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Psychoacoustical correlates of musically induced chills

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• **ABSTRACT**

Music listening is often accompanied by the experience of emotions, sometimes even by so-called "strong experiences of music" (SEMs). SEMs can include such pleasurable reactions as shivers down the spine or goose pimples, which are referred to as "chills". In the present study, the role of psychoacoustical features was investigated with respect to the experience of chills. Psychoacoustical parameters of short musical segments (total duration: 20 s), characterized as chill-inducing, were analyzed and compared with musical excerpts which did not induce chill responses. A significant increase of loudness in the frequency range between 8 and 18 Bark (920-4400 Hz) was found in those excerpts for which chills were reported. Frequency-dependent changes of loudness seem to play an important role in the induction of chills.

Keywords: emotion, music, psychoacoustics, chill.

Listening to music can be accompanied by so-called "strong experiences of music" (SEMs) (Gabrielsson, 2001; Gabrielsson & Wik, 2003). These SEMs manifest themselves in physical sensations, such as a lump in the throat, moist eyes, tachycardia, piloerection (the goose pimple reaction), and shivers down the spine. Such physical sensations are called chills, and an initial systematic approach to their phenomenology was made by Sloboda (1991) using a two-step survey study. More than 100 participants were first asked to indicate score sections which induced strong psychophysiological experiences of music. Then these sections were classified, allowing Sloboda to find a limited number of physiological responses related to those chills, such as shivers down the spine, increased heart rate, lump in the throat, or piloerection. In our study, we defined chills as goose pimples and/or shivers down the spine in response to emotionally powerful music. For us, chills are usually very pleasurable for the listener (see Goldstein, 1980; Panksepp, 1995).

The defintion of emotion used in this study is based on the component process model by Scherer (2004). According to this model, emotions consist of a subjective feeling component, a physiological arousal component, and a motor component. Chills provide an interesting phenomenon for emotion research, because they seem to combine an intense subjective feeling experience with measurable physiological arousal (*e.g.*, piloerection caused by activity of the peripheral nervous system). In a neurophysiological PET study, Blood & Zatorre (2001) showed that subjective reports of chill reactions are related to the activation of particular brain regions (*e.g.*, the ventral striatum, midbrain, amygdala, orbitofrontal cortex, and ventral medial prefrontal cortex) which contribute to the neurophysiological reward system. This system is stimulated, for example, by sexual activities or drug abuse. Thus, chills are an indicator of exceptionally pleasurable experiences elicited by music. These strong reactions to music depend on various factors, such as musical expertise, familiarity with musical style, gender, and psychoacoustical features of the stimulus (for an overview see Juslin & Sloboda, 2002).

Chill reactions seem to be determined by individual variables, such as familiarity with the particular piece or musical style and the personal musical preference (Grewe, Nagel, Kopiez & Altenmüller, 2007). Additionally, there is evidence for the influence of structural factors (*i.e.*, the onset of a solo voice or a change in volume or melody) and psychoacoustical features on the experience of chills. This finding is supported by Sloboda's (1991) earlier results, which showed that musical structures, such as the "harmony descending cycle of fifths to tonic," melodic appoggiaturas, and melodic or harmonic sequences can induce chills. With respect to goose pimples and shivers, Sloboda emphasized the role of unexpected harmonic changes and sudden dynamic and temporal changes.

However, it is not yet clear which psychoacoustical parameters of music could be relevant for the experience of chills. In our study, we considered the following psychoacoustical calculated parameters: loudness, roughness, and tone-to-noise ratio. These parameters were chosen for two reasons: First, according to Zwicker & Fastl's (1999) model of sensory pleasantness, these parameters seem to influence the pleasantness of sounds. Second, all of these are psychoacoustical parameters for which algorithms are available. However, we had to bear in mind that even unpleasant sounds can cause goose pimple reactions. For example, Halpern (1986) played unpleasant sounds—for instance, the scratching of fingernails on a blackboard—to participants and found that a decrease of the loudness of the lower frequencies (< 4 kHz) made an unpleasant sound more comfortable. Thus, the author concluded that frequencies below 4 kHz appear to play an important role in producing (uncomfortable) chills that accompany unpleasant sounds.

