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Physiological correlates and emotional specificity of human piloerection

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ABSTRACT

Piloerection is known as an indicator of strong emotional experiences. However, little is known about the physiological and emotional specificity of this psychophysiological response. In the presented study, piloerection was elicited by audio stimuli taken from music and film episodes. The physiological response accompanying the incidence of piloerection was recorded with respect to electrodermal, cardiovascular and respiratory measures and compared to a matched control condition. The employment of an optical recording system allowed for a direct and objective assessment of visible piloerection. The occurrence of piloerection was primarily accompanied by an increase of phasic electrodermal activity and increased respiration depth as compared to a matched control condition. This physiological response pattern is discussed in the context of dominant theories of human piloerection. Consideration of all available evidence suggests that emotional piloerection represents a valuable indicator of the state of being moved or touched.

1. Introduction

According to most recent theories, human emotion is intrinsically tied to the concomitant activity of the autonomic nervous system. Empirical research has put forth an increasing number of indicators of physiological activity which are considered to be relevant for discriminating between specific subtypes of emotions (for a review, see Kreibig, 2010). One physiological indicator related to strong emotional experience is piloerection. In Charles Darwin's seminal work on "*The Expression of the Emotions in Man and Animals*" (1872), he already acknowledged that "hardly any expressive movement is so general as the involuntary erection of the hairs, feathers and other dermal appendages" (p. 95).

Piloerection, on the one hand, is known as a response to cold as a primary physical elicitor. In animals, the erection of coat hair or feathers serves to increase the isolation layer of air around the body. In humans, piloerection in response to cold is considered as a relic of the thermoregulatory response of our furred ancestors in evolution (Campbell, 1996). On the other hand, piloerection is also known as a response to strong psychological elicitors. In animals, it can be observed in states of anger or anxiety (Darwin, 1872), but it was also observed in the course of courtship of male chimpanzees (Nishida, 1997). In humans, the study of emotional piloerection (i.e., goose bumps) is tightly linked to the study of chills or thrills. While piloerection actually denotes the visible erection of body hair, the phenomenon of chills or thrills usually relates to a subjective experience. This subjective experience is sometimes described by the sensation of 'shivers down the spine' and it was found to be a necessary but not sufficient concomitant of visible piloerection (Craig, 2005). However, it should be noted that *piloerection* and *chills* are sometimes also found to be used interchangeably in the scientific literature.

According to self-report data, the most common psychological elicitors of piloerection or chills are moving music passages, or scenes in movies, plays or books (Goldstein, 1980). Other typical elicitors involve great beauty in nature or art, seeing or reading something heroic, nostalgic moments or physical contact with other persons. In empirical research, most attention has been drawn to chills or piloerection in response to music (e.g., Grewe et al., 2005; Panksepp, 1995; Zatorre, 2005). Some musical structures were identified to trigger chills more frequently than others. These structures involve crescendos, the violation of expectations (e.g., by unexpected harmonies), and the entry of a solo voice, a choir or an additional instrument (Grewe et al., 2007b; Guhn et al., 2007; Nagel et al., 2008; Panksepp, 1995; Sloboda, 1991). These effects are assumed to require active listening which involves directed attention and processes of cognitive appraisal (Grewe et al., 2007b). As a more general effect, familiar music pieces are reported to be more powerful in eliciting chills or piloerection than unfamiliar ones (Craig, 2005; Grewe et al., 2007a; Panksepp, 1995).

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1.1. Psychophysiological correlates of subjectively reported piloerection

Music is also the most common stimulus in the study of psychophysiological correlates of piloerection-evoking experiences. Rickard (2004) compared emotionally powerful music (i.e., individually selected moving and personally meaningful music) to arousing music (i.e., music preselected to elicit high subjective and physiological arousal). He showed that emotionally powerful music elicited more subjective responses of chills and higher skin conductance level (SCL), whereas the conditions did not differ significantly with respect to heart rate (HR) or skin temperature (ST). Craig (2005) found that music sections containing reports of chills were associated with higher skin conductance response (SCR) amplitudes than sections preceding or following chills, but not with changes in ST. Guhn et al. (2007) identified music passages apt to elicit chill responses and found that participants who actually reported experiencing chills showed higher SCR amplitudes than those who did not; the groups did however not differ with respect to HR. Grewe et al. (2009) found that music episodes which elicited subjective reports of chills were associated with increases in SCR amplitude, SCL, and HR but with no difference in respiratory rate (RR). In a similar study, Salimpoor et al. (2009) showed that music episodes which elicited subjective reports of chills resulted in higher SCL, HR, RR, and lower blood volume pulse amplitude and ST as compared to matched neutral episodes. In a positron emission tomography (PET) study, subject-selected music, which reliably elicited subjective reports of chills, was compared to music that elicited chills in others (Blood and Zatorre, 2001). Chill music was associated with higher HR and RR but with no significant difference in electrodermal measures or ST. Moreover, cerebral blood flow related to chill intensity showed a pattern typical for processes involved in reward, euphoria and arousal, including ventral striatum, midbrain, amygdala, orbitofrontal cortex, and ventral medial prefrontal cortex.

Summing up, there is evidence that the experience of chills is associated with increases in electrodermal activity, HR and RR. These results, however, are faced with the methodological concern that some of the physiological responses associated with chills (e.g., SCR) might be due to experimental procedures which commonly require participants to indicate chill experiences by motor responses (e.g., pressing a button or raising a finger).

1.2. Hypotheses on the origin of emotional piloerection

Emotionally arousing experiences are commonly accompanied by increased physiological arousal. Even within a stimulus, some specific physiological indicators are found to systematically co-vary with emotional intensity over time (e.g., Guhn et al., 2007; Chapados and Levitin, 2008; Salimpoor et al., 2009). Studies involving such detailed time analyses revealed evidence that the occurrence of self-reported chills or piloerection is related to peaks in emotional and physiological arousal (Rickard, 2004; Guhn et al., 2007; Grewe et al., 2007a, 2009). It thus was concluded that chills or piloerection may be useful indicators which mark individual peaks in emotional arousal. That is, when emotional arousal surpasses a certain threshold, it may not only be accompanied by high physiological arousal, but also more specifically piloerection then is likely to occur. This line of interpretation could be considered to constitute the *peak arousal hypothesis* of piloerection.

