanying psychoacoustic analysis presented in the bottom panel. Chill response consistency is evident at 1:00 min. The psychoacoustic parameters loudness, roughness, and fluctuation show peaks at this point in time.
The musical experience and habit questionnaires revealed that chill responders differed from chill nonresponders in several ways. First, chill responders indicated higher familiarity with classical music ($M = 5.2, \text{SD} = 1.4$ vs. $M = 3.2, \text{SD} = 1.4$; one missing value, $U = 14.0, p < .01$, two-tailed). Second, chill responders rated music as more important in their lives ($M = 6.9, \text{SD} = 0.4$; two missing values vs. $M = 6.0, \text{SD} = 1.0$; one missing value, $U = 15.5, p < .05$, two-tailed). Third, chill responders identified more with the music they preferred ($M = 6.5, \text{SD} = 0.7$ vs. $M = 5.0, \text{SD} = 1.2$; one missing value, $U = 10.0, p < .01$, two-tailed). Fourth, chill responders more readily listened to music in everyday life in a situation similar to the experimental setting ($M = 5.0, \text{SD} = 1.9$ vs. $M = 3.0, \text{SD} = 1.6$; one missing value, $U = 18.0, p < .05$, two-tailed).

**Psychoacoustic Analysis**

From the personal pieces, we collected 190 chill-eliciting excerpts, 20 seconds in length beginning 10 seconds before the chill onset. We analysed the psychoacoustic loudness, sharpness, roughness, and fluctuation parameters of each excerpt.

We first calculated the means of all chill excerpts for all four psychoacoustic parameters using the 90th percentile value as the level of significance. Overall mean curves showed no significant peaks at the chill onset. However, a small elevation in loudness was an indication that building pre-categorized groups of excerpts for further analysis might reveal peaks at the chill onset in sub-categories. Sub-categories were arranged according to: (1) individual participants; (2) music training (i.e., musical experts, musical amateurs, or nonmusicians); (3) type of chill (i.e., goose bumps, shivers, or both goose bumps and shivers down the spine); (4) memory type associated with the chill-eliciting music (i.e., positive, negative, or no memories); and (5) whether the piece was rated as very intense or not very intense. Comparison of resulting mean curves revealed no clear psychoacoustic characteristics of groups related to the chill onset.

We next compared loudness, sharpness, roughness, and fluctuation peak frequency data—as well as in their differentiation one to four seconds before chill onset—for chill excerpts, nonchill excerpts from chill pieces, and nonchill excerpts from nonchill pieces using chi-square tests. Figure 6 shows the percentage of excerpts that showed a peak at the chill-onset, and at the four one-second intervals preceding chill onset for chill excerpts, and nonchill excerpts within pieces that did and did not elicit chills at other points. For two nonchill comparisons, the onset was a randomly chosen point in time within the piece of music.

As illustrated in Figure 6, significant chill frequencies were evident for each psychoacoustic parameter, although...
not always at chill onset. Nineteen percent of all chill excerpts showed peaks in loudness at chill onset, compared to 9% at random points within nonchill excerpts, χ²(2, N = 570) = 11.0, p < .01. Fourteen percent of all chill excerpts showed a peak in sharpness one second before onset, compared to 7-8% at random points within nonchill excerpts, χ²(2, N = 570) = 6.2, p < .05. For the roughness parameter, there was a difference at the onset, but in this case, nonchill pieces showed a higher number of peaks (27% of the cases) than chill pieces, χ²(2, N = 570) = 19.9, p < .01. Finally, differences in fluctuation between chill and nonchill excerpts were evident at one and four seconds before onset. At -1 seconds, 13% of chill excerpts showed a peak in fluctuation, compared to 6% and 11% in nonchill excerpts, χ²(2, N = 570) = 7.2, p < .05. No other significant differences between chill and nonchill excerpts were evident.

Chills and Pleasantness

Our overall evaluation of chills and pleasantness revealed that chills were significantly correlated with perceived pleasantness of the pieces, r(51) = .45, p < .01. We asked the participants to describe what element of the music they perceived as being particularly pleasurable, in an attempt to identify potential chill triggers. The individual statements could be classified into seven categories of musical events: (1) beginning of a piece; (2) entry of instrumental or human voice(s); (3) volume or changes in volume (e.g., fortissimo,
pianissimo, crescendo, diminuendo); (4) melody, theme or motive; (5) tempo, rhythm; (6) contrast of two voices; and (7) harmony. Using a chi-square test we compared prevalence per category for the statements of: (a) chill responders regarding pieces that aroused chills (chill pieces); (b) chill responders regarding pieces that did not arouse chills (nonchill pieces of chill responders); and (c) chill nonresponders’ pieces (nonchill pieces of chill nonresponders).