Rationale and hypotheses of the study

The rationale of this study was to investigate the role of psychoacoustical factors in the induction of chills. The study followed the hypothesis that the selected psychoacoustical features differ between music in which chills (frequently) occur and music that does not produce chills. However, it is important to note that the present design of the study is "correlational" and "post hoc," and, thus, results are not based on a systematical manipulation of parameters.

Method and Material

Stimuli and participants

Musical examples were obtained from an extended experiment. In this study the psychophysiological and psychological correlates of chills were investigated (Grewe, Nagel, Kopiez & Altenmüller, 2007). A group of 38 participants (age: M = 38; SD = 16; range: 11-72 years; 9 males, 29 females) brought along their favourite musical pieces which could be expected to arouse chills in them. Participants listened to their own music and to seven pre-selected musical pieces. They reported chills by pressing a mouse button during listening to the music. Five of the pre-selected musical pieces and most of the participants' favourite musical pieces were instrumental music. Sections of 20 seconds length (10 seconds before and after the time of a reported chill onset) were extracted for psychoacoustical analysis. The musical excerpts used for psychoacoustical analysis came from four sources: The first source is called C (chill excerpts from chill pieces; 190 excerpts). The features of this group of samples were compared with those of the other three groups of samples. In group NC (non-chills sections from chill pieces; 195 excerpts), clippings of 20 seconds' length were taken from the same musical pieces as in C, but from randomly selected sections not overlapping with chill onsets. In group NN (random excerpts from non-chill pieces; 195 excerpts), sections were taken from those musical pieces that were also brought in as participants' favourite music but which did not produce chills. In group PRE (pre-selected pieces with chills; 69 excerpts), the excerpts of chill-inducing sections from the standard set of 7 pre-selected musical pieces were also considered. An overview of the different groups of stimuli used in this experiment is shown in Table 1.

Psychoacoustical analysis

The parameters loudness and roughness were psychoacoustically analyzed using the formulas described in Zwicker & Fastl (1999). The calculation was done using the software dBSONIC (2003). Additionally, tone-to-noise ratio (TNR) was calculated with the same software. The musical excerpts were not normalized either before they were presented or before the calculation was carried out. The normalization was

Table 1

Description of 4 different sources of music stimuli (C, PRE, NC, NN) used for psychoacoustical analysis

Source	C	PRE	NC	NN
Chill excerpts from chill producing pieces (participants' favourite music with reported chills)	Reported chill 10 seconds before and after a chill event (190 excerpts)		Random excerpts (195 excerpts)	
Non-chill sections from chill producing pieces (participants' favourite music without reported chills)				Random excerpts (195 excerpts)
Pre-selected music pieces with chills		Reported chill 10 seconds before and after a chill event (69 excerpts)		

omitted because the excerpts were parts of entire musical works with naturally changing characteristics during the pieces. The following section contains a short explanation of the applied algorithms:

Loudness [sone] (see Zwicker & Fastl, 1999, 204-238) was calculated according to ISO 532 B. The calculation was done for the frequency range of 20 Bark, corresponding to a range between 0 and 6420 Hz (as determined by the software). Loudness can be understood as weighted decibels [dB(A)] of the signal. The weighting transforms amplitude information to account for some of the nonlinearities in the human perception of amplitude; 1 sone corresponds to a 1 kHz sinusoid at 40 dB(A). The software-parameters are listed in Table 2.

Roughness [asper] was calculated according to the method used by Zwicker & Fastl (1999, 257-264). Roughness measures the surface characteristics of sounds (the modulation strength). It is defined as the mean difference from a mean frequency; 1 asper is defined by a 60 dB 1 kHz sinusoid modulated 100% in amplitude at 70 Hz. Roughness time series were sampled down to 5 Hz. The parameters are listed in Table 2.

Tone-to-noise ratio (TNR) [tu] was calculated according to the E DIN 45681-2002 (1 tu [tonality unit] = 1 kHz sinusoid at 60 dB. TNR is commonly used to measure the tonality of stationary sounds. It is defined as the ratio of the power of a tone to the power of the critical band centred on that tone (excluding the tone power). This parameter was chosen as a measure for the density of events in a given time window.