While in many studies the phenomenon of chills and piloerection is associated with highly pleasurable experiences (Goldstein, 1980; Blood and Zatorre, 2001), a different view was put forward by Panksepp (1995, 2003). In a series of thoughtful experiments he presented evidence that the experience of chills is rather related to the emotional quality of sadness than to pleasure or happiness. Moreover, he found that women experience chills more frequently and also judge chill-inducing music higher in sadness than men do. Based on this evidence he proposed an evolutionary explanation of piloerection. He argues that separation calls of lost young animals used to inform parents about the whereabouts of their offspring. These calls might have induced internal feelings of coldness and chills which enhanced the motivation for social reunion. A preserved responsivity to certain acoustical features (e.g., sustained high-frequency notes as often presented by solo performers) may represent an unconditional component of the chill response. This theoretical approach, which could be termed *separation call hypothesis*, thus relates piloerection to sensations of coldness and sadness.

1.3. Methodological issues

Although piloerection can be conceived as a psychophysiological response, its assessment, so far, used to rely on self-reports. Previous investigations commonly requested participants to report on subjective experience of chills or piloerection by immediately pressing a button or raising a finger and maintaining this motor response as long as the sensation persisted. This method involves several issues which may reduce internal validity. First, this method relies on self-reports, and usually does not distinguish between the subjective sensation of chills and the objective phenomenon of visible piloerection (for an exception see Craig, 2005). Second, the need to immediately give motor responses to perceived onset and offset of piloerection is prone to cause unwanted physiological responses. Finally, this procedure requires the participants to monitor themselves continuously, which can be assumed to distract them from the actual stimulus and impede the experience of strong emotions. These issues lead researchers to claim that "[f]uture work must seek to use more objective measures to analyze this phenomenon" (Panksepp, 1995, p. 192). Recently, a method for the objective assessment of visible piloerection has been put forward (Benedek et al., 2010). An optical recording device is attached to the skin surface (e.g., the forearm), and the recordings from the skin are analyzed by means of spectral analysis. This method allows for continuously recording the intensity of piloerection without requiring any response by the participant.

1.4. Aims of the current study

This study aims at a better understanding of piloerection as a psychophysiological index of emotion. By means of the employment of an objective assessment method, a number of methodological as well as conceptual issues regarding the phenomenon of emotional piloerection shall be reconsidered. First, the relevant stimulus conditions leading to visible piloerection shall be studied focusing on the aspects of stimulus familiarity (unfamiliar vs. familiar), stimulus selection (pre-selected vs. self-selected), and stimulus type (music vs. film audio tracks). Second, the psychophysiological correlates of piloerection shall be established with respect to electrodermal, cardiovascular and respiratory measures. As the objective assessment method does not require interaction of the participant, this can be achieved without risking physiological biases or artifacts due to motor responses. Third, the gathered evidence shall be used to further examine the emotional specificity of emotional piloerection. At this, two dominant hypotheses on the origin of piloerection shall be tested: the *peak arousal hypothesis* and the *separation call hypothesis*.

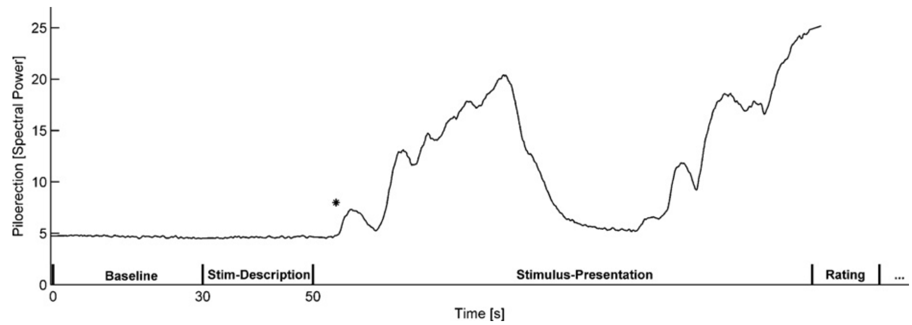

Fig. 1. A sample recording of relative piloerection intensity is depicted over the time course of a single trial including baseline period (30 s), stimulus description (20 s), stimulus presentation (variable duration) and rating (variable duration). The initial stable level of piloerection intensity indicates no visible piloerection. In this trial, piloerection occurs shortly after the onset of stimulus presentation; after some time it fades away, before it occurs for a second period of time. The asterisk marks the first detected onset of piloerection within this trial. This point in time is used for the analysis of the short-term physiological response.

2. Method

2.1. Participants

Fifty psychology students (43 females, 7 males) with a mean age of 21.9 years (*SD* = 3.0) participated in the current study in exchange for course credit. All participants gave written informed consent.

2.2. Materials

The stimulus pool contained 60 audio tracks, which were taken from 37 music pieces and 23 film clips. The stimuli were collected in the course of pilot studies, in which participants were asked to name pieces of music or film episodes that reliably elicited piloerection. Five pieces of music, which showed an excess length of more than 6 min, were cut down, keeping only the first 3 min including a fade-out. The duration of music pieces thus ranged from 90 s (Theme of Pirates of the Caribbean) to 309 s (The Scientist). The film clips were cut to a reasonable length, for which the meaning of the selected episode could be maintained. The film clips were converted to audio tracks including fade-in and fade-out. The duration of the film's audio tracks ranged from 41 s (Knocking on Heaven's Door) to 148 s (Dead Poets Society). A detailed list of all stimuli employed in this experiment can be found in Appendix.

For each stimulus, a short text description was prepared. For musical stimuli, these descriptions simply named the title and interpreter or composer; for the film episodes, it named the film title and briefly described the context of the episode using no more than 80 words. All stimuli were normalized to the same average root mean square (RMS) power, so that they featured equal average loudness.

2.3. Experimental task and procedure

Participants listened to eight different audio tracks, four music pieces and four audio tracks of film clips. Half of the stimuli of each category were pre-selected by the experimenter and half were self-selected by the participants. The pre-selected stimuli were chosen based on the most frequent nominations in pilot tests. The pre-selected audio tracks were "My heart will go on" performed by Celine Dion and "Only time" performed by Enya; the pre-selected film audio tracks were taken from Armageddon (an astronaut says goodbye to his daughter before he sacrifices himself heroically for the sake of mankind) and Braveheart (William Wallace encourages his suppressed fellows to fight against tyranny and re-conquer their long lost freedom). The *pre-selection* condition allows comparing responses to identical powerful stimuli across participants. The *self-selection* condition pays tribute to the assumption that self-selected stimuli, which account for individual preferences, are more powerful to elicit piloerection than pre-selected ones (Craig, 2005; Grewe et al., 2007a).

The experiment took place in a sound proof cabin. The average temperature in the cabin was 21.4 °C (*SD* = 1.8). The participants were shown the titles of the pre-selected stimuli and then they were asked to choose from a list of track titles two additional music tracks and two additional film audio tracks, for which they expected to experience piloerection most likely. Then they were seated in a chair with a neck-rest, with their non-dominant forearm placed on a soft armrest. After attachment of the physiological sensors, the participants were asked to find a comfortable position and to avoid any unnecessary movement during the stimulus presentation. During the experimental session, the experimenter sat outside of the cabin and monitored the stimulus presentation and the recorded physiological data.