As shown in Figure 7, chill responders gave significantly more statements regarding chill pieces (77%) compared to nonchill pieces (58%). Chill nonresponders gave even fewer statements (48%), $\chi^2(2, N = 216) = 26.4, p < .01$. The three groups differed regarding how many statements fit into the seven categories of musical events: the comments of chill nonresponders could be categorized in about half of the cases (25% categorized statements vs. 24% noncategorized statements), while chill responder statements fit into the categories 45% (nonchill pieces) and 69% (chill pieces) of the time. Thus, for chill pieces, 90% of statements could be categorized, whereas only 51% of chill nonresponder statements could be categorized, $\chi^2(2, N = 216) = 7.0, p < .05$.

We found significant differences between participants’ statements for most of the single categories of musical events: entry of a voice and increase in or change in volume showed the most pronounced differences. In almost one third of the chill pieces (29%), the entry of a voice was perceived as particularly pleasurable. This was independent of whether it was a human voice or instrument. For nonchill pieces, an entry of a voice was mentioned for 11% (chill responders) and 7% (chill nonresponders) of the pieces, $\chi^2(2, N = 216) = 13.5, p < .01$. Volume (i.e., extraordinarily loud or quiet passages; fortissimo, pianissimo) or a change in volume (crescendo, diminuendo) was shown in 25% of the chill pieces as being most pleasurable. In nonchill pieces, volume was mentioned for just 9% (chill responders) and 4% (chill nonresponders) of the pieces, $\chi^2(2, N = 216) = 16.0, p < .01$. The contrast of two voices was named for 10% of the chill pieces as being a pleasurable element, but for just 3% of nonchill pieces listened to by chill responders and 1% of pieces listened to by chill nonresponders, $\chi^2(2, N = 216) = 6.9, p < .05$. “Melody” summarizes statements discussing melodies, motives or themes as being extraordinary pleasurable. This category showed a difference between statements of chill responders and chill nonresponders (4%), but not between chill pieces (15%) and nonchill (14%) pieces listened to by chill responders, $\chi^2(2, N = 216) = 8.2, p < .05$.

**Discussion**

What can we conclude from the various data collected in this interdisciplinary and exploratory study? Summarizing our findings, it can be stated that chills are relatively rare peak experiences. Not all people perceive chills in response to music, and responders and nonresponders can be characterized by personality factors, and according to their experience with musical styles. They differ in statements concerning how important music is in their lives, how much they identify with their preferred musical style, and in which situations they enjoy music. Chill responders react more to distinct musical structures such as the entrance of a voice, whereas nonresponders seem to listen to music in a less discriminating way. Mere acoustical features like peaks in loudness, sharpness, or fluctuation are of secondary importance. Inter-individually, chills do not occur at a distinct point in time in response to a certain acoustical pattern, but in response to musical structural parts. Intra-individually, some chill-events are relatively stable responses to musical structures, such as the entrance of a voice, and show habituation after a few days. The musical structures that are associated with chills are mostly perceived consciously and are felt as being highly pleasant.

One important question concerned the frequency of chills. While Panksepp (1995) found a mean of up to 4.4 chills/minute for “Making love out of nothing at all” by Air Supply in a group of 14 students, we found chill reactions in response to the same piece in less than 10% of our participants. Those listeners who had reported chills had a “chill rate” of 1.1 per minute. There are three possible explanations for this difference. First, Panksepp used a group of participants that was much more homogeneous than our group. Second, the Air Supply song was much better known in 1995 than today, and it seems to be more familiar to the American students than to the German participants. Panksepp highlighted that both familiarity and liking were strong variables that were positively related to the number of chills. Finally, the participants in Panksepp’s study filled in the questionnaires in a group situation, whereas our participants performed the experiment in individual settings. It cannot be disregarded that chill reactions, and emotions in general, are influenced by a group situation.