Table 2

Parameters and options used in the software dBSONIC (2003) for calculation of loudness, roughness, and tone to noise ratio

Psychoacoustic parameters	
Sound field:	free field
Loudness time interval:	2 ms
Roughness time interval:	100 ms
Roughness block length:	500 ms
Tone-to-noise ratio method:	DIN 45681-E (2002)
Time interval:	20000 ms
Frequency resolution:	2.7 Hz
FFT window overlap:	50 %
Calculated frames:	1
Fourier spectrum:	A-weighted

Results and Discussion

The selected psychoacoustical parameters in the four groups of stimuli were averaged over time and summed up over the critical band range of 20 Bark. Musical pieces in which chills were reported (group C) showed a significant increase in loudness and roughness and a reduced TNR compared with those excerpts without chills (group NC; Kruskal-Wallis test for all three parameters, $p < .01$, see Figure 1).

However, data in group PRE (pre-selected pieces which elicited chills) did not match this result. This is most likely due to the fact that chills occurred in only four of the seven pre-selected musical pieces. The data of group PRE, therefore, have much less variance compared with the groups C, NC and NN, in which most samples were taken from various musical pieces.

The decreased TNR and increased roughness might be interpreted as an indirect measurement of the density of events in the musical pieces included in our study. Roughness is the result of multiple sounds played together with small differences in

