SCRUTINISING PANKSEPP'S (1995) SEPARATION CALL HYPOTHESIS OF PILOERECTION AND CHILLS: AN EMPIRICAL STUDY

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Scrutinising Panksepp's (1995) separation call hypothesis of piloerection and chills: an empirical study

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Abstract

The present research acts as a comprehensive test of the separation call hypothesis of piloerection (colloquially known as goosebumps) and chills (Panksepp, 1995, 2009). This theory claims that: (1) piloerection and chills are triggered by musical features that resemble infant cries; (2) these cry-like sounds induce feelings of separation distress; (3) these social feelings are connected to piloerection and chills as part of a social thermoregulatory response. Panksepp also directly analogises cry sounds to high pitched crescendos, suggesting that high frequencies may be an important auditory feature for separation call elicited chills. In the present study, these claims were tested by measuring piloerection, chills, separation distress and bodily temperature in response to a range of audio excerpts. This included audio of infant cries and music excerpts with cry-like features (reflecting separation calls) and audio of infant babbles and music excerpts with cry-dissimilar features (not reflecting separation calls). Versions of each excerpt with the auditory frequencies manipulated either 25% higher or lower were also presented to test the relevance of pitch. The findings contradicted each claim of the hypothesis: the only measure to differ between the cry/cry-like and babble/cry-dissimilar stimuli was chills, and in this case chills were more common in response to the music excerpts than actual audio of infant cries. This is opposite to the expected relation. These findings call the separation call hypothesis into question. In light of this, alternate priorities for future research are discussed.

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Declaration

The data from the section of this report labelled ‘Pilot 1’ was collected as part of a larger research project led by Dr Jonathon McPhetres. I acted as a research assistant on this project and was part of a team involved in both the collection and pre-processing of the data. The analysis and interpretation of the data presented in this report is my own work.

The research presented under the sections labelled ‘Pilot 2’ and ‘Main Study’ is my own work, conducted under the supervision and guidance of Dr Jonathon McPhetres.

Statement of copyright

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Data availability

Copies of the materials, research datasets and analysis scripts used for the present research can be found on the Open Science Framework:
https://osf.io/nydtq/?view_only=83598c61f87840dca277937556e10ce2

1. Introduction

The occurrence of both objective piloerection and subjective chills sensations in response to non-thermal stimuli have been consistently documented. Various theories exist to explain these responses and the specific contexts they occur in (see de Fleurian & Pearce, 2021; McPhetres & Zickfeld, 2022), each drawing upon a mixed pool of disjointed evidence. As such, no one theory has yet prevailed as a compelling psychological explanation for piloerection or chills. As a step towards greater clarity, the present study spotlights one of the prominent theories in this area- the separation call hypothesis (Panksepp, 1995). Currently, this theory is largely reliant on inferences from indirect evidence. To address this, the present research is designed to establish whether the claims of the separation call hypothesis actually hold to direct scrutiny.

1.1. Defining and distinguishing piloerection and chills

1.1.1. Definitions

Piloerection, colloquially known as goosebumps, is an objective autonomic nervous system response that involves the contraction of the arrector pili muscles and thus the erection of hair from the skin. In non-human animals, piloerection serves as a thermoregulatory mechanism (Chaplin et al., 2013). Whilst the thermoregulatory benefits of piloerection in humans have been questioned, piloerection does still occur in humans as a response to cold environments (Tansey & Johnson, 2015) and can induce increases in skin temperature (McPhetres, 2023). Human piloerection can however also be induced by a wide range of non-thermal stimuli, such as music and film clips (Benedek & Kaernback, 2011; Craig, 2005; Sumpf, Jentschke & Koelsch, 2015; Wassiliwizky, Jacobson et al., 2017). Research directly investigating this kind of piloerection, commonly assumed to be emotionally induced, is currently quite sparse. As such, ideas about this kind of 'emotional' piloerection often draw from a larger body of research investigating chills, a related subjective phenomenon.

Chills have been defined in contemporary research as an 'emotional experience accompanied by gooseflesh, shivers and/or tingling sensations' (Bannister, 2020b, p.298). Alternate terms such as 'thrills', 'frissons' or' skin orgasms' have been used to describe this same experience (Harrison & Loui, 2014), however 'chills' stands as the most popular term used in modern research. Whilst some studies attempt to objectively validate the occurrence of this response using measures of skin conductance responding (Beier et al., 2022; Egermann et al., 2011; Grewe et al., 2007), chills are largely operationalised using subjective self-report measures. As such, the present research draws a distinction between piloerection as an objective experience, and chills as subjective experiences.

