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Chills in different sensory domains: Frisson elicited by acoustical, visual, tactile and gustatory stimuli

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Abstract

'Chills' (frisson manifested as goose bumps or shivers) have been used in an increasing number of studies as indicators of emotions in response to music (e.g., Craig, 2005; Guhn, Hamm, & Zentner, 2007; McCrae, 2007; Panksepp, 1995; Sloboda, 1991). In this study we present evidence that chills can be induced through aural, visual, tactile, and gustatory stimulation. Additionally, chills were elicited by mere mental self-stimulation – even without any external stimulus. Subjective ratings and physiological responses (i.e., skin conductance response, heart rate, breathing rate) of 36 participants reporting chills were recorded in response to stimuli of the named sensory domains. Chills in response to all external stimuli showed similar physiological correlates. However, they differed in the subjective affective perception: more chills occurred in response to *negative* valent and arousing sounds and pictures, while more chills were reported for *positive* valent music independent of arousal. These findings suggest that the chill phenomenon could be a valuable indicator of strong emotions. However, the measurement of chills should be combined with other methods of emotion measurement, since chills can be a response to psychological events of different affective value.

Keywords

chill, emotion, frisson, music, physiology

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In the past decade, an increasing number of studies presented 'chills' as an interesting parameter for emotion research (see e.g., Blood & Zatorre, 2001; Craig, 2005; Guhn et al., 2007). The concept of using chills as an indicator of strong and pleasant emotions was introduced by Goldstein (1980). The relation of chills to endogenous opiates shown in Goldstein's study indicated the hedonic impact of these bodily reactions. When participants were treated with the endorphin antagonist naloxone, they perceived fewer chills in response to music. Like Goldstein, all the following studies used music to elicit chills.

The examination of chills using PET revealed the activation of the reward system during chills in response to music (Blood & Zatorre, 2001). Structures such as the nucleus accumbens, the ventral tegmental area, thalamus, insula, and anterior cingulate were found to be more active during a chill reaction, while activity in the amygdala and ventral medial prefrontal cortex was reduced. This pattern of activity has been observed typically during euphoria and/or pleasant emotions (Breiter et al., 1997).

Several studies have demonstrated that chills have psychological as well as physiological correlates (Craig, 2005; Guhn et al., 2007; Rickard, 2004). This information made chills even more interesting as a parameter; no other known indicator of emotions combines a strong, positive, subjective feeling, and a measurable physiological arousal response in one reaction. According to the emotion model of Scherer, an emotion consists of a relatively short event comprising a synchronized reaction of physiological arousal, subjective feeling and motor response (Sander, Grandjean, & Scherer, 2005; Scherer, 2005). The synchronous measurement of these parameters across time in response to music revealed that each single emotion parameter can also occur independently of the others, which makes their interpretation as an emotion difficult (Grewe, Nagel, Kopiez, & Altenmüller, 2007a).

Sloboda (1991) found that chills are correlated with various musical structures, such as unprepared harmonies and sudden dynamic or textural changes. A more recent study (Guhn et al., 2007) presented further arguments for a direct relation of musical structures and chills. If distinct musical structures could be found that were capable of simply triggering these pleasurable peak experiences, chills would be an ideal tool for experiments concerned with positive emotion. Based on findings that suggested acoustical structures as triggers of chills, some authors speculated about the evolutionary meaning of chills (e.g., Panksepp & Bernatzky, 2002).

However, there are also arguments that the frequency of chills depends very much on the familiarity of the listener with the music that induces the chills (e.g., Panksepp, 1995) and on the (possibly implicit) cognitive evaluation of the music (Grewe, Nagel, Kopiez, & Altenmüller, 2005; Grewe, Nagel, Kopiez, & Altenmüller, 2007b). Even if some musical and acoustical structures seem to be more likely to elicit chills than others (Guhn et al., 2007; Nagel, Kopiez, Grewe, & Altenmüller, 2008), no effective chill trigger has been found in music so far. In a former study we tested a great variety of participants of different ages and musical/social background with stimuli of various musical styles, such as classic, pop, rock, dance, soundtracks, and so forth (Grewe et al., 2007b). Musical events, such as the entrance of a voice, changes in loudness and contrasts between two voices, were found to elicit chills more frequently than other musical structures.

There seem to be commonplace acoustic phenomena that can trigger chills reliably in all people: scratching fingernails on a blackboard or dentists' drills, for example. However, so far no study has been performed to test chill reactions to these triggers. As previously stated, chills in response to music show some interesting similarities to the classical definitions of an emotion: they result from a combination of a physiological arousal and subjective feeling response; they are related to distinct musical structures (external events); and, in contrast to moods, they are of a short duration (Merten, 2003; Sander et al., 2005; Scherer, 2005). Thus it might be valuable to examine whether chills occur in response to stimuli of other sensual domains (visual, tactile, gustatory) and whether they reflect the same emotional meaning in response to other stimuli as to music. Has a chill in response to a dentist drill the same emotional meaning compared to a chill in response to Rachmaninoff's 2nd piano concerto? Or do the goose bumps and shivers in both cases have a different affective source and meaning, although they seem to be the same? Some studies have already compared emotions in response to environmental sounds and music (Gomez & Danuser, 2004) and found differences in affective ratings as well as physiological responses.

Several theories about the meaning of chills are being discussed currently: Konečni assumed that the underlying psychological mechanism is aesthetic awe (Konečni, 2005), while Panksepp hypothesized that chill-eliciting sounds are similar to separation calls (Panksepp, 1995). Finally, David Huron suggested that chills might be related to threatening gestures, such as when a cat bristles its fur, and other fight and flight responses (Huron, 2004). All authors have good arguments for their theories; however, it is plausible that the chill reaction occurs in different circumstances, having different causes and different affective meanings.

In the study we present here, we compared the capacity of chill induction of visual, acoustical, tactile, and gustatory stimuli. Additionally, we tested whether chills can occur independently of external stimuli, elicited only by the associations and recalls of the participant. The resulting chills from the different sensual domains were compared according to their subjective emotional meaning as well as their physiological correlates. To avoid misunderstandings and inconsistent terminology, we would first like to define our use of terms for this article. Some authors have used the term *chill* or *thrill* in a wider sense and include other bodily experiences, such as tears or a funny feeling in the stomach. We define chills as goose bumps and shivers down the spine, and we explained them as such to all participants in our study. The term *emotion* is used according to the component process model suggested by Scherer (see e.g., Sander et al., 2005; Scherer, 2004, 2005). According to this model, an emotion contains a subjective feeling component, a physiological arousal component, and a motoric component. With these definitions we hope to avoid definitional and conceptual shortcomings which have recently been criticised in the field of music and emotion (Konečni, 2003).