The experiment was controlled by means of self-developed Matlab (The Mathworks, Natick, MA, USA) routines. The eight audio tracks were presented in randomized order. Each trial consisted of a 30-s rest period (i.e., baseline), followed by the presentation of the stimulus description (20-s), the stimulus presentation and a subsequent rating. In the rest period, a message on the PC screen informed the participants to sit and relax. After that, the stimulus description was presented on the screen. Then, the screen was blank and the presentation of the stimulus started. The stimuli were presented via closed Beyerdynamic DT 770 PRO headphones (Heilbronn, Germany) at an average sound pressure level (SPL) of 63 dB. After the stimulus presentation, various questions were presented on the screen. The participants were asked to rate the arousal (low–high) and valence (negative–positive) experienced during the stimulus on a 9-point SAM rating scale (Bradley and Lang, 1994). They were asked how moved they were by the stimulus on a 6-point scale (not moved–very moved). Finally, participants were asked to indicate whether they were familiar with the stimulus track, whether they had experienced chills, and whether they had experienced piloerection (all three questions employing binary format: yes–no). At this, participants were told that shivers down the spine and piloerection often may feel similar but that piloerection, in contrast to shivers down the spine, is defined by visible erection of hair. The sequence of one trial is depicted in Fig. 1, together with a sample record of piloerection taken from a responsive participant.

The experiment took in total about 60 min per participant. The procedure was approved by the Ethics Committee of the German Psychological Society.

2.4. Acquisition of physiological data

Continuous assessment of piloerection was carried out by means of an optical recording device, which captured video data from the unilaterally illuminated skin surface (Benedek et al., 2010). The recording device was attached to the dorsal forearm at the side of the non-dominant hand. The sampling rate was set to 10 Hz. For acquisition of the other physiological signals a 16-channel bioamplifier (Nexus-16; Mind Media B.V.; Roermond-Herten, The Netherlands) providing 24 Bit A/D-conversion and the recording software Biotrace (Mind Media B.V.) were used. A customer-specific SC sensor ensured the acquisition of raw, unfiltered SC data. The sensor maintained a voltage of less than 0.8 V between the two flat Ag–AgCl electrodes of 10 mm diameter placed at the medial phalanges of the digits III and IV of the non-dominant hand. According to common recommendations (Fowles et al., 1981), the electrodes were prepared with an isotonic paste (EC33, Grass Technologies). The recorded voltage reflects changes in skin resistance (SR). SC data was obtained by computing the reciprocal of SR. SC data was sampled at 32 Hz. Digital blood volume pulse was recorded via a photoplethysmograph placed on digit II of the non-dominant hand and sampled at 128 Hz. Respiration was assessed via a respiration belt placed on the chest. The respiration belt contained a piezoelectric sensor responsive to stretch and the data were sampled at 32 Hz.

2.5. Scoring of physiological data

2.5.1. Piloerection measure

The recorded video from the skin of the forearm was analyzed using the Matlab analysis software Gooselab V1.20 (www.goosecam.de). Gooselab essentially computes frame-by-frame two-dimensional discrete Fourier transforms, from which a continuous measure of the intensity of piloerection can be derived (Benedek et al., 2010). Based on the piloerection intensity data, onset and offset of piloerection were identified. The baseline activity was defined as the piloerection amplitude in the rest period (300 frames). Onset of piloerection was identified at the time when the measure exceeded a certain threshold, which was defined as the average baseline value plus three standard deviations of baseline values; the offset was identified at the time when the measure went below the threshold. Valid piloerection periods had to show above-threshold activity for at least one second.

2.5.2. Electrodermal measures

Skin conductance data was analyzed with the Matlab analysis software Ledalab V3.2.3 (www.ledalab.de) using the Continuous Decomposition Analysis (Benedek and Kaernbach, 2010a). This method returns the skin conductance level (SCL) as a continuous measure of tonic electrodermal activity (EDA), as well as the phasic driver underlying SC data as a continuous measure of phasic EDA. Both continuous measures were argued to be robust with respect to common artifacts. The phasic driver is the result of a multi-step deconvolution approach applied to SC data. The method is based upon a physiological model of the general SCR shape (Benedek and Kaernbach, 2010b), and aims at retrieving the activity properties of the underlying sudomotor nerve activity, in order to avoid underestimation biases due to overlapping responses. The integrated skin conductance response (ISCR), which is defined as the time integral of the phasic driver for a relevant time interval, then reflects the phasic EDA response to a given event or stimulus. To account for the typically skewed distribution of electrodermal response measures, the ISCR was standardized using the formula

$$\text{ISCR} = \log(1 + |\text{ISCR}|) \times \text{sign(ISCR)}$$

2.5.3. Cardiovascular measures

Heart rate (HR) and digital pulse volume amplitude (PVA) were derived from the blood volume pulse signal (Millasseau et al., 2000). The computation of HR is based on a peak detection algorithm implemented in the recording software Biotrace. The signal was checked for outliers (instantaneous HR increase > 6 bpm) and corrected by means of a local weighted-average interpolation. The PVA was defined as the amplitude from base to peak of single pulse waves. The computation of a linear spline function resulted in a robust continuous measure of PVA sampled at 32 Hz.

2.5.4. Respiratory measures

Peak detection was applied to the smoothed signal recorded from the respiration belt, and the detected peaks were edited for outliers (respiratory cycles < 0.5 s). Respiratory rate (RR) was defined as the number of peaks per minute. An uncalibrated index of respiratory depth (RD) was derived by computation of the amplitude from base to peak of single ventilator cycles (Lorig, 2007). The computation of a linear spline function resulted in a robust continuous measure for both respiratory parameters sampled at 32 Hz.

2.5.5. Scoring of the general physiological response to piloerection eliciting stimuli

The general physiological response to a stimulus was defined as the relative change of a physiological measure from the baseline to the subsequent stimulus. The corresponding reactivity scores for each physiological variable and each single trial were computed as follows: first, raw scores were defined as the arithmetic mean of the physiological data within each experimental condition (baseline period and stimulus period). Second, difference scores were computed by subtracting the baseline raw score from the stimulus raw score. Finally, the difference scores were normalized by means of division by the standard deviation of the data within the baseline period of the respective trial, which corresponds to a linear *z*-transformation. Initial analyses based on untransformed data revealed biases due to interindividual differences in the absolute level of difference scores. The application of a normalization procedure (*z*-transformation), therefore, represents a useful method to account for the individual differences in absolute physiological responsivity (e.g., Kreibig et al., 2007; Stemmler, 1989). Moreover, the normalization procedure is vital in face of the planned matching procedure (see Section 2.6), and it provides information on the effect size. A normalized reactivity score of 1 thus reflects an increase of one standard deviation from baseline of the respective measure in response to the stimulus.