1.1.2. Elicitors of piloerection and chills

By far the most common elicitor of piloerection and chills investigated in the present research base is music (for reviews see De Fleurian & Pearce, 2021; McPhetres & Zickfeld, 2022). Experimental research has however shown that chills can be elicited by various types of auditory, photographic, tactile and gustatory stimuli (Grewe et al., 2010). Similarly, research measuring the objective occurrence of piloerection has shown the tactile, thermal and audio-visual stimuli are all effective elicitors of this response (McPhetres, 2023). Whilst research in all these areas is relevant for understanding piloerection and chills responses, the present research specifically addresses piloerection and chills as elicited by auditory stimuli as this is the context under which the claims of the separation call hypothesis directly relate.

1.1.3. The link between piloerection and chills

A conceptual link between piloerection and chills is evident given that researchers commonly reference piloerection when listing the experiences that define the chills (see Bannister, 2019; Guhn, 2007; Huron & Margulis, 2010; Koelsch, 2010). A couple of studies indicate that a more empirically grounded- albeit still poorly understood- link between these phenomena may also exist.

One study found that all instances of piloerection elicited by a selection of musical stimuli occurred between the self-reported onset and offset of a chill response, though only half of chills were accompanied by piloerection (Craig, 2005). Participants in this study also reported the general intensity of the chills they experienced across the session, and participants who reported the highest chill intensity levels all experienced piloerection. This suggests that piloerection might occur when chills hit a certain level of intensity. These findings should however be treated cautiously due to methodological issues. Piloerection was identified using live observation and the observer was able to see when participants reported chills. This may have biased the way piloerection was coded and exaggerated the ubiquity of chills during piloerection.

A more recent study where piloerection was analysed using body camera footage has however produced similar findings (Sumpf, Jentschke & Koelesh, 2015). A modest correlation was reported between the frequency of piloerection and chills in response to self-selected musical and film stimuli, and the authors claim that piloerection often coincided within a few seconds of a chill response. Piloerection was again found to be less common than chills: less than half of participants who experienced chills experienced any instances of piloerection. Physiological changes in cardiac activity (such as an increase in heart rate) were also observed during chills accompanied by piloerection but not during chills unaccompanied by piloerection. The authors take this as evidence that piloerection is part of a physiological response that occurs when chills surpass an intensity threshold, however alternately this can be taken as evidence that piloerection and chills are associated with distinct patterns of physiological activation. This study does however also suffer from some methodological weakness: in this case the occurrence and timing of chills was retrospectively reported by participants and then mapped onto precise timepoints by the researchers. This method led to data loss when participants' reports weren't sufficiently detailed and may have produced reporting errors.

Overall, a couple of preliminary studies suggesting that piloerection may occur alongside chills that surpass a certain level of intensity exist. Research hasn't however conclusively established whether these responses have the same psychological basis or are distinct and merely associated. The present study therefore tests both as separate measures and makes no concrete assumptions about the nature of their relation.

1.2. Correlates of piloerection and chills

1.2.1. Emotional correlates: a brief introduction

Chills and piloerection have been linked to various emotions and emotional properties. Potentially the most prominent of these associations reported in the literature is with affective arousal (emotional intensity). One key study in this area found that chills elicited by music often coincided with peaks in continuously self-reported emotional arousal (Grewe, Kopiez & Altenmüller, 2009). Short term increases in skin conductance level were also observed, a measure commonly used as a physiological indicator of arousal (Kreibig, 2010). Multiple further studies have investigated this association using a variety of different methodologies, and a systemic review of these studies finds that most report a positive association with self-reported arousal (McPhetres & Zickfeld, 2022).

Multiple studies have also reported associations with affective valence (emotional positivity/negativity). Findings In this area are however quite mixed, with multiple studies associating chills and piloerection with both sadness and happiness (see Panksepp, 1995; Wassiliwizky et al., 2015; Sumpf et al, 2015). This demonstrates that the emotional experiences associated with piloerection and chills either vary or cannot be fit neatly into a positive/negative dichotomy. Research has also attempted to connect chills and piloerection to more specific types of emotional experience, for example both responses have been associated with the self-reported feeling of being emotionally moved (Benedek & Kaernback, 2011, Wassiliwizsky et al., 2015) and piloerection has been associated with feelings of awe (Quesnel & Riecke, 2018; Schurtz, 2011). Other research has however failed to replicate these specific correlations (being moved: Mori & Iwanaga, 2021; awe: McPhetres and Shtulman, 2021). Taking this into account it doesn't seem like either of these emotional experiences can fully explain the emotional aspect of chills and piloerection. It remains possible that the nature emotional component of these responses isn't fixed and may vary based on individual or situational differences.

Evidence relating to the affective correlates of chills and piloerection, and the specific relevance of this evidence to the separation call hypothesis, is explored in greater detail in later sections of this report (see Section 1.6.).