Based on personal experience, we expected that goose bumps and shivers would occur in response to all kinds of stimuli. It was furthermore expected that chills might be of different valence, so the individual ratings were expected to differ. However, physiological correlates should be equal, since the sympathetic nervous system should always be activated when goose bumps or shivers really occur. Both the erection of hairs on the skin and the Skin Conductance Response (SCR – mostly based on changes in sweating and blood flow) are mediated by the peripheral nervous system, which does not react specifically for one type of reaction.

To summarize, the aim of this study was to compare chill reactions to different sensual domains in terms of frequency, subjective feeling response, and physiological arousal.

Methods

Pre-experiments

Prior to the main experiment, we performed two pre-experiments to select the stimuli and test the experimental setting. In the first pre-experiment, 11 participants reported their chill responses to a selection of 30 pictures, 45 sounds, and 35 music excerpts. The pictures were selected from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2001) according to the ratings reported in the manual. Pictures with extreme emotional ratings on the valence/arousal scale were preferred; however, pictures with extremely offensive content (e.g., dismembered bodies) were avoided. We aimed for inducing strong emotion, not trauma. The sounds were selected from different sources (see Table 2); unfortunately, we could not use the International Affective Digital Sound System (IADS), because the sounds of this collection were too short to elicit chills. The music excerpts were selected from previous studies (Grewe et al., 2007a, 2007b) in which they had shown to be effective in the induction of chills. Based on this pre-study, 23 stimuli from each category were chosen for the main experiment. The chosen stimuli are described in detail in the *stimuli* section below.

In the second pre-study, the experimental setting was tested. Further exploratory tactile and gustatory stimuli were tested on six participants. These stimuli are also described in more detail below. This second pre-experiment also guaranteed that all questionnaires were understood properly and that the experimental session was not too long (approximately 2hr).

Participants

In the main study 36 volunteers participated: 19 females and 17 males. The mean age was 29 (*SD* = 8, Range: 19–58 years). The group of participants consisted of 20 students and participants of other professions (e.g., a medical doctor, a software-developer, employees, etc.). About half of the participants (16) played one or more instrument(s). On a scale from 0 (no musical education) to 10 (professional musician), the participants reported a relatively low mean of musical education (mean = 2.7, *SD* = 2.9, Range: 0–10).

Stimuli

A total of 73 stimuli were presented: 23 pictures, 23 sounds, 23 musical excerpts, two tactile and two gustatory stimulations. The two tactile and gustatory stimulations were each repeated during the experiment, but all other stimuli were presented only once. Each picture from the IAPS collection was presented for 20 seconds, matching the duration of stimulation for all stimuli (see Table 1). Additionally, participants were asked to induce a chill without any stimulation by recalling chill-eliciting events or other associations.

The sounds are listed in Table 2. A selection of human, animal, nature, and technical sounds was created from different sources. We tried to include sounds of all four sectors of the 2-dimensional emotion space (2-DES, high-low valence, high-low arousal). To obtain a duration of 20 seconds for each stimulus, some sounds were repeated in loops or combined from different sources.

The musical stimuli were chosen based on the results of a previous study (Grewe et al., 2007b). That study had tested seven musical pieces chosen by the authors, and a large number of pieces selected by the participants – each participant brought in five to ten pieces for the experiment. The current study used a subset of the musical pieces that had been found to elicit chills in the previous study. The 20-second sound excerpts were chosen according to the musical structures which were shown to be effective in producing chills, (i.e., the entry of a voice and increasing volume). Most pieces were orchestral music (classical music, soundtracks), but stimuli also included a piece of pop music (‘Easy Lover’ by Phil Collins). The volume of sounds and music excerpts was normalized with the exception of ‘cat purr,’ ‘leaves,’ and ‘waves crashing,’ which would have been altered to unnatural and unpleasant loudness by normalization.

Table 1. Pictures from International Affective Picture System (IAPS)

	IAPS No.	Motive
1	1120	Snake
2	1300	Pitbull
3	1460	Cat
4	1710	Puppies
5	1750	Hares
6	1931	Shark
7	2050	Baby
8	2205	Hospital
9	2800	Child
10	3180	Injured woman
11	3230	Sick person
12	3530	Gun attack
13	4220	Woman/beach
14	5760	Lawn
15	5830	Sunset
16	6230	Pistol
17	6350	Knife attack
18	8030	Ski jump
19	8160	Mountain climber
20	8179	Bungee jump
21	8185	Parachute
22	8190	Skiing
23	9250	War victim

Table 2. Sounds

Short name	Description	Name on website	Website
Ape	screaming ape; loop	animals059.wav	http://grsites.com
Applause	a group of people giving applause; loop	applause_2.wav	http://www.pacdv.com
Baby happy	several happy baby sounds; loop	people006.wav / people131.wav / people133.wav	http://grsites.com
Baby crying	several sad baby sounds, crying, screaming; loop	people019.wav / people021.wav / people136.wav	http://grsites.com
Dog barking	barking dog	bellenderhund.mp3	http://www.hoerspielbox.de
Lion	Growling and hissing of big cats; loop	animals090.wav / puma.mp3	http://www.pacdv.com http://grsites.com /
Leaves	Rustling leaves	apark02.mp3	http://www.hoerspielbox.de
Dentist drill	Sounds of dentist drill	Dentist	Prof. Trevor Cox, Salford University's Acoustic Research Centre, http://www.sound101.org

(Continued)

Table 2. (Continued)

Short name	Description	Name on website	Website
Female screams	Fearful screams of various female voices	people089.wav / people090.wav / people148.wav / people149.wav	http://grsites.com
Female laughing	Laughing of several females	people039.wav / people040.wav / people041.wav	http://grsites.com
Female moaning	Different females moaning, erotic	People123.wav / People124.wav / People125.wav	http://grsites.com
Woman crying	Several crying and sobbing female voices	people033.wav / people034.wav / people035.wav / people036.wav	http://grsites.com
Cheer	Cheering crowd of people; loop	cheer.wav	http://www.pacdv.com
Cat meow	Cat meowing; loop	miau01.mp3	http://www.hoerspielbox.de
Cat purr	Cat purring	Katze_schnurrt.mp3	http://soundarchiv.com
Rattlesnake	Rattle of a rattlesnake	animals077.wav	http://grsites.com
Scratch	Scratching of a garden tool on metal		Halpern, Blake, & Hillenbrand (1986)
Man laughing	Several male voices laughing	laugh_1.wav / laugh_2.wav / laugh_3.wav / laugh_4.wav	http://www.pacdv.com
Crash of waves	Swoosh of crashing waves	gmeer01.mp3	http://www.hoerspielbox.de
Styropor on Glass	Scratching styropor on glass		Halpern/Kopiez
Fingernails on blackboard	Scratching of fingernails on a blackboard		Björn Katzur
Violin	A very bad version of "Für Elise" by Beethoven "played" on a violin	Violin	Prof. Trevor Cox, Salford University's Acoustic Research Centre, http://www.sound101.org
Worst scraping sound	Scratching of metal on metal	Worst Scraping Sound	Prof. Trevor Cox, Salford University's Acoustic Research Centre, http://www.sound101.org

For tactile stimulation a head massage device (Head Wizard™, from www.heavenstherapy.com) and a feather were used (see Figure 1). The feather was used to stimulate the neck of the participant with slow movements, while the massage device, moved gently up and down and in circles, was used on the head. Participants were informed and asked whether they agreed to this type of stimulation before the experiment began.