2.5.6. Scoring of the short-term physiological response accompanying the onset of piloerection

The short-term response was analyzed for an extended response window ranging from 15 s before to 15 s after the first incidence of piloerection per trial (see asterisk in Fig. 1). To provide reliable scores at a reasonable temporal resolution, first, all physiological signals were down-sampled from 32 Hz to 1 Hz. Then, reactivity scores were computed for each data point within the response window (i.e., 30 scores) similar to the method described for the general physiological response. The baseline raw scores were defined as the arithmetic mean of the initial 5 s of the response windows (i.e., 15–10 s before piloerection onset). Difference score were then computed by subtracting the baseline raw score from the raw score of the respective data point in the response window. Finally, the difference scores were normalized by means of division by the standard deviation of the down-sampled data of the entire trial (i.e., baseline and stimulus period). A standardized reactivity score of 1 thus reflects an increase of one standard deviation from the initial baseline period of the respective measure to a specific point in time within the response window.

2.6. Matching of trials

In order to control for the effect of objective stimulus properties (i.e., stimulus duration, or sound level) on the physiological response, trials that elicited piloerection (*piloerection condition*) were to be matched with trials which involved the same audio track but which did not elicit piloerection in a different participant (matched control condition: *no-piloerection condition*). Moreover, the serial position within the presentation order of the matched track should also be as similar as possible.

Visible piloerection was obtained in 70 out of 400 trials (50 participants, 8 stimuli; see Section 3). All but one trial (98.6%) could be matched to non-piloerection-trials involving the same audio track. In 73.9% of the cases the matched tracks had exactly the same serial presentation position; in the remaining cases the serial position between the matched tracks differed by one (13.0%), two (7.3%), or up to five positions (5.8%). In this matching procedure trials were not used more than once, but the same participant could contribute different trials to both conditions. Finally, the *piloerection condition* consisted of 69 unique trials featuring piloerection, and the *no-piloerection condition* consisted of another 69 unique trials featuring the same audio track but no piloerection, thus finally exploiting 138 out 400 trials in a contrast of conditions.

2.7. Statistical analysis

2.7.1. Handling of missing data

In the case of missing data, trials as well as corresponding matched trials were excluded from further analysis. Considering the reactivity scores of the general physiological response, the percentage of missing data for single physiological variables ranged from 2.9% to 4.3% of trials, resulting in 63–65 valid pairs of trials. Considering the reactivity scores of the short-term physiological response, the percentage of missing data for single physiological variables (including missing data due to the case that the specified response window exceeded the recorded data) was 2.2% of trials for all physiological variables, resulting in 66 valid pairs of trials.

2.7.2. Analyses related to piloerection incidence

The piloerection incidence was analyzed for correlation with gender, stimulus selection (pre-selected vs. self-selected), stimulus type (music track vs. film audio track), and stimulus familiarity (unfamiliar vs. familiar) by means of χ^2-tests. Piloerection incidence was contrasted with the incidence of subjective reports on piloerection and chills. Finally, the *piloerection condition* was compared to the *no-piloerection condition* with respect to rated arousal, valence and extent of being moved.

2.7.3. Analysis of physiological parameters

The analysis of physiological parameters was calculated on standardized reactivity scores and always refers to the trials of the *piloerection* and *no-piloerection conditions*. For the analysis of the general physiological response, first, physiological parameters were analyzed for deviations from zero (significant increase or decrease) separately for both piloerection conditions by means of one-sample *t*-tests. In a second step, the physiological parameters were tested for univariate differences between the matched piloerection conditions by means of independent *t*-tests. For the analysis of the short-term physiological response, physiological parameters were analyzed for deviations from zero over the course of the response window separately for both piloerection conditions by means of one-sample *t*-tests. An alpha level of .05 was used for all statistical tests. For the latter analyses, which involve a large number of tests (30 *t*-tests per condition, which however need not be considered independent), the multiple-test Type I error rate inflation was accounted for by means of a sequentially rejective, ordered Bonferroni procedure (Simes, 1986). This method maintains that Type I error does not exceed the nominal alpha level while having a lower type II error probability as compared to the more conservative Bonferroni method, and it is considered especially advantageous in the case of correlated test statistics (Rosenthal and Rubin, 1984; Simes, 1986).

3. Results

3.1. Incidence of piloerection

The stimuli elicited visible piloerection in 40% of the participants. While piloerection was successfully evoked in nearly half of the female participants (47%), none of the small subsample of male participants showed piloerection in the course of the experiment. Women thus experienced visible piloerection more frequently than men ($\chi^2 = 5.43$, $p < .05$). The most responsive participants showed piloerection in seven out of eight trials (88%). The number of incidences of piloerection per trial ranged from one to nine with an average number of 2.87 (*SD* = 1.92). Interestingly, for 13% of the trials with visible piloerection, the first incidence was already detected in the phase of stimulus description, which is before the audio stimulus actually started.

Considering the total number of trials, piloerection occurred in 18% (i.e., 70 out of 400 trials). Within an experimental session, the ratio of piloerection incidences was correlated with the trial number ($r = .84$, $p < .01$), indicating that the probability of piloerection increased from the first trial (10%) to the last trial (24%). Pre-selected stimuli elicited piloerection equally often (17%) as self-selected stimuli (18%; $\chi^2 = 0.07$, *ns*), but film audio tracks significantly more often elicited piloerection (24%) than music tracks (11%, $\chi^2 = 11.71$, $p < .001$). Most tracks were familiar to the partici-

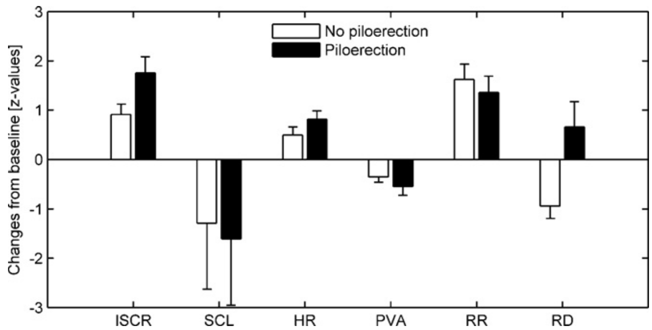

Fig. 2. General physiological response (standardized change from baseline to stimulus) of trials which elicited visible piloerection (dark bars) as compared to matched trials (no piloerection, light bars). Whiskers indicate the standard error of mean. ISCR: integrated skin conductance response, SCL: skin conductance level, HR: heart rate, PVA: pulse volume amplitude, RR: respiratory rate, RD: respiration depth.

pants (89%), which was especially true for the self-selected tracks (94%), but also for the pre-selected ones (83%). Familiar tracks elicited in 16% of the cases piloerection; interestingly, this ratio was significantly higher (33%) for the small amount of unfamiliar tracks ($\chi[1] = 8.80$, $p < .01$).