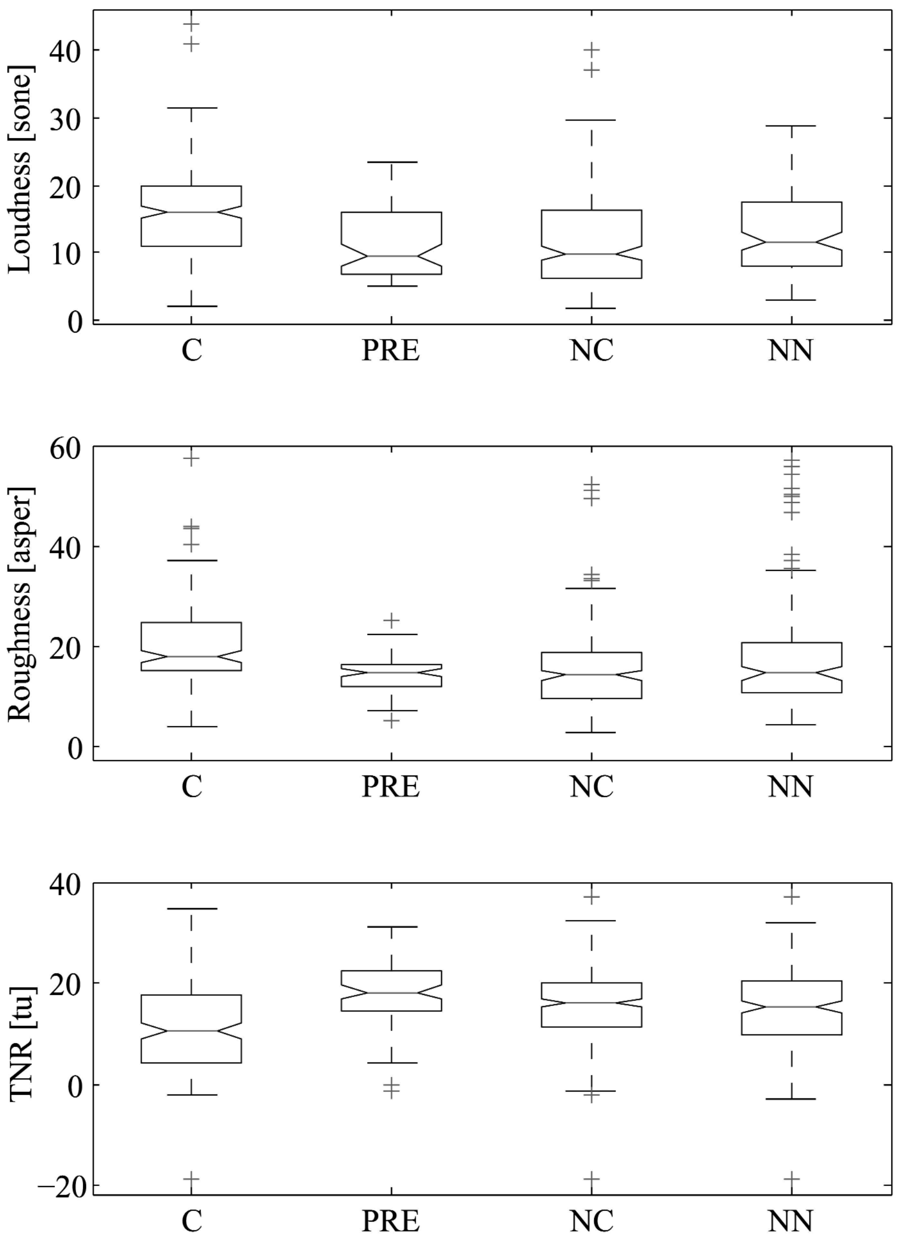

Figure 1.

Boxplots of the time-averaged loudness-, roughness-, and TNR-data of the musical pieces from the four groups C (chill excerpts from chill pieces), PRE (chill excerpts from pre-selected pieces), NC (non-chill excerpts from chill pieces), and NN (non-chill excerpts from non-chill pieces). Parameters in C differ significantly from those of the other groups.

frequency. Such a situation occurs when many instruments play at the same time, when many notes are played in short time spans, or when the instruments playing are not tuned. The resulting sensation appears, however, to be perceived by the listener as pleasant or, at the very least, as chill-producing. The same accumulation of musical events leads to a decreased TNR.

The time series of psychoacoustical changes were also analyzed. In addition to the increased mean of loudness in group C (participants' favourite pieces with chill experience), an increase of loudness could be observed around the onset of the self-reported chills (see Figure 2). Trend-removed loudness curves were averaged across each time point (time resolution was 5 Hz). For statistical analysis, the averaged data were sampled down to five data points for the entire segment length (20 s), with each point covering a time-span of four seconds. A Kruskal-Wallis test reached significance for the vicinity around $t = 0$ s for groups C and PRE ($p < .001$). A post-hoc Scheffé test confirmed that loudness in C and PRE significantly increased at $t = 0$ s ($p < .001$). The course of changing loudness reached its maximum at about $t = 1.5$ s after the self-report of chills ($t = 0$ s).

This increase of loudness is not equally distributed over all frequencies, and there is a prominent increase between the frequency bands of 8 and 18 Bark (920-4400 Hz). Figure 3 shows the surface plots of the parameter loudness for the

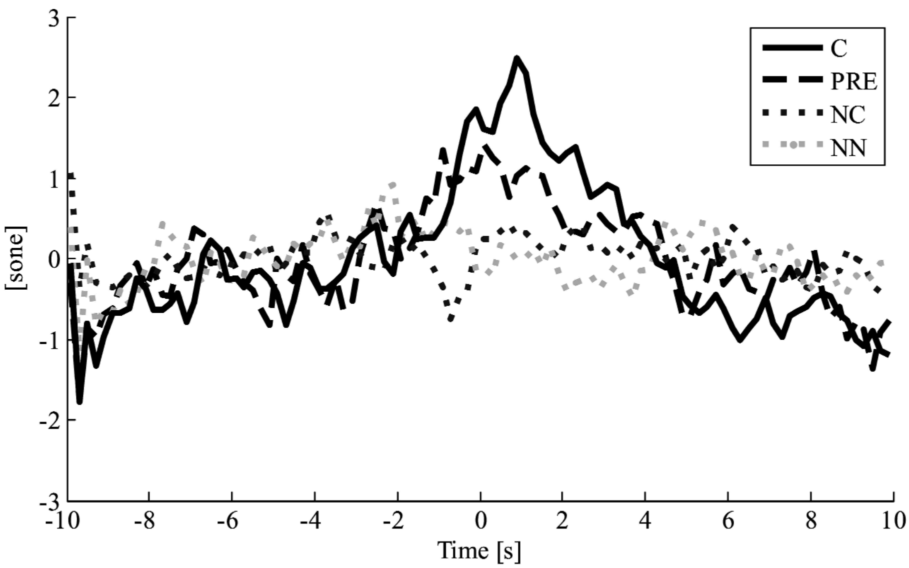

Figure 2.