Table 3. Musical stimuli

Short Name	Composer	Title	Artist	Reference
The Hebrides	Felix Mendelssohn–Bartholdy	The Hebrides Overture, Op. 26, Fingals Cave	Bernard Haitink & London Philharmonic Orchestra	Philips Classic 467 077–2
Beethoven 1	Ludwig van Beethoven	Klavierkonzert No.5 in Es, Op. 73 Emperor II 2–3 Übergang	Claudio Arrau	Philips 456 709–
Brahms Viol./Cello	Johannes Brahms	Konz. Violine und Cello a-moll Op. 102, Allegro	Herbert von Karajan, Anne-Sophie Mutter & António Meneses	Deutsche Grammophon 439 007–2
Neun Pforten	Wojciech Kilar	The Ninth Gate (OST)–Opening Titles	Stepan Konicek & The City of Prague Philharmonic and Chorus	SSD 1103
Ben Hur	Miklos Rozsa	Ben Hur (OST)–Attack!	Miklos Rozsa & MG-M Studio Orchestra	Rhino Records, R2 72197
Cesar Franck	Cesar Franck	Orgelmusik Im Hohen Dom zu Passau–Choral Nr. 3 a-moll	Georges Athanasiades	Tudor 725
Medallion	Klaus Badelt and Hans Zimmer	Pirates of the Caribbean–The Curse of the Black Pearl (OST)– The Medallion Calls	Klaus Badelt	EMI 3532372
Four Seasons	Antonio Vivaldi	The Classic Composers Series - Vivaldi (Seasonal Romance)–The Four Seasons–Summer–Presto	H.-J. Walther und das Hamburger Kammerorchester	Pegasus (EAN: 5034504002326)
Forrest Gump	Alan Silvestri	Forrest Gump (OST)–Forrest Gump Suite	Alan Silvestri	Sony BMG 4769412
Cello Concerto	Edward Elgar	Cello Concerto in E minor, Op. 85 –Adagio–Moderato	Giuseppe Sinopoli und Mischa Maisky	CD 445 511–2 GMA
Lohengrin	Richard Wagner	Lohengrin–Overtüre	Sir Georg Solti und die Wiener Philharmoniker	Decca 421 053–2
Sibelius	Jean Sibelius	Konzert für Violine und Orchester d-moll, Op. 47–Allegro moderato	Kurt Masur, Thomas Zehetmair und das Gewandhausorchest-er Leipzig	TELDEC 8.43241 ZK

(Continued)

Table 3. (Continued)

Short Name	Composer	Title	Artist	Reference
Beethoven 2	Ludwig van Beethoven	Klavierkonzert No.5 in Es, Op. 73 Emperor II 2–3 Übergang	Claudio Arrau	Philips 456 709–2
Easy Lover	Phil Collins	Easy Lover	Phil Collins	WEA 3984–23795–2
Nimrod	Edward Elgar	Nimrod–Adagio	Sir Simon Rattle and the City of Birmingham Symphony Orchestra	EMI Classics CDC 5 55001 2
Albinoni	Tomaso Albinoni	Classical Relaxation Vol.1–10–Adagio in g-moll	unknown	Delta Music 015835
Brahms Quintet	Johannes Brahms	Brahms Quintet in b-moll, Op. 115–Allegro	unknown	EMI Classics Red Line
Confutatis	Wolfgang Amadeus Mozart	Requiem KV 626–Confutatis	Chor und Orchester der MHH	Non-professional recording
Lacrimosa 1	Wolfgang Amadeus Mozart	Requiem KV 626–Lacrimosa	Chor und Orchester der MHH	Non-professional recording
Lacrimosa 2	Wolfgang Amadeus Mozart	Requiem KV 626–Lacrimosa	Chor und Orchester der MHH	Non-professional recording
Tuba Mirum	Wolfgang Amadeus Mozart	Requiem KV 626–Tuba Mirum	Herbert von Karajan and the Wiener Philharmoniker	Deutsche Grammophon B00005MJ17
Barbossa	Klaus Badelt und Hans Zimmer	Pirates of the Caribbean–The Curse of the Black Pearl (OST)–Barbossa Is Hungry	Klaus Badelt	EMI 3532372
Nabucco	Guiseppe Verdi	Nabucco–Ouverture	Guiseppe Sinopoli	Deutsche Grammophon B000001G4N

Finally, two sour juices were used as gustatory stimuli: grapefruit and lemon. The lemon juice had a pH of 3, the grapefruit juice was less sour (pH 5). Both tactile and gustatory stimuli where intended as a first exploratory approach. These stimuli were chosen because they showed a capacity to induce chills in a few pre-experiments – they were not intended to cover the whole range of possible emotion-inducing tactile and gustatory stimulations. Tactile and gustatory

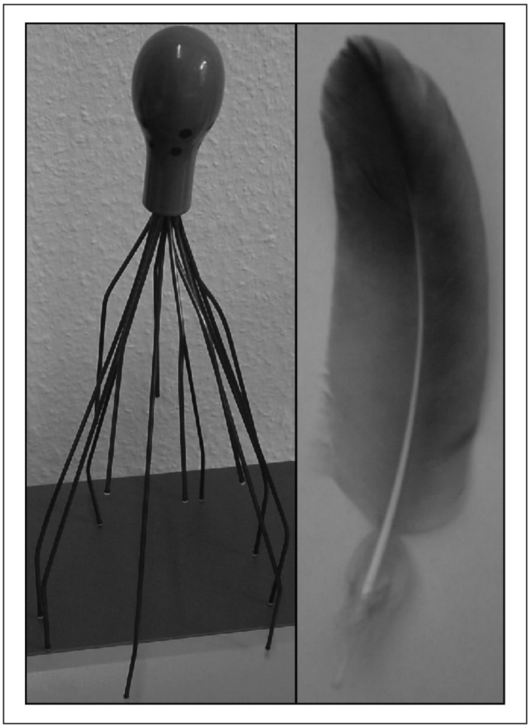

Figure 1. Head massage device and feather used for tactile stimulation

stimulation could not be precisely standardized to 20-second stimulation. However, stimulation was limited to approximately 20 seconds.