Subjective experiences of chills were reported to 61% of the stimuli. The incidence of chills experiences was generally higher than the incidence of objective visible piloerection. See Appendix for the complete track list including ratios of stimulus selection, chill experiences, and effective elicitation of piloerection.

The objective assessment of piloerection did not concur in all respects with the subjective reports. Participants reported to experience piloerection when no piloerection was detected in 11% of the trials. Moreover, in 6% of trials (i.e., 34% of piloerection trials), participants reported not to have experienced piloerection, although it was detected. In 88% of these misses, participants reported to have experienced chills. In total, 86% of trials with visible piloerection were also accompanied by the subjective experience of chills.

The subjective experience associated with the *piloerection condition* was compared to the matched *no-piloerection condition*. The experience in the piloerection condition was judged as equally arousing ($M = 4.15$, $SD = 2.33$; $t[61] = 0.78$, *ns*), more negative by trend ($M = 6.84$, $SD = 1.74$ vs. $M = 6.36$, $SD = 2.06$; $t[61] = 1.82$, $p = .07$), and significantly more moving ($M = 3.62$, $SD = 1.13$ vs. $M = 3.19$, $SD = 1.24$; $t[61] = 2.81$, $p < .01$) as compared to the matched control condition.

3.2. General physiological response to piloerection eliciting stimuli

Fig. 2 depicts the normalized change of electrodermal, cardiovascular, and respiratory measures for the piloerection condition as compared to the matched control condition (no piloerection). First, the general response direction (from baseline to stimulus) was analyzed separately for both conditions by means of one-sample *t*-tests. Tracks of both conditions (piloerection, and no-piloerection) largely elicited a similar physiological response relative to the baseline period. This response was characterized by an increase of phasic EDA (ISCR; $t[62] = 4.41$, $p < .001$; $t[62] = 5.32$, $p < .001$), no significant change in tonic EDA (SCL; $t[63] = -0.96$, *ns*; $t[63] = -1.16$, *ns*), an increase of heart rate (HR; $t[64] = 2.97$, $p < .01$; $t[64] = 4.93$, $p < .001$), a decrease of pulse volume amplitude (PVA; $t[64] = -5.29$, $p < .001$; $t[64] = -7.69$, $p < .001$) and an increase in respiration rate (RR; $t[62] = 5.23$, $p < .001$; $t[62] = 4.00$, $p < .001$). The conditions differed in the general response direction only with respect to respiration depth (RD). The *piloerection condition* showed a decrease in RD ($t[62] = -3.70$, $p < .001$), whereas the *no-piloerection condition* did not ($t[62] = 1.45$, *ns*).

In a second step, parameters of physiological reactivity were tested for differences between the *piloerection condition* and the matched *no-piloerection condition* by means of independent *t*-tests. At this, it could be shown that both conditions did not differ significantly in the baseline period used for computation of reactivity scores (ISCR: $t[62] = -0.19$, *ns*; SCL: $t[63] = -0.90$, *ns*; HR: $t[64] = 1.83$, *ns*; PVA: $t[64] = -0.32$; *ns*; RR: $t[64] = -1.11$, *ns*; RD: $t[62] = 0.43$, *ns*). The *piloerection condition* elicited stronger increases in ISCR ($t[104.5] = -2.15$, $p < .05$) and showed a higher respiration depth ($t[91.36] = -2.96$, $p < .01$). The two conditions did not differ significantly with respect to SCL ($t[126] = 0.15$, *ns*), HR ($t[128] = -1.46$, *ns*), PVA ($t[128] = 1.23$, *ns*) and RR ($t[124] = 0.65$, *ns*).

3.3. Short-term physiological response accompanying piloerection onset

Fig. 3 depicts the course of the normalized electrodermal, cardiovascular, and respiratory reactivity measures in the time period around the first onset of piloerection per trial (−15 to +15 s). In the period ranging from 15 to 10 s before the onset of piloerection all physiological measures showed a quite stable baseline activity. The experimental conditions did not show significant differences in the baseline period for most physiological measures (ISCR: $t[65] = -0.37$, *ns*; SCL: $t[65] = -0.68$, *ns*; PVA: $t[65] = -0.81$, *ns*; RR: $t[65] = -1.00$, *ns*; RD: $t[65] = 1.52$, *ns*); however, the HR in the baseline period was found to be somewhat higher in the no-piloerection condition ($t[65] = 2.15$, $p = .048$; $M = 78.36$ bpm, $SD = 11.59$) as compared to the piloerection condition ($M = 73.81$ bpm, $SD = 14.49$). Significant deviations of physiological reactivity from the baseline activity ($p < .01$) are marked by solid bars in Fig. 3. In the *piloerection condition*, the ISCR was significantly increased 1–3 s after the onset of piloerection. After that, it tended to stay at an enhanced level of activity ($p < .05$). SCL did not rise above the pre-onset baseline until about 8 s after the onset of piloerection. The HR increased, and the PVA decreased shortly before the onset of piloerection, and both measures stayed at this level for the remaining period under consideration. The RR showed no significant deviation from baseline activity. The RD showed a significant increase shortly after piloerection onset, and stayed on this elevated level for the remaining period under consideration. The analysis of the short-term response for the matched *no-piloerection condition* did not yield a significant response of any physiological measure within the entire period under consideration.

4. Discussion

4.1. Objective vs. subjective assessment of piloerection

The employment of an objective and direct assessment method of human piloerection, which does not require any interaction of the participant (Benedek et al., 2010), allows for an unbiased assessment of the physiological responses associated with emotional piloerection. It avoids unnecessary distractions from the stimulus as well as potential physiological artifacts. The presented data revealed that self-reports on visible piloerection may be erroneous. Participants happen to fail to report on piloerection although it is objectively detected, and they report on piloerection when none is detected. At least the latter case may in part be due to the fact that detection of piloerection was limited to one location at the forearm. This location, however, is known as one of the most common sites for experiencing piloerection (Craig, 2005; Goldstein, 1980). The observed inconsistency could also result from difficulties to distinguish piloerection from the sensation of chills. The objective assessment of piloerection thus may help to increase internal validity in the study of piloerection by distinguishing it from merely subjective sensations.