Time-series of trend-removed mean of loudness. A significant increase can be seen at about t = 1.5 seconds after chill onset in the data of C (chill excerpts from chill pieces) and PRE (chill excerpts from pre-selected pieces).

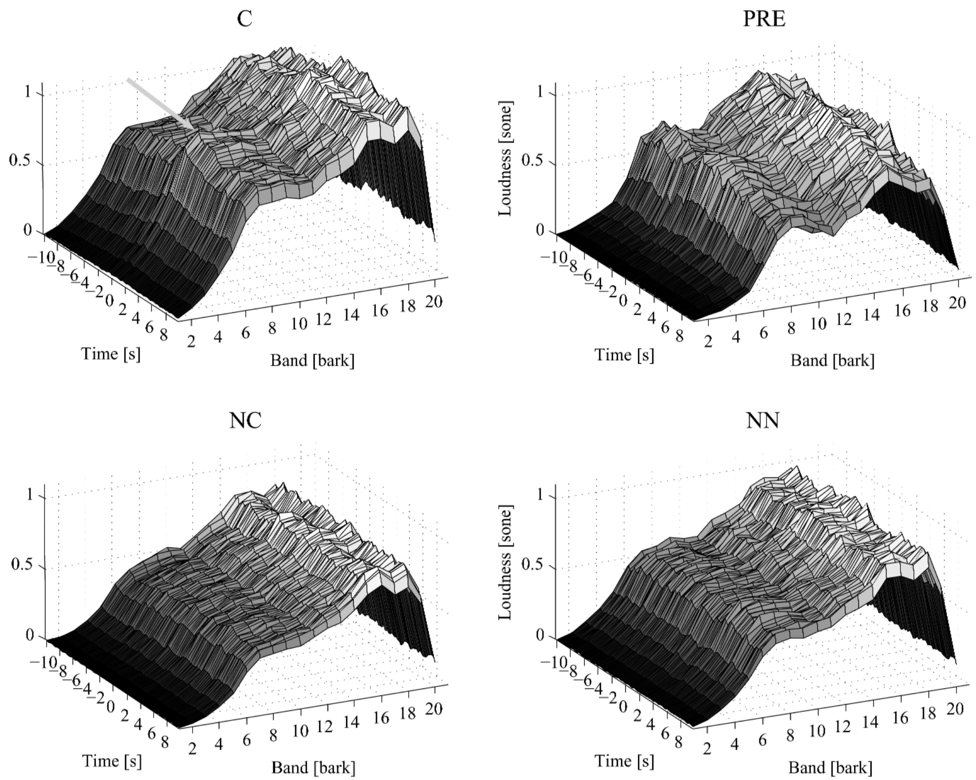

Figure 3.

Spectral analysis of the loudness courses for the four groups of stimuli. The increase is prominent in groups C (chill excerpts from chill pieces) and PRE (chill excerpts from pre-selected pieces) within the range of 8 to 18 Bark (indicated by arrow for group C).

stimulus groups C, PRE, NC and NN. An arrow indicates the salient increase in group C (chill excerpts from chill pieces). To emphasize the increased loudness after a chill onset, a difference diagram of the loudness data of groups C and NC was calculated (Figure 4). Both groups are supposed to have similar distributions of specific loudness since they are taken from the same musical pieces, even if C is somewhat louder on average than NC. The increase in C cannot be found in the group of NC, thus underscoring the increase in the range of 8 to 18 Bark. However, the increase in the vicinity of 8-18 Bark is the same frequency range to which the human ear is most sensitive.