Procedure

All experiments were performed in individual sessions. After welcoming the participants, the researcher gave them a questionnaire regarding demographic data and musical preferences. The belts for measuring heart rate and breathing rate, as well as the electrodes for skin conductance measurement, were explained. The heart belt was then placed on the thorax by the participants themselves; the breathing belt was put around the abdomen. Participants sat in a comfortable armchair in front of a computer screen. The electrodes for SCR measurement were placed on the index and middle finger of the nonactive hand, the ground electrode on the palm of the other hand. Participant and researcher were separated during the experiment by a room divider, in order to protect the privacy of participants without leaving them alone in the room.

Participants answered the first questionnaire (see Questionnaires section). Then, a one-minute baseline was recorded, while they relaxed. All stimuli were presented for 20 seconds after a 10-second baseline. After each stimulus, an additional 5 seconds were recorded to assess delayed reactions. Thus, each trial took 35 seconds. Pictures, sounds, and musical excerpts were presented in randomized order in three blocks. Items were not blocked by category. Each participant received different orders of items in the three randomized blocks. The exploratory tactile stimuli were presented before each block and after the last block as follows: participants were stimulated twice with the head massage device and twice with the feather. The feather or massage device was chosen at random. Stimulation lasted 20 seconds after a 10-second baseline. After that, the experimental setting was explained in a standardized manner. Participants were asked to press the button of a computer mouse whenever they perceived a chill during a stimulus. Chills were explained as goose bumps or shivers down the spine. After stimulation, participants were asked to answer the second questionnaire (see Questionnaires section), which had been explained in detail before the experiment was started. To ensure that all participants had the same information and could recall all explanations during the whole session, they were given a written summary of the instructions which they could read when necessary throughout the session.

As a last control measurement prior to the experiment, participants were asked to press the mouse button at random to control for a possible influence of the motor action on the physiological parameters.

The gustatory stimuli were presented after the main experiment. Participants were asked to drink 50 ml of grapefruit juice in one swallow from an open glass. Thus, both smell and taste could influence chill reactions. After the grapefruit juice, the participants drank a bit of water, and then they were asked to drink 10 ml of lemon juice in one swallow. At the moment the juices reached the lips of the participant, the researcher sent a trigger signal. The gustatory test was the only condition in which the participants could not use the mouse button to indicate chills, since they had to hold the glass with one hand. Thus, chills were reported retrospectively in this condition.

The last test was the 'imagination' condition. Participants tried to evoke a chill by recalling emotional events or other thoughts without any external stimulation. If no chill was reported by the subject after 10 minutes, the trial was stopped. After the imagination task, the experiment ended.

Questionnaires

Participants answered four questionnaires developed by researchers. While the first and fourth questionnaires were printed on paper, the second and third questionnaires were both presented on the computer screen. The first questionnaire consisted of a participation agreement and questions about demographic data. The second questionnaire, from here on called 'PreChill,' asked for musical education and preferences, as well as a self-judged sensitivity for chills and alertness. Answers were given using sliders on scales from 0–10 (accuracy .1) or by choosing from a list of possible answers (multiple answers possible). The first two questionnaires were answered before the experiment started.

The third questionnaire, 'SubChill,' was answered after each stimulus. SubChill asked for familiarity with the stimulus, perceived valence, arousal, and chills. Participants could report pleasantness and intensity of perceived chills. Additionally, they identified where on their bodies a chill occurred and what feature of the stimulus they thought elicited the chill.

The last questionnaire asked whether chills in response to different stimuli were perceived differently, and what categories participants would use to describe them (startle/surprise, personal recollection, feeling of coldness, increased attention, others). Multiple responses were possible.

Data analysis

Skin conductance data. When recording the Skin Conductance Level (SCL, tonic part), we measured the absolute values of individual skin conductance which depend on many factors, such as the moisture level of the skin, temperature, and blood flow. As a standard procedure, the high pass filtered SCL and the SCR (Skin Conductance Response, phase part) were calculated (Boucsein, 2001).

Heart rate. Cubic interpolation was used to calculate the heart rate from single recorded heart beats. Because the individual heart rates are often on a different level, heart rate was normalized by subtracting the mean baseline heart rate prior to each stimulus. Due to this normalization, data were more robust for all individual long-term influences.

Breathing rate. The extension of the breath belt was filtered from 1668 Hz to 0.5 Hz. By calculating the differentiation of the raw data, the maxima of inspiration could be determined. Breathing rate corresponds to the distance of these peaks. If breathing rates less or more than 10–18 breaths per minute (brpm), or extremes lower than 8 brpm or higher than 30 brpm, resulted (Fox, Schmidt, & Henderson, 2000), data were controlled visually and corrected. The breathing rate was normalized in the same way as the heart rate. Here, the 1-minute baseline before the experiment was used as a reference, since the 10-second baseline did not provide enough data to calculate a breathing rate.

Statistical tests. Wilcoxon tests were used to test for differences between sensory domains. Linear relations between selected features of the stimuli were tested using Pearson correlations. Lines of best fit were calculated using the robuster function of Matlab 7.1.

Comparing chill excerpts and non-chill excerpts. In order to compare the subject-reported and physiological data of chills, we collected chill excerpts from all data. The term *chill excerpt* refers to the data collection of the SCR, SCL, HR and breathing excerpt for the subject-reported chill incident. The idea behind the collection of chill excerpts was that strong individual emotional reactions may differ as to the point in time in which they occur. Previous studies have shown that chills cannot be 'triggered' in a simple stimulus–response manner (Grewe et al., 2007b; Guhn et al., 2007). Thus, the perception of a chill was used as an indicator for individual peak experiences, independent of the distinct musical event that elicited the reported chill. For each reported chill, the corresponding events in SCR, SCL, HR, and breathing were cut out in 10-second windows, beginning 5 seconds before the chill onset. For each reported chill, a corresponding non-chill excerpt from the physiological data of the same participant was cut out. These non-chill excerpts were randomly collected from periods of the same piece in which no chill was reported. Chills reported in the first 10 seconds of a piece were not collected because the physiological data would have been influenced by the orientation response (Sokolov, 1990) elicited by the beginning of the stimulus.