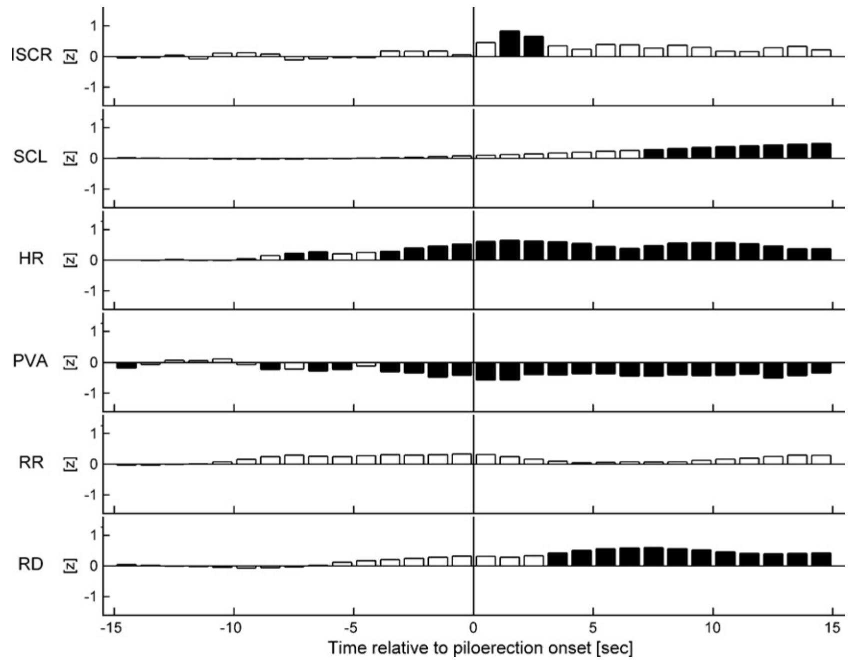

Fig. 3. Time course of the short-term response of physiological measures for a time range of ±15 s around the first onset of piloerection within a trial. The bars indicate the standardized change (relative to the averaged value in the 15–10 s period before piloerection onset) at 1-s time steps. Dark bars indicate significant deviations from zero; white bars indicate non-significant deviations. ISCR: integrated skin conductance response, SCL: skin conductance level, HR: heart rate, PVA: pulse volume amplitude, RR: respiratory rate, RD: respiration depth.

4.2. *Evoking emotional piloerection*

Emotional piloerection is a rare phenomenon, at least, when it is studied in the laboratory. In this experiment, visible piloerection was successfully evoked in 40% of the participants and in 18% of the trials. That is, 60% of the participants did not show piloerection for any of the presented stimuli, although these stimuli were apt to evoke piloerection in others. This ratio is consistent with previous findings. In a survey by Sloboda (1991) only 62% of the participants could remember to have experienced piloerection in response to music at least once within the last five years. Under experimental conditions the rate of evoked piloerection often does not succeed 20–30% (e.g., Grewe et al., 2007a,b; Konečni et al., 2007). Moreover, the results indicate a gender bias, such that men are less likely to experience piloerection. This is in line with previous research (Panksepp, 1995); however, the interpretation of this finding is limited by the unequal sex ratio in this study's sample.

Interestingly, the ratio of piloerection increased over the course of an experimental session. The presentation of a series of relevant stimuli could be assumed to cause a state of sensitization. The psychophysiological phenomenon of sensitization can be described as a breakdown of inhibitory processes, which is known to affect both cognitive as well as neurovisceral systems (Thayer and Friedman, 2002), and thus could result in an increasing probability for the experience of piloerection. Additionally, the participants may have felt increasingly comfortable in the experimental setting and were able to get more and more engaged with the stimuli.

It was suggested that piloerection occurs more often in response to familiar and especially to self-selected stimuli (Craig, 2005; Grewe et al., 2007a). Our results, however, are rather in line with other studies which do not support this assumption (e.g., Guhn et al., 2007). Self-selected music did not result in higher piloerection rates, and the low subset of unfamiliar stimuli was found to be even more powerful. However, due to experimental reasons, participants did not bring their favorite stimuli, so that self-selection was limited to a given stimulus pool. Moreover, the participants were familiar with close to 90% of the stimuli which restricts conclusions with respect to familiarity.

So far, empirical investigations strongly focused on music as trigger of emotional piloerection. Most interestingly, in this study audio tracks of film clips were found to be more successful in eliciting piloerection than pieces of music. In emotion research, film clips are readily used for the elicitation of various emotional states (Kreibig, 2010). It could even be hypothesized, that films are potentially more apt to elicit strong feelings than pieces of music. First, films combine auditory and visual information and, therefore, can convey emotional meaning more comprehensively. Second, films usually take longer than music pieces, so there is more time to build up strong emotional states. In this experiment, however, only the audio tracks of films were used, and the selected episodes were on average shorter than the music pieces. But considering the high familiarity of the stimuli, which often includes multiple expositions to favorite pieces, the elicited emotional response could be conceived as a conditioned response (Konečni et al., 2007; Panksepp, 1995). Listening to the audio track of a film clip, or even reading the episode description, may then suffice to trigger the full-scale experience associated with the film. Film clips thus also appear to be very appropriate and powerful for the research on emotional piloerection. In this context, it would be very interesting to contrast the effects of auditory, visual and audiovisual stimulus presentation of film clips for the induction of strong emotional states and especially for the elicitation of piloerection.

4.3. *Psychophysiological correlates of emotional piloerection*

The present experiment studied the physiological response related to emotional piloerection with respect to short-term effects (i.e., responses accompanying the onset of piloerection) as well as more general effects (i.e., effect of the entire stimulus). In order to explore the very specificity of this physiological response, conditions for which the same stimuli in one case did and in other case did not elicit piloerection were contrasted. The general physiological response in the *no-piloerection condition* was characterized by significant increases of phasic electrodermal activity, heart rate, vasoconstriction, and rapid and shallow breathing. This response pattern reflects increased activity of various subsystems of the sympathetic nervous system, and suggests that listening to audio tracks which *potentially* elicit piloerection induces a state of high physiological arousal. Listening to audio tracks which *effectively* elicit visible piloerection evokes a largely comparable general physiological response. As a difference, however, it is characterized by a more pronounced increase in phasic electrodermal activity, and by higher respiration depth. These differences refer to the reaction to the entire stimuli. The *onset* of piloerection is accompanied by a multifaceted physiological short-term response. This immediate response cannot simply be attributed to objective characteristics of the audio track (e.g., acoustical features), since no significant physiological short-term changes were observed for the same time period in the matched control condition. Some of these onset-related physiological changes (increases in phasic electrodermal activity, and breathing depth) appear to be more persistent and to contribute to the observed characteristics of the general physiological response, while others apparently rather reflect transient changes (increases in tonic electrodermal activity, heart rate, and vasoconstriction). At this, baseline differences in heart rate may have affected the differential reactivity of heart rate. Post hoc analyses, however, showed that both effects were very robust (increase in heart rate for piloerection: $p < .001$; no increase in heart rate in absence of piloerection $p > .50$) and thus may not be fully attributed to baseline differences.