Halpern (1986) found that frequencies lower than 4 kHz play an important role in producing (uncomfortable) chill reactions to unpleasant sounds, such as fingernails scratching on a blackboard. A similar frequency range might be important

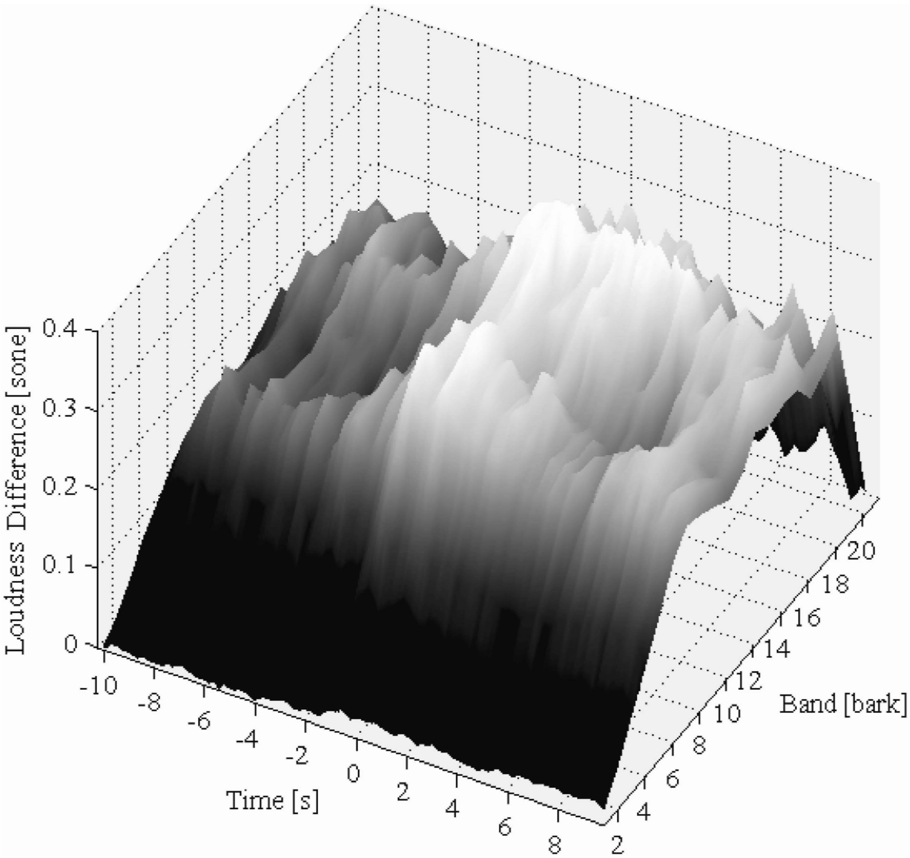

Figure 4.

Difference plot of the spectral analyses for C (chill excerpts from chill pieces) and NC (non-chill excerpts from chill pieces) in order to emphasize the increase in the range between 8 to 18 Bark.

for producing pleasant chills. Further experiments should clarify the difference between these two types of reactions towards sounds. We also found a significant increase in loudness before and after chill onsets. However, the question as to why an increase in loudness is related to the chill phenomenon is hard to answer. In general, an increase in loudness indicates that an object requires more attention as it comes nearer. Moreover, the accumulation of musical events leading to an increase in loudness could be perceived by listeners as pleasurable. We do not assume that there is a stereotypical, uniform relationship between psychoacoustics and emotional experience in terms of a simple stimulus-response reaction. In other words, it seems likely that increasing loudness triggers chills, but the mean loudness level when chills are experienced is also an important factor.

Conclusions and Outlook

Psychoacoustical features seem to play an important role in the emotional experiences of chills. Increasing and decreasing loudness between 8 and 18 Bark appears to influence the probability that chills will be experienced by participants. A systematical variation of this parameter should be done in a follow-up experiment.

Finally, there is a need for a sophisticated and standardized way to parameterize elements, such as melody, harmony, and tempo. Such a standardized method could be used to study the influence of the latter structural features on the development of loudness in music. A thorough understanding of the impact of music on listeners' perception of chills should consider both aspects.