Since participants reported different numbers of chills, we calculated the averages of the data (Intensity, SCR, HR, breathing) of all chill excerpts for each participant. Thus, in the analysis, each participant was included with his or her average subjective intensity and physiological chill response. Means of reported chill excerpts were compared with non-chill excerpts. Data of HR and SCL were normalized according to their average starting points (baselines) in order to avoid influences of the individual variety in heart rate and skin conductance level. The physiological data of reported chill excerpts were compared with a random permutation test. To test for the significance of differences between the excerpts, a permutation test with 5000 random permutations was performed for each set of data (Good, 1994). This nonparametric test compared two data sets based on two matrices. For each permutation, elements of the two matrices

Table 4. Frequency of reported chills

Sensory domain	Minimum		Median	Maximum	
	No. of reacting participants	Stimuli	No. of reacting participants	No. of reacting participants	Stimuli
Pictures	1	1460, Cat 1710, Puppies 5760, Lawn	4	10	2800 (child)
Sounds	3	Man laughing	12	24	Fingernails on blackboard
Music	6	Easy Lover	12	16	Cello concerto Four Seasons
Tactile	22	Feather		31	Head massage
Gustatory	9	Grapefruit		16	Lemon
Imagination	17				

were randomly distributed on two new matrices. For instance, if a matrix of chills consisted of the datasets A1, A2, A3 and the matrix of the non-chill control consisted of the datasets B1, B2, B3, a possible random permutation would be B4, A7, B8 vs. A3, A9, B11. The test compared the differences between the averages of the chill and non-chill matrix. When less than 5 per cent of the random permutations resulted in a bigger difference, the test became significant. To estimate the strength of effect, the Cohens *d* value was calculated for the most extreme difference between both curves. A Cohens *d* of 0.2 was interpreted as a weak effect, a value of 0.5 as a medium effect, and of 0.8 and higher as a strong effect.

Results

Frequency of reported chills

Stimuli from all sensory domains were able to elicit chill reports in at least one participant (see Table 4). The most successful domain was the tactile stimulation with a maximum of 31 out of 36 participants reporting a chill. The two sour juices, which were tested as exploratory stimuli, resulted in chill reports from 25% ($n = 9$) of the participants. Pictures seem to be the least successful stimuli in chill induction. Even the most emotional stimuli from the IAPS generated chill reports from just 10 participants. Sounds and music excerpts were equally successful, both eliciting chill reports from one-third of the participants on average. However, sounds showed a larger deviation in effectiveness among participants.

Subjective ratings of stimuli

Average of subjective ratings of domains. Participants rated their emotional reactions to every stimulus on valence and arousal scales (–5 to 5). The average ratings are presented separately for (a) pictures, sounds, music, and (b) tactile, gustatory, and 'mind' chills (chills elicited in the imagination task), since the exploratory stimuli were not sufficient for statistical analysis. Music was rated highest on the valence scale with a median of 2.3, differing significantly from sounds with a median of –1.7 ($Z = -5.23$, $p < .001$) and pictures with a median of 0 ($Z = -5.23$,

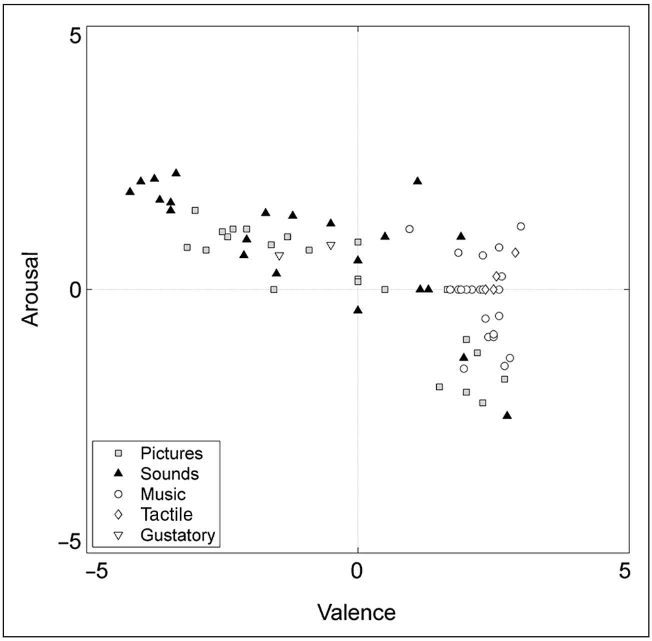

Figure 2. Overview of all stimuli relative to the emotion ratings

$p < .001$). Sounds and pictures also differed significantly in valence ratings (Z = –4.17, $p < .001$). On the arousal scale sounds rated highest with a median of 1.1, differing significantly from music (median 0, Z = –3.41, $p < .001$) and pictures (median 0, Z = –3.92, $p < .001$). Music and pictures did not differ in arousal.

Tactile stimuli reached the highest average ratings for valence (median 2.8, 4.4 upper quartile, –0.2 lower quartile), while gustatory stimuli were rated –0.7 on valence (1.3 upper quartile, –2.5 lower quartile). Both tactile and gustatory stimuli were perceived with medium arousal (both median 0.4). Tactile and gustatory stimuli had extremely heterogeneous ratings. Arousal ratings of tactile stimulation had an upper quartile of 1.3 and a lower quartile of –1.3, while arousal ratings of gustatory stimuli varied between an upper quartile of 1.8 and a lower quartile of 0.

Subjective ratings of individual stimuli. Figure 2 gives an overview of the ratings of all stimuli. Not all quadrants of the 2-DES could be covered with the stimuli. None of the stimuli elicited low valence/low arousal feelings, even if, according to the IAPS ratings, at least some of the pictures were expected to cover this quadrant. Most quadrants were covered by the sound stimuli, which elicited feelings of positive and negative arousal and positive and negative valence. Music was perceived as positive only for both high and low arousal. The exploratory stimuli were perceived as neutral or high on arousal. The two gustatory stimuli elicited negative feelings; the tactile stimulation induced positive valence.

Subjective perception of chill eliciting stimuli. The frequency of reported chills depending on the subjective perception of stimuli is presented in Figure 3. Valence of sounds correlated negatively with reported chill frequency ($r = –0.74$, $p < .001$) and positively with arousal ($r = 0.52$, $p < .05$). Reported chills in response to pictures showed a similar relation to feeling ratings:

valence correlated negatively with reported chill frequency ($r = -0.73$, $p < .001$), arousal showed a positive correlation ($r = 0.71$, $p < .001$). Reported chills in response to music, however, showed a different relation. For music, valence was correlated positively to reported chill frequency ($r = 0.65$, $p < .001$). For arousal, no relation to the frequency of reported chills was found ($r = 0.08$, $p > .05$). For the exploratory stimuli, no correlations could be calculated, since there were not enough stimuli. Chills in response to pictures were mostly described using the category 'startle/surprise,' chills in response to sounds by the category 'personal recollection,' and chills in response to music by the category 'increased attention.'