Taken together, the obtained results are thought to provide novel insights concerning the conditions and physiological pattern of emotional piloerection. The generalization of these findings, however, is limited by the employment of a convenience sample, which involved an unequal sex ratio. Future studies should also account for general physiological status variables (e.g., smoking status, menstrual cycle) as well as relevant health criteria.

4.4. Revisiting the peak arousal and separation call hypothesis

On the one hand, it has been argued that the incidence of piloerection may mark a peak in emotional arousal (Rickard, 2004; Guhn et al., 2007; Grewe et al., 2007a, 2009). On the other hand, the psychobiological model formulated by Panksepp (1995) conceives emotional piloerection as an evolutionary relic of a thermoregulatory response to an induced sensation of coldness, and links it with the emotional quality of sadness. The physiological responses associated with emotional arousal, the sensation of coldness, or sadness are well studied, and it is feasible to discriminate between emotional states by comparing the physiological pattern accompanying them (see e.g., Kreibig, 2010; Stephens et al., 2010). We shall, therefore, examine whether the specific physiological response obtained for emotional piloerection and the available behavioral evidence favor one of these views.

4.4.1. Reconsidering the peak arousal hypothesis

A peak state of emotional arousal is commonly assumed to be accompanied by increased activity of the sympathetic nervous system as a necessary but however not sufficient condition. The observed increase in phasic electrodermal activity, and the short-term increase in heart rate and peripheral vasoconstriction (i.e., decrease in PVA) are in line with the peak arousal hypothesis. In addition, high arousal should be associated with rapid shallow breathing behavior (Shea, 1996). The absent difference in respiration rate, as well as the observed increase in breathing depth thus does not support a state of peak arousal. Finally, the piloerection condition did not differ from the high arousing matching condition with respect to self-reported arousal, but rather differed in the extent of being moved. In sum, the peak arousal hypothesis cannot be fully supported by the present data.

4.4.2. Reconsidering the separation call hypothesis

The separation call hypothesis links piloerection to sadness and the sensation of coldness. The physiological response associated with non-crying sadness is primarily characterized by an increase in heart rate, and by deepened breathing (for an overview see Kreibig et al., 2007; Kreibig, 2010). The observed short-term increases in heart rate as well as the increase in respiration depth are consistent with a state of sadness. Moreover, the short-term increase of peripheral vasoconstriction and increase in phasic EDA are largely compatible with previous evidence related to the physiological response for sadness (Frazier et al., 2004; Gross and Levenson, 1997; Krumhansl, 1997; Kreibig et al., 2007; Kunzmann and Grühn, 2005). Finally, the trend towards more negative feelings during piloerection is fully in line with a state of sadness. The separation call hypothesis also assumes the involvement of a sensation of coldness. Besides the occurrence of piloerection, the observed short-term increase of vasoconstriction is consistent with a thermoregulatory response to coldness. However, the strong immediate and general increases in electrodermal activity oppose this view. Thus, the involvement of a sensation of coldness cannot be fully supported. As an additional argument, Panksepp's finding that women are more responsive to piloerection, which he attributed to a higher responsivity of women to separation calls due to their dominant role in parenting, was supported in the present study. While Panksepp (1995) showed that this is true for self-reports, it now was also found for visible piloerection. Finally, the finding that film audio tracks are more powerful in eliciting piloerection than music pieces also suggests that piloerection may be predisposed to social stimuli, since films usually convey more social content than music pieces. Summing up, it can be concluded that the specific physiological response pattern accompanying piloerection at large as well as further behavioral evidence clearly favor Panksepp's separation call hypothesis to the hypothesis of peak arousal.

4.5. The emotional specificity of piloerection

The stimuli employed in this experiment are apt to induce states of high emotional arousal. The crucial factor for the actual elicitation of emotional piloerection, however, appears not to be associated with an additional peak in arousal, but rather with the presence of a specific emotional quality which is related to sadness and the emotional state of being moved. A simple attribution of piloerection to the basic emotion of sadness, however, may fall short of the goal to fully describe its emotional specificity. While piloerection may often be accompanied by indices of sadness, the emotion of sadness is not known to be generally accompanied by piloerection. This suggests that the emotional state indicated by piloerection represents a more specific emotional state than sadness and maybe even a subtype of sadness. Following Panksepp one might conclude that this subtype could be the emotional state of social loss or separation distress (Panksepp, 1995, 2003). In this study we have reported strong evidence supporting this conclusion, and consideration of the fact that the two most powerful stimuli of this experiment (taken from the films Armageddon and Titanic) describe acts of selfless self-sacrifice and end with the death of beloved ones, may be viewed as further support. However, it also has to be acknowledged that the literature consistently links piloerection with highly pleasurable experiences (Blood and Zatorre, 2001; Goldstein, 1980; Grewe et al., 2007a,b, 2009; Konečni, 2005), and the underlying stimuli are usually rated very high in liking (Grewe et al., 2007a; Panksepp, 1995; Rickard, 2004). At this, it appears hard to conciliate the emotional states of social loss or separation distress with such positive experiences and evaluations. As an alternative, the emotional state marked by piloerection might be viewed to represent the state of *being moved* or *touched*, as suggested by the significant association of piloerection and self-report measures on the extent of being moved. The state of being moved or touched was conceptualized by Scherer and Zentner (2001) as being "accompanied by moist eyes, chills, thrills or gooseflesh" (p. 384) and exemplified by "tears shed during sentimental movies in the cinema or the flash of warmth experienced when hearing about a good deed." (p. 384). Scherer and Zentner also noticed that in some languages such as English or French there does not exist a proper noun denominating the state of being moved, while it would correspond to the concepts of *Rührung* or *Ergriffenheit* in German. In line with the presented evidence, this description thus links the state of being moved not only to piloerection but also with physiological indicators of sadness. Similarly, Konečni (2005) assumes that the state of being moved or touched is commonly accompanied by the physiological responses of chills or thrills. In his model, being moved is considered subordinate to the emotional experience of awe. Konečni et al. (2007) again provided evidence that moving stories about heroic acts of selfless self-sacrifice are especially powerful elicitors of self-reported chills. At this, the negative-end stories elicited more chills than positive-end or neutral, but the stimuli at large were found to cause an improvement of mood. So there is evidence for a strong social component in the state of being moved, which has recently also been linked to empathy, intersubjectivity, and the activity of mirror neurons (Bråten, 2007). Moreover, such stimuli (e.g., self-sacrifice) probably elicit quite complex emotional experiences which cannot always be unambiguously attributed to either positive or negative valence (for examinations of emotional states involving mixed valence, see Cacioppo et al., 1999; Carrera and Oceja, 2007; Hemenover and Schimmack, 2007; Larsen et al., 2001, 2009). This is especially evident for the concept of awe, which was conceived as a mixture of fear and joy (Konečni, 2005, 2008). The state of being moved (either to tears or by awe) thus appears strongly related to sad or awe-inspiring experiences that still give us pleasure and that we like. And it is just these ambivalent emotional experiences that are commonly found to be indicated by piloerection.