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• Correlaciones psicoacústicas de los escalofríos inducidos musicalmente

La escucha musical es con frecuencia acompañada por la experiencia de emociones, a veces incluso por las denominadas "fuertes experiencias de música" (SEMs). SEMs pueden incluir reacciones placenteras tales como escalofríos en la columna o "carne de gallina", que son descritos como "escalofríos". En el presente estudio, se investiga el papel de hechos psicoacústicos respecto a la experiencia de esos "escalofríos". Parámetros psicoacústicos de segmentos musicales breves (con una duración total de 20 segundos) caracterizados por inducir al escalofrío, se analizaron y se compararon con fragmentos musicales que no inducían a respuestas con escalofrío. Se encontró un incremento significativo de volumen en el rango de frecuencias entre 8 y 18 Bark (920-4400 Hz) en los fragmentos que producían escalofríos. Los cambios de volumen vinculados a la frecuencia parecen jugar un papel importante en la inducción de escalofríos.

• Correlati psicoacustici dei brividi indotti dalla musica

L'ascolto musicale è spesso accompagnato dall'esperienza di emozioni, talvolta perfino dalle cosiddette "forti esperienze musicali" (*strong experiences of music*, SEMs). Le SEMs possono includere reazioni piacevoli come brividi lungo la schiena o pelle d'oca, che vengono indicati come "brividi". Nel presente studio, si è indagato il ruolo degli aspetti piscoacustici in relazione all'esperienza dei brividi. I parametri psicoacustici di brevi segmenti musicali (durata totale: 20 secondi), caratterizzati come induttori di brividi, sono stati analizzati e confrontati con estratti musicali che non inducevano reazioni di brividi. Si è riscontrato un significativo aumento di sonorità nell'ambito di frequenze compreso fra 8 e 18 Bark (920-4400 Hz) in quegli estratti per i quali si erano registrati i brividi. Cambi di sonorità dipendenti dalla frequenza sembrano rivestire un ruolo importante nell'induzione di brividi.

• Corrélats psychoacoustiques de frissons induits par la musique

L'écoute de la musique s'accompagne souvent d'émotions et parfois même ce que l'on appelle « strong experiences of music » ou SEM (de fortes expériences à l'écoute de la musique). Les SEM peuvent induire des réactions agréables comme des frémissements ou de la chair de poule, que l'on appelle des « frissons ». Dans notre travail, nous avons étudié le rôle de caractéristiques psychoacoustiques en liaison avec ces frissons. Nous avons analysé les paramètres psychoacoustiques de courts fragments de musique, dont la durée totale était de 20 secondes et qui pouvaient induire des frissons, et les avons comparés avec des extraits de musiques qui n'induisaient pas de tels frissons. On a trouvé que dans les extraits qui induisaient des frissons, il y avait une augmentation significative de volume, dans la gamme de fréquence entre 8 et 18 Bark (920-4400 Hz). Il semble que les changements de volume liés à la fréquence jouent un rôle important dans l'induction de ces frissons.

• Psychoakustische Korrelate musikinduzierter Chillerlebnisse

Musikhören wird oft als emotional empfunden und manchmal sogar von sehr starken, auch körperlichen Reaktionen begleitet, die als „strong experiences of music“ (SEM) bezeichnet werden. Eine besonders angenehme SEM ist der „Chill“, der eine Gänsehaut oder einen Schauer, der über den Rücken läuft, bezeichnet. Die vorliegende Studie untersucht die Bedeutung psychoakustischer Merkmale von Musik für das Erleben von Chills. Musikausschnitte von je 20 s Länge, welche vorher als chillinduzierend charakterisiert worden waren, wurden hinsichtlich psychoakustischer Parameter analysiert und mit nicht-Chill induzierenden Ausschnitten verglichen. Im Frequenzbereich von 8 bis 18 Bark (920-4400 Hz) zeigte sich ein signifikanter Lautheitsanstieg in den von Chills begleiteten Musikstücken. Frequenzabhängige Lautheitsänderungen scheinen demnach eine wichtige Rolle bei der Chillinduzierung zu spielen.