1.2.2. Psychophysiological correlates

Besides piloerection, the main physiological correlate of chills identified in the current literature is an increase in skin conductance. As reported in a systematic review of chills and piloerection research (McPhetres & Zickfeld, 2022), over 90% of studies that measured an association between phasic skin conductance responses and chill events reported a significant increase, and 70% of studies that measured tonic skin conductance levels reported a significant increase. This same review found evidence that this association extends to piloerection itself: two out of three relevant studies found that tonic increases in skin conductance level were associated with non-thermal piloerection (see Benedek & Kaernback, 2011; Wassiliwizky, Koelsch et al., 2017).

Another, slightly less consistent, physiological correlate identified in the literature is increased heart rate. Around 60% of studies measuring the association between heart rate and chills have found such an association (McPhetres & Zickfeld, 2022), with 75% of studies directly measuring piloerection finding the same.

More generally, chills are often described in research (and described to participants) as a response associated with subjective experiences of bodily shivering or tingling sensations (e.g. Bannister, 2020b; Grewe et al., 2007; Maruskin, Thrash & Elliot, 2012; Mori & Iwanaga, 2021; Panksepp, 1995). These descriptions imply the occurrence of a physiological response, though the objective nature of this response is unclear. It is also unclear whether reports of shivers and tingling represent physiologically distinct responses, or whether these are just different terms to describe the same underlying experience.

1.2.3. Individual difference correlates

The most commonly reported personality correlate of chills is openness to experience. This is one of the ‘Big Five’ factors of personality, and is associated with traits of being curious, imaginative and innovative (McCrae, 2007). A moderate to small correlation between openness to experience and self-reported propensity to experience chills has been observed in multiple survey studies (Bannister, 2020b; Silvia & Nusbaum, 2011; Mori & Iwanaga, 2014). Some research has also managed to demonstrate this effect in experimental conditions by measuring chills in response to live music (Colver & El-Alavi, 2015), however other research has failed to find this effect in experimental conditions (Mori & Iwanaga, 2014). Little research has been done investigating the association openness to experience to objective piloerection, however one study did find that people who can induce piloerection at will scored highly on scales measuring this trait (Heathers et al., 2018). Overall, a fairly substantial body of evidence exists to suggest that openness to experience is a factor with some effect on frequency of chill and piloerection responding, though the extent of this effect is unclear.

Research also commonly tests the effects of demographic factors on rates of chills and piloerection. A couple of studies have found higher rates chills and piloerection for female compared to male participants (Benedek & Kaernbach, 2011; Panksepp, 1995). A systematic review of chills research however indicates that the vast majority studies do not find an effect of gender on these responses, with reported relationships for other commonly assessed demographic factors such as age being similarly sparce (De Fleurian & Pearce, 2021). Chills and piloerection therefore don’t appear to be demographically sensitive phenomena.

It is relevant to note that at a population level, chills are quite common experiences. In one survey study, over 90% of respondents indicated that they sometimes experience chills in response to music (Bannister, 2020b). Because of this, whilst some people (such as those with high openness to experience) may be more prone to chills and piloerections, these responses do not appear to be unique to people with a specific set of characteristics.

1.3. Types of chills

Some researchers have attempted to distinguish between different types of chills based on the various correlates describe above. After conducting a series of cluster and factor analyses on surveys of participants' freely reported experiences during chills, Maruskin, Thrash and Elliot (2012) differentiated goosetingles from coldshivers. According to this model goosetingles are associated with tingling sensations, an approach response to the chill eliciting stimulus, and positive emotions of awe and surprise. In contrast, coldshivers are associated with subjective coldness, shivering sensations, an avoidance response to the chill eliciting stimulus, and negative emotions of disgust, fear and sadness. This research also specifically associates self-reported goosebumps with goosetingles and not coldshivers. It cannot however be assumed that this relation holds for objective piloerection. This is because humans are notably poor detectors of this response: a study using audio-visual stimuli showed that goosebumps reported via button press rarely coincided within 8 seconds of objective piloerection, and some participants seemed to be unable to detect piloerection at all (McPhetres, Han et al., 2024).

More recently, Bannister (2019) distinguished between warm, cold and moving chills. These categories were selected based on analyses of participants' self-reported ratings for a variety of features that coincided with chills in response to a collection of multi modal stimuli. In this case, warm chills typically occurred in response to stimuli with themes of communion and love and gratitude, and were associated with happiness, smiling and feelings of bodily warmth. This roughly aligns with descriptions of goosetingles. Cold chills typically occurred in response to stimuli with themes of distress and support, and were associated with sadness, frowning and feelings of bodily coldness. This roughly aligns with descriptions of coldshivers. Finally, moving chills did not have any strong associations to stimulus theme and were associated with feelings of tenderness, affection and being moved, along with bodily sensations of a lump in the throat and tears. Contrary to research into goosetingles and coldshivers, self-reported goosebumps, shivers and tingling sensations were all moderately associated and did not correspond with distinct chill types.