Looking for an evolutionary based rationale of emotional piloerection, one might also speculate that the ambivalent experience of being moved or touched in response to the sublime may involve feelings of vulnerability or even imminence (Keltner and Haidt, 2003; Konečni, 2005). In animals, erection of body hair is known as a mechanism, which makes them appear larger and stronger, and which is applied in situations of imminence (Darwin, 1872, p. 87) as well as in the course of courtship (e.g., Nishida, 1997). According to this notion, emotional piloerection in humans could also be viewed as an evolutionary relic corresponding to a response to the threatening aspect of being moved or touched.

Taken together, one might conclude that piloerection may represent a specific psychophysiological indicator designating the ambivalent emotional state of being moved. Considering the generally low specificity of single parameters derived from autonomic nervous system activity (Kreibig, 2010), piloerection could be conceived as a very valuable additional indicator to be included in future research on emotion.

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Appendix.

See Tables A1 and A2.

Table A1
Audio track stimulus pool: pieces of music.

ID	Title (interpreter or composer)	Duration	Selection ratio (%)[a]	Chill ratio (%)[b]	Piloerection ratio (%)[c]
M01	My Heart will go on (Celine Dion)	03:00[d]	100	50	14
M02	Only Time (Enya)	03:00[d]	100	46	8
M03	Pirates of the Caribbean-theme (Hans Zimmer)	01:30	20	50	10
M04	Canon in D major (Johann Pachelbel)	03:00[d]	0	–	–
M05	Postwar Dream (Pink Floyd)	03:02	0	–	–
M06	Dieser Weg [This way] (Xavier Naidoo)	04:08	4	50	0
M07	Last Unicorn (America)	03:07	4	50	50
M08	Back to Black (Amy Winehouse)	04:01	0	–	–
M09	Streets of Philadelphia (Bruce Springsteen)	03:16	4	0	0
M10	Wicked Games (Chris Isaak)	04:05	0	–	–
M11	The Scientist (Coldplay)	05:09	6	33	0
M12	Colorblind (Counting Crows)	03:25	14	57	0
M13	Zombie (The Cranberries)	04:45	8	50	25
M14	Time after Time (Cindy Lauper)	04:01	0	–	–
M15	Lacrimosa (W.A. Mozart)	03:49	2	100	0
M16	The Best of You (Foo Fighters)	04:13	2	100	0
M17	Tears in Heaven (Eric Clapton)	04:36	8	50	0
M18	Wonderwall (Oasis)	04:18	12	67	17
M19	Against all Odds (Phil Collins)	03:27	4	100	–
M20	Purple Rain (Prince)	04:12	4	100	50
M21	Hallelujah (Rufus Wainwright)	04:08	22	55	18
M22	Angel (Sarah McLachlan)	04:30	4	50	0
M23	Nothing Compares to You (Sinead O'Connor)	05:07	14	57	14
M24	Hedonism (Skunk Anansie)	03:27	0	–	–
M25	Fields of Gold (Sting)	03:40	6	100	33
M26	Bittersweet Symphony (The Verve)	03:00[d]	20	60	0

Table A1 (*Continued*)

ID	Title (interpreter or composer)	Duration	Selection ratio (%)[a]	Chill ratio (%)[b]	Piloerection ratio (%)[c]
M27	Hey there Delilah (Plain white Ts)	03:52	4	100	0
M28	Fast Car (Tracy Chapman)	04:58	2	100	0
M29	Walking in Memphis (Marc Cohn)	04:10	2	100	0
M30	Total Eclipse of the Heart (Bonnie Tyler)	03:00[d]	10	100	20
M31	Vincent (Don McLean)	04:02	2	0	0
M32	Flugzeuge im Bauch [Airplanes in the tummy] (Herbert Grönemeyer)	03:54	4	100	0
M33	Heartbeats (Jose Gonzalez)	02:40	2	0	0
M34	Streets of London (Ralph McTell)	04:08	2	0	0
M35	The Sound of Silence (Simon and Garfunkel)	04:31	10	100	0
M36	Time of My Life (Bill Medley)	03:00	4	50	50
M37	Confutatis (W.A. Mozart)	02:19	0	–	–

Note: The stimuli M01 and M02 were preselected in this experiment; all other stimuli were offered for self-selection.
[a] Probability that the stimulus was selected from the stimulus pool.
[b] Probability that the stimulus elicited a subjective experience of chill.
[c] Probability that the stimulus elicited visible piloerection.
[d] This audio track was truncated after 3 min including a fade-out.

Table A2
Audio track stimulus pool: film audio tracks.

ID	Title	Duration	Selection ratio (%)[a]	Chill ratio (%)[b]	Piloerection ratio (%)[c]
F01	Armageddon	01:41	100	72	26
F02	Braveheart	01:22	100	54	20
F03	Titanic	02:20	26	84	54
F04	Dead Poets Society	02:28	18	78	33
F05	Forrest Gump	01:41	24	83	17
F06	Gladiator	01:19	4	100	50
F07	Lord of the Rings I	01:02	10	80	40
F08	Lord of the Rings III	01:02	14	71	29
F09	Independence Day	01:45	2	100	0
F10	King Arthur	00:46	4	0	0
F11	Knocking on Heaven’s Door	00:41	10	40	0
F12	Ransom	02:14	2	0	0
F13	Moulin Rouge	01:46	14	57	43
F14	Romeo and Juliet	02:03	14	86	0
F15	8 MM	01:48	10	80	40
F16	Troy	01:18	2	0	0
F17	Hook	01:13	0	–	–
F18	Brokeback Mountain	00:55	2	100	0
F19	Grey‘s Anatomy	02:43	10	60	20
F20	City of Angels	02:26	18	67	11
F21	The Sixth Sense	01:39	10	40	20
F22	Seven	02:21	4	100	0
F23	Shakespeare in Love	02:03	2	0	0

Note: The stimuli F01 and F02 were preselected in this experiment; all other stimuli were offered for self-selection. The episode description used in the experiment can be obtained on request from the authors.
[a] Probability that the stimulus that the stimulus was selected from the stimulus pool.
[b] Probability that the stimulus elicited a subjective experience of chill.
[c] Probability that the stimulus elicited visible piloerection.

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