A similar “pre-selection” of listeners took place in Soboda’s (1991) experiment. As in Panksepp’s study, the homogeneity of the participant group was not intended; about 500 people were given the questionnaires, but only 83 participants answered them. Even if
FIGURE 7. Categorization of participant descriptions of perceived pleasantness for chill excerpts, non-chill excerpts within chill pieces, and non-chill excerpts within non-chill pieces. $p < .01; * p < .05$
This group was still relatively heterogeneous, the musical analysis of emotion provoking segments was based on the statements of musical performers (12 professionals and 13 amateurs). Only two respondents were nonperformers. In our experiment, participants could directly report a chill in response to the music, without explicitly naming or describing the musical passage. In part, we found the same structural elements such as “a sudden dynamic change,” and according to our results, we can confirm the principle behind the two factors, “new or unprepared harmony” and “sudden dynamic or textural change” as the occurrence of something new, or an unexpected event in music. Interestingly this seems to be a general principle for emotional reactions to music evident in further work from our laboratory (Grewe, Nagel, Kopiez, & Altenmüller, 2007).

Corresponding to Goldstein (1980), we found that there were chill responders and nonresponders, and that it was possible to characterize chill responders according to their personality, musical experience, and preferences. Chill responders showed a preference for less intensive stimuli, they are not “thrill and adventure seekers” (the word thrill has a different connotation in the context of the SSS-V), and they are more reward dependent, i.e., they especially like approval and positive emotional input from their environment. Music as a stimulus fits these needs perfectly. Compared with bungee jumping or skydiving, it is a rather “soft” stimulus, and it seems to “transmit” emotions in some way. The need to clarify in which way music transmits emotions remains. As a very important result, we found that chill responders are more familiar with classical music. Most chills occurred in classical music, in the standard pieces as well as the personal pieces. That does not mean that it’s necessarily classical music that arouses chills, but it is a hint that familiarity with certain musical styles is of importance in order to respond to it with strong emotions. This finding also corresponds to the results of Panksepp’s study (1995) that the most chills were found among individuals who were familiar with the music selection. However, it should be noted that during pilot testing, we were able to trigger numerous chills in one participant with a piece of electronic jazz that was completely unknown to the participant. The participant reported being very familiar with, and fond of, electronic jazz, thus suggesting that explicit knowledge of the musical structure is not as important as implicit knowledge.

Further experience from pilot testing contributed to the decision not to ask for the musical structures connected to chills in a direct way, as Sloboda (1991) did in his study. Only the musical performers were able to name musical events properly. Since chills are perceived as highly pleasant, we asked in an open question what was particularly pleasant within each piece. As the responses showed, nonexperts also reported that distinct musical structures were pleasant, even if they were unable to use proper music terminology (e.g., “strings became louder, more strings entered” instead of “crescendo”).

It is also crucial to weigh the importance of a stimulus for perceiving chills. Music was neither equally important to chill responders and nonresponders, nor did the two groups equally identify with their preferred musical style, as the results of the questionnaires showed. Giving importance to music and identifying with a certain style seems to be an active decision that may be based on social experiences. Every musical style has its social context and social groups seem to identify rather strongly with “their” style. Hip hop, techno, classical music, and death metal are examples, even if postmodernism has broken down many barriers.

Additionally, chill responders reported listening to music in everyday life in a situation similar to the experiment. One of the most characteristic features of the listening situation in our experiment was that listeners were alone and separated from their surroundings via headphones. Many listening situations in everyday life are much more social, e.g., clubs, parades, or concerts. This is important when we regard the communicational aspect of music. Music has often been called “the language of emotions” (Gabrielsson & Lindström, 1993). Many studies have shown that identification of basic emotions in music works reliably in experts as well as in nonexperts (Cunningham & Sterling, 1988; Hevner, 1936; Terwogt & van Grinsven, 1991). This is significant, because even if a listener enjoys music via headphones and alone, this may still be a communicative act that includes active interpretation. Music may be a “communicational offering” (in analogy to Bach’s “Musical Offering”), but it’s the listener who decides whether he is interested in this offering. This fits the finding that the entry of a voice is perceived as being especially pleasurable, and was mentioned mostly in chill-pieces. There is one of Panksepp’s (1995) findings that also can be used as an argument for this hypothesis: he found that “the piercing simplicity of certain solo pieces that emerge from a richer orchestral background” can intensify emotional feelings.

It is even possible that the listener identifies with and imitates the music. This occurs when listeners sing along, when they start to “conduct” the music on a CD (as one of our participants reported in the questionnaires), or when they dance to the music (reported by another participant as being her main response to music).
This shows that it would be a misunderstanding to interpret listening to music as a passive act. Music arouses different emotional processes in people; it sets them to (e-)motion.