Physiology of reported chills in response to different domains

In contrast to the subjective feeling responses, physiological correlates of chills in response to different domains are rather homogeneous (see Figure 4). Reported chills in response to pictures, sounds, music and tactile stimulation all led to an increase in SCR initiating approximately one second after the reported chill. These increases differed significantly from a control (excerpts from the same participants reacting to the same type of stimuli without perceiving a chill; random permutation test with 5000 permutations, $p < 0.05$). The increase for tactile stimulation was much higher compared to all other domains. Sounds and tactile stimulation showed an additional difference in heart rate between reported chills and controls. For the breathing rate, no significant differences could be stated. A control experiment examined the physiological responses elicited by pressing a button in the absence of any reported of chill: no physiological differences were evident between these button presses and the control excerpts.

'Mind' chills

As a surprising result, 17 participants reported chills without any external stimulus, by only recalling emotional events. These 'mind' chills were reported by participants as varying extremely widely in both valence and arousal, with ratings reaching from −5 to 5 on both scales. When the physiological correlates of these reported chills were compared to random excerpts, only a significant difference in heart rate about three seconds prior to the reported chills was found. Differences in SCR were not significant, even if a clear increase in SCR after the reported chill could be stated.

Discussion

Chills (frisson reported as goose bumps or shivers) in response to different sensory domains were compared regarding their emotional meaning and physiological correlates. The observations reported suggest that chills can be induced by a variety of stimuli via several sensory modes, including music, sounds, pictures, tactile, and gustatory stimulation. Interestingly, chills were reported even without any external stimuli when participants recalled strong emotional events of both negative and positive valence. It seems important to note here that the comparison of absolute numbers of chills elicited by the sensory domains should be interpreted with caution. Music stimuli could be preselected regarding their effectiveness while the other stimuli were exploratory. Interestingly, despite this sounds elicited more chills compared to preselected music. Familiarity with a stimulus was shown to be an important factor (Panksepp, 1995) for chill stimulation. Furthermore, acoustical features as well as referential meaning of single stimuli could not be taken into account in this exploratory study. The stimuli