Whilst there are some differences between these two models, they both broadly agree that different types of chills may be distinguished based on temperature and valence associations. Specifically, warmth and positive affect in response to chills seem to align, and coldness and negative affect seem to align. These potential chill types are however still quite vaguely defined, with the potential existence of a third type of ‘moving’ chills (Bannister, 2019) complicating any dichotomous distinction between chills based on temperature and valence.

Another distinction made in recent research separates vigilance and social chills (Bannister & Eerola, 2023). This claim is supported by a study where the framing of different chill inducing music pieces was manipulated. Vigilance framing was achieved by either introducing the piece with a written description that emphasised the structural developments in the music or by presenting the piece alongside an animation that visualised these structural developments in real time. Social framing was achieved by either introducing the piece with a description that emphasised social narratives of the music or by presenting the piece alongside an animation depicting a socially moving scenario. Framing influenced self-reported emotional responses: vigilance chills were associated with awe whilst social chills were associated with being moved. Physiological differences were also found between the two types of chills: vigilance chills were associated with higher skin conductance levels, lower skin conductance responding and lower skin temperatures compared to social chills, though these effects were all quite small.

The conceptual distinction between vigilance and social chills doesn’t fit well within the framework provided by the separation call hypothesis, which proposes that the structural features, social responses and feelings of coldness associated with chills are all related. The separation call framework is somewhat more compatible with models distinguishing cold and negative chills from warm and positive chills, with the claims of the theory aligning more with the former. As a reliable method for distinguishing these types of chills has not yet been established, the present research however tests chills as a unitary measure.

1.4. Theoretical perspectives: a brief overview

The present research focuses on the separation call hypothesis of chills and piloerection, a theory proposed by Jaak Panksepp (1995, 2009). This is one of the most prominent theories of chills: as of July 2024 the initial paper proposing the theory (Panksepp, 1995) has been cited by over 950 articles on Google Scholar. Whilst Panksepp’s own research focused solely on subjective chills, he specifically references piloerection as a relevant, objective counterpart to this phenomenon that should be further investigated (Panksepp & Bernatzky. 2002).

The separation call hypothesis can be broadly summarised into 3 connected claims: (1) that chills occur in response to sounds that resemble infant separation cries, for example high pitched crescendos; (2) that these cry-like sounds induce separation distress, which is characterised by feelings of social loss and a desire for social contact; and (3) that these socially rooted feelings are part of a social thermoregulatory response whereby chills manifest from a sense of ‘coldness’ that motivates a desire to seek ‘warmth’ from social contact. These claims are discussed in detail in subsequent sections of this report.

Aside from the separation call hypothesis, other notable theories of chills and piloerection include theories of peak arousal and contrastive valence. Peak arousal theory is based around the evidence linking piloerection to chills (as mentioned in Section 1.2.1.), proposing that chills and piloerection arise from peaks in physiological and emotional arousal (Benedek & Kaernbach, 2011). Contrastive valence theory proposes that emotional piloerection and chills manifest in response to violations of musical expectation, which activate a vigilance response (Huron, 2006; Huron & Margulis, 2010). These experiences are thought to be perceived as pleasurable due to the juxtaposition of a fleeting, unconscious fear response shortly followed by positive stimulus appraisal. Findings linking chills to the entrance of a new instrument (Grewe et al., 2007) and to changes in acoustic features such as loudness and roughness (Bannister, 2020a, Bannister & Eerola 2018, Beier et al., 2022, Grewe et al., 2007) can be interpreted as consistent with this idea. There are however multiple other ways the relevance of these auditory features can be interpreted (including as representations of separation calls, discussed in Section 1.5.2.).

1.5. Separation calls, piloerection and chills

1.5.1. Separation call properties

The central claim of the separation call hypothesis is that musical chills are triggered by sounds that resemble infant separation calls, aka infant cries that function to elicit a caregiving contact response (Panksepp, 1995). Cries in response to parental separation- and caregiver responses to these cries- have been observed and studied across a range of mammals (Newman, 2007). For example, infant guinea pigs have been shown to have a substantially higher cry vocalisation rate when isolated from their mother compared to when their mother is present (Pettijohn, 1979), and recordings of separation calls from infant marmosets have been shown to trigger exploratory behaviours in marmoset parents (Sánchez, Ziegler & Snowdon, 2014). This suggests that the use of infant cry vocalisations to elicit caregiver contact is a deeply ingrained, adaptive response that developed early in mammalian evolution.

Panksepp (1995) specifically characterises what he describes as the human separation call as ‘a prolonged wail with a fundamental frequency of around 500 Hz and with successive harmonics up to 4500 Hz’ (p.200). A review of research into infant cries further clarifies that these calls last around 0.5 to 1.5 seconds, have either a falling or a rising-falling melody contour and have a fundamental frequency between 200 and 600 Hz (Solits, 2004). This same review however