There is an interesting finding from Blood and Zatorre (2001) showing that during chills, the activity of the thalamus and the anterior cinguli is elevated. Both brain systems are involved in attention. Sloboda found that “new or unprepared harmony” or “sudden dynamic or textural change” is associated with chill reactions. Meyer (1956, 2001) described unexpectedness as the most important aspect for evoking emotional processes. When we look at what chill responders and chill nonresponders perceived as being especially pleasant in chill pieces and nonchill pieces, we find an interesting parallel: the entry of a solo voice, special qualities in loudness, the entrance of a motive or theme, and the contrast of two voices seem to raise the attention of participants. Obviously, it is not so much the distinct musical feature, but the focus of attention on the music that is important for arousing chills. Results from the psychoacoustical analysis give further evidence for this hypothesis. Peaks in loudness, sharpness, and fluctuation can be found in a small number of chill pieces, but no overall acoustical pattern that triggers a chill could be determined. This hypothesis is supported by two results. First, chills of different responders within one piece did not occur at the same point in time, but in response to the same musical structures as evident from the case study of Bach’s “Toccata BWV540.” Second, in one individual some chills occurred regularly in response to musical structures (results from control experiment), suggesting that a conscious but not necessarily explicit evaluation of music is crucial for perceiving a chill. Chills do not seem to be an automatic, reflex-like response to any acoustical pattern. Our findings suggest that the question of whether chills induce emotional feelings, or emotional feelings induce chills (Panksepp, 1995), should be answered by the latter alternative. A cognitive, implicit evaluation triggered by attention-raising structures leads to an emotional process, and a chill occurs in the context of this process.

We summarized the evidence from this experiment in a model (Figure 8). Whether or not a chill is triggered depends on the relationship of the music to the listener: chill-eliciting music may contain some structural elements, like the entry of a voice or special qualities in loudness, but these are basic structures that can be found in almost all musical styles. Thus, several listener-dependent factors may be important. First, that the listener’s personality involves appreciation of a more delicate stimulus such as music (i.e., general reactivity); and second, that the listener is familiar with the style of the music that is presented, and that they are in an appropriate listening context and are willing to listen attentively (i.e., special reactivity). Third, in some cases, like the example of the “Barrabam-call” from Johann

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FIGURE 8. Model of chills in response to music.
Sebastian Bach’s “Matthäus-Passion” BWV 244 (Sloboda, 1991), there may be a shortcut to attention. A choir that enters with a fortissimo call may arouse the attention of even nonexperienced listeners who normally need stronger stimuli than music. If these factors are evident, the structural elements of the presented musical stimulus are capable of defying expectations and thereby focusing the attention of the listener on the music as well as on his bodily reactions. This emotional process works like positive feedback; the more attentively the listener follows the music and feels his own reaction to the stimulus, the stronger this process becomes. The chill can ultimately be interpreted as the consequence of a strong stimulation of the whole nervous system.

When thinking about the evolutionary bases of pleasure and chills in reaction to music, one should consider the possibility that it is not the phenomena such as the pilerection or shivers that make chills evolutionarily important, but the emotional process that takes place in response to a stimulus that contains information. In social groups, it is not only important to communicate facts, but also one’s emotional status. Music can be understood as an emotional communication system, and it is essential to learn to understand the communication of the social group to which one belongs. It has been said that most social groups have a certain style of music. If we want to belong to a group, we need to understand their emotional communication, which is partly found in music. This may be one reason why a certain musical style becomes important to us, and why we begin to identify with this style. It’s not the music, but the feelings of the people we hear playing that are important to us. When our implications and expectations regarding such “important” music are violated we become attentive; and we start to learn the new pattern. This learning process is accompanied by an emotional process, on the one hand by motivation, on the other hand by compassion. Being able to sympathize with the feelings of others may be the best way to understand them. When our level of concentration is especially high, when the emotional process is very strong, and/or when our senses are completely focussed on the music, a chill may result.

Coming back to the opening question, we propose that it is not the music as a physical stimulus that manipulates our moods, but it is we using the music as a communicative offering to influence our feelings in a re-creative process. There may be some strong effects in music, such as the “Barrabam-call,” which trigger chills directly. But even in this example, it seems to be a process mainly based on the heightened attention of the listener. The reason why we largely are not aware that we actively influence our feelings by listening to music is because this process is mostly implicit, based on associations, memories, and expectancies. Our own mind seems to react automatically to music. We sense no effort; music is recreation, but yet it is the listener’s re-creation.

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