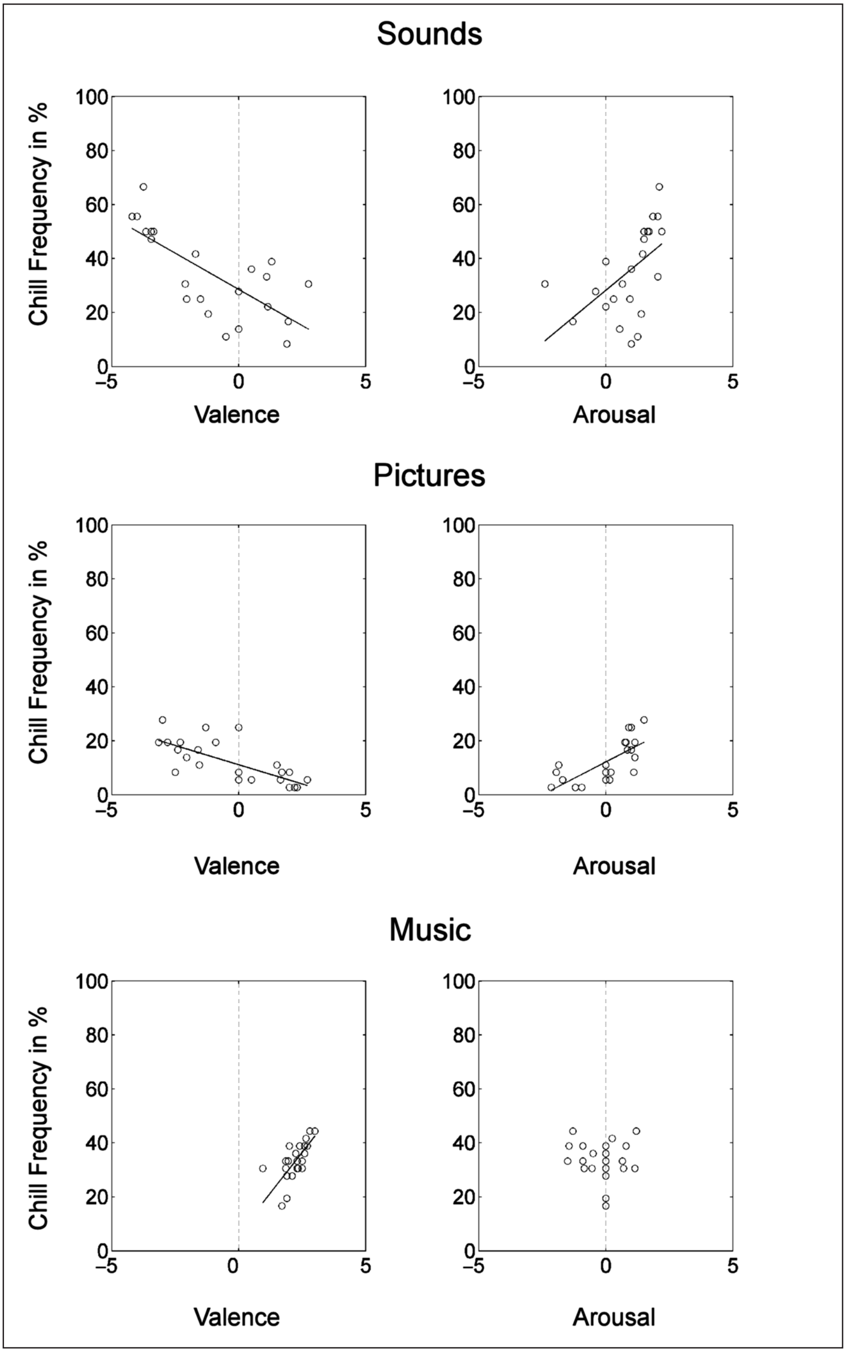

Figure 3. Frequency of reported chills relative to emotion ratings

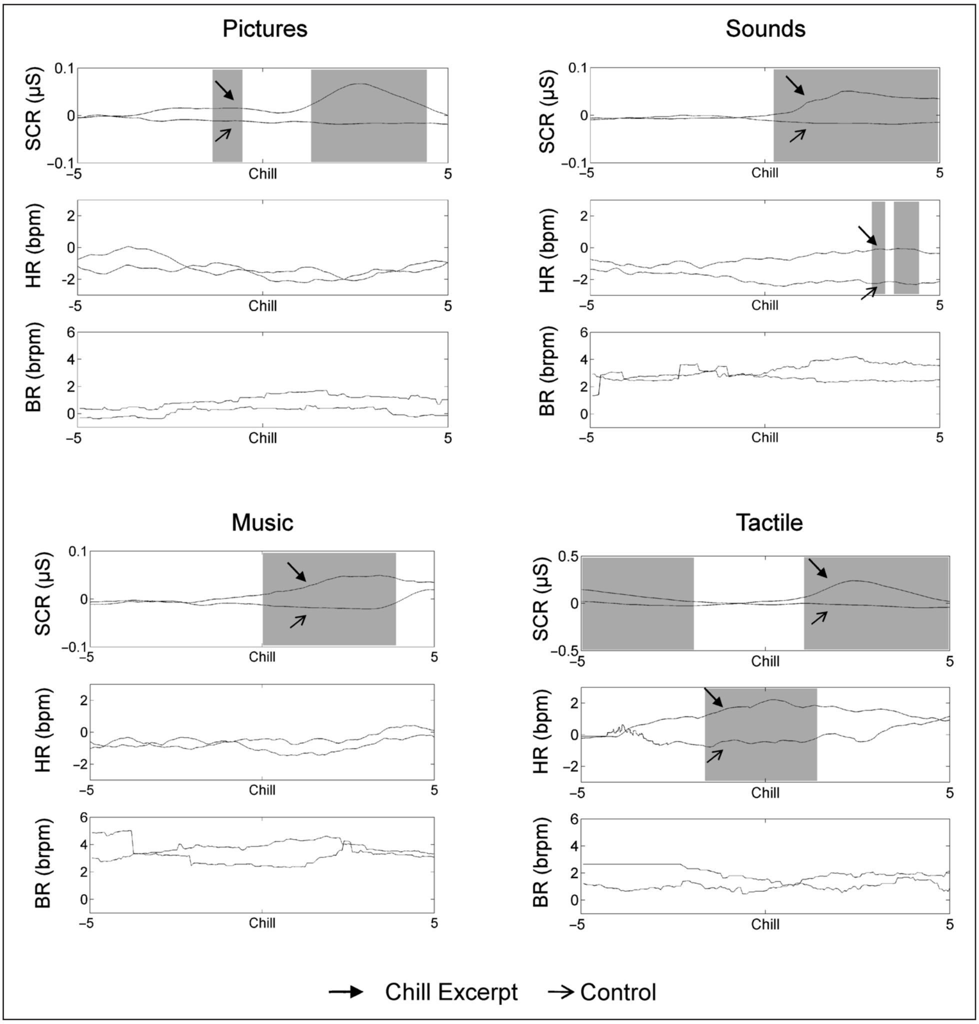

Figure 4. Physiological responses to different domains of stimulation

representing the sensory domains were chosen to cover the complete emotion space (positive/negative valence and arousal). However, only the IAPS provided a previously evaluated stimulus set. Thus, the absolute differences in chill induction between the sensory domains can only be interpreted as tendencies.

Physiological correlates of chills

The skin conductance response during reported chill episodes was similar for all sensory domains, and seemed to not be influenced by breathing or the mere pressing of the button. For tactile stimulation, the SCR was much higher compared to all other sensory domains, which might be an artefact of the different number of stimuli for the exploratory tactile stimulation, and should thus not be over-interpreted. As expected, the reported chill response was associated with an activation of the sympathetic nervous system, indicated by the skin conductance response (Boucsein, 2001). Only tactile and sound chills showed a correlate in heart rate. Accordingly, sounds were rated higher in arousal compared to music and pictures. Since skin conductance responses have a highly individual delay in the range of seconds, the minimal temporal differences between the reactions in different sensory domains cannot be interpreted. Only 'mind' chills showed no physiological correlate in SCR in contrast to the control excerpts. Since the control SCR during the mind chills task also showed activation, it might be argued that participants were excited during the whole mind task. This is plausible, since they actively recalled emotional events. We could speculate that when there is an external stimulus, the time preceding the stimulus might be less arousing. During the mind condition, participants stimulated themselves constantly. Thus, there is no 'off' modus before the reported chill.

Chills and subjective feeling

While sounds and pictures elicited more reported chills when they were negative and arousing, frequency of chill reports showed a positive correlation to valence and no clear relation to arousal. This suggests that goose bumps and shivers are neither specific sensory responses nor specific emotional responses, but rather they are nonspecific physiological phenomena. However, chills are actually related to feelings, since they seem to increase in response to stimuli with extreme emotional content (Grewe, Kopiez, & Altenmüller, 2009). The studies by Goldstein (1980) and Blood and Zatorre (2001) suggested the relation of chills in response to music to pleasurable feelings, which could be confirmed by the results of this study. The selection of music excerpts was based on their effectiveness at producing chills in a previous study which tested many kinds of different musical styles. All music excerpts were perceived as positive; thus we cannot rule out that music excerpts might also induce negative chills. However, the majority of chills in response to music seem to indicate very positive emotions. In contrast, most chills in response to sounds and pictures seem to indicate negative feelings. We conclude from these results that chills are not an emotion themselves, but they can be used as an indicator of a strong positive or negative emotion. The affective quality of the emotion indicated by a chill must be confirmed by the participant. The mere physiological response of piloerection (goose bumps) might be interpreted as nothing other than some kind of over-stimulation of the periphery nervous system. This stimulation can have several reasons, one of which seems to be a strong emotional response. That chills can be elicited without any external stimulus suggests that cognitive activity alone may be sufficient to lead to chills.

What possible advantage might result from using chills as an indicator of strong emotion, when this reaction has to be confirmed and specified by self-report anyway? First of all, chills denote a specific event in time. When, for example, music is used to induce emotions, a self-report of the emotional perception of the music covers the complete duration of the stimulus. Emotions are defined as relatively short events, in contrast to moods (e.g., Merten, 2003). There are techniques which allow a continuous rating of feelings over time (Schubert, 2001, 2004). However, chills in response to music indicate a climax in feeling intensity and physiological response (Blood & Zatorre, 2001; Grewe, Kopiez, & Altenmüller, 2009; Nagel et al., 2008). As has been stated previously, so far the perception of chills is the only known reaction to combine a strong subjective feeling with a physiological peak response. Furthermore, they are easy to explain to and to be reported by participants. As an event, they have a clear beginning and end; participants can easily report the beginning of a chill, while they may have difficulties indicating the exact beginning of a strong feeling.

Perhaps the most important advantage of using chills is their ability to indicate individual peak responses. The induction of strong positive emotions is jeopardized by many difficulties. While negative emotions seem to be triggered more easily and homogeneously, positive emotions are strongly influenced by individual factors, such as tastes, associations, and personal ethical standards. Studies which take these individual factors into consideration are often difficult to compare with other studies (e.g., Gabrielsson & Lindström, 1993, 2003). In our current study we show that chills can be elicited by mere cognitive activity without any external stimulus. We have already suggested that in the case of musical chills, the individual appreciation is the basis for this strong aesthetic response (Grewe et al., 2007b). Individual cognitive appreciation is unlikely to happen in a stimulus–response like manner. Here chills might offer the opportunity of locating individual peak experiences, independent of the exact physical event which elicited them. If it is true that the listener's appreciation and not an acoustic trigger is the cause of a pleasant chill, then chills might be a highly interesting tool to track these aesthetic responses. That the appreciation of music is often not explicit, but intuitive, makes chills even more interesting: implicit appreciation based on unconscious mechanisms can rarely be measured using analytic self-report.

Clearly, having a strong emotion does not always equate with perceiving a chill. However, chills are one interesting possibility to individualize strong emotional reactions for further analysis when they are conscientiously combined with other methods of emotion psychology, such as retrospective self-report and physiological measurements. In principle they can be used in all sensory domains.

Considering these results, one might raise the question of whether chills should be associated with one specific musical trigger or with an evolutionary cause. Chills might occur in many different circumstances, some of which are related to strong emotions, such as fight and flight reactions, aesthetic awe or social loss. We would like to suggest that chills need to be used in combination with other emotion measurements. Accordingly, they could provide some interesting opportunities which, depending on the experimental setting, might offer new information in the complex and developing field of emotion research.

References

Blood, A.J., & Zatorre, R.J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences*, *98*(20), 11818–11823.

Boucsein, W. (2001). Physiologische Grundlagen und Meßmethoden der dermalen Aktivität [Physiological basics and methods of measurement of dermal activity.]. In F. Rösler (Ed.), *Bereich Psychophysiologie* (Vol. 1, pp. 551–623). Göttingen: Hogrefe.

Breiter, H.C., Gollub, R.L., Weisskoff, R.M., Kennedy, D.N., Makris, N., Berke, J.D., et al. (1997). Acute effects of cocaine on human brain activity and emotion. *Neuron*, *19*(3), 591–611.

Craig, D.G. (2005). An exploratory study of physiological changes during "chills" induced by music. *Musicae Scientiae*, *IX*(2), 273–287.

Fox, N., Schmidt, L., & Henderson, H. (2000). Developmental psychophysiology. Conceptual and methodological perspectives. In J.T. Cacioppo, L.G. Tassinary & G.G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 665–686). New York: Cambridge University Press.

Gabrielsson, A., & Lindström, S. (1993). On strong experiences of music. *Musik Psychologie*, *10*, 118–139.

Gabrielsson, A., & Lindström, S. (2003). Strong experiences to music: A descriptive system. *Musicae Scientiae*, *VII*(2), 157–217.

Goldstein, A. (1980). Thrills in response to music and other stimuli. *Physiological Psychology*, *8*(1), 126–129.

Gomez, P., & Danuser, B. (2004). Affective and physiological responses to environmental noises and music. *International Journal of Psychophysiology*, *53*, 91–103.

Good, P. (1994). *Permutation tests: A practical guide to resampling methods for testing hypotheses.* New York: Springer.

Grewe, O., Kopiez, R., & Altenmüller, E. (2009). The chill parameter: Goose bumps and shivers as promising measures in emotion research. *Music Perception*, *27*(1), 61–74.

Grewe, O., Kopiez, R., & Altenmüller, E. (2009). Chills as an indicator of individual emotional peaks. *Annals Of the New York Academy of Sciences*, *1169*, 351–354.

Grewe, O., Nagel, F., Kopiez, R., & Altenmüller, E. (2005). How does music arouse "chills"? Investigating strong emotions, combining psychological, physiological, and psychoacoustical methods. *Annals Of the New York Academy of Sciences*, *1060*, 446–449.

Grewe, O., Nagel, F., Kopiez, R., & Altenmüller, E. (2007a). Emotions over time: Synchronicity and development of subjective, physiological, and facial affective reactions to music. *Emotion*, *7*(4), 774–788.

Grewe, O., Nagel, F., Kopiez, R., & Altenmüller, E. (2007b). Listening to music as a re-creative process: Physiological, psychological and psychoacoustical correlates of chills and strong emotions. *Music Perception*, *24*(3), 297–314.

Guhn, M., Hamm, A., & Zentner, M. (2007). Physiological and musico-acoustic correlates of the chill response. *Music Perception*, *24*(5), 473–483.

Halpern, D.L., Blake, R., & Hillenbrand, J. (1986). Psychoacoustics of a chilling sound. *Perception & Psychophysics*, 39(2), 77–80.

Huron, D. (2004). *Sweet anticipation: Music and the psychology of expectation.* Cambridge, MA: MIT Press.

Konečni, V. J. (2003). Review of P.N. Juslin and J.A. Sloboda (Eds.), Music and emotion: Theory and research. *Music Perception*, *20*(3), 332–341.

Konečni, V.J. (2005). The aesthetic trinity: Awe, being moved, thrills. *Bulletin of Psychology and the Arts*, *5*, 27–44.

Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (2001). *International Affective Picture System: Instruction manual and affective rating* (No. Technical report A-5): NIMH Center for the Study of Attention and Emotion; The Center for Research in Psychophysiology; University of Florida.

McCrae, R.R. (2007). Aesthetic chills as a universal marker of openness to experience. *Motivation and Emotion*, *31*(1), 5–11.

Merten, J. (2003). *Einführung in die Emotionspsychologie* [Introduction to emotion psychology]. Stuttgart: Kohlhammer.

Nagel, F., Kopiez, R., Grewe, O., & Altenmüller, E. (2008). Psychoacoustical correlates of musically induced chills. *Musicae Scientiae*, *XII*(1), 101–113.

Panksepp, J. (1995). The emotional sources of "chills" induced by music. *Music Perception*, *13*, 171–207.

Panksepp, J., & Bernatzky, G. (2002). Emotional sounds and the brain: The neuro-affective foundations of musical appreciation. *Behavioural Processes*, *60*, 133–155.

Rickard, N.S. (2004). Intense emotional responses to music: A test of the physiological arousal hypothesis. *Psychology of Music*, *32*(4), 371–388.

Sander, D., Grandjean, D., & Scherer, K.R. (2005). A systems approach to appraisal mechanisms in emotion. *Neural Networks*, *18*, 317–352.

Scherer, K.R. (2004). Which emotions can be induced by music? What are the underlying mechanisms? And how can we measure them? *Journal of New Music Research*, *33*(3), 239–251.

Scherer, K.R. (2005). What are emotions? And how can they be measured? *Social Science Information*, *44*(4), 695–729.

Schubert, E. (2001). Continuous measurement of self-report emotional response to music. In P.N. Juslin & J.A. Sloboda (Eds.), *Music and emotion: Theory and research* (pp. 393–414). Oxford: Oxford University Press.

Schubert, E. (2004). Modelling perceived emotion with continuous musical features. *Music perception*, *21*(4), 561–585.
Sloboda, J. (1991). Music structure and emotional response: Some empirical findings. *Psychology of Music*, *19*, 110–120.
Sokolov, E.N. (1990). The orienting response, and future directions of its development. *Pavlovian Journal of Biological Science*, *25*, 142–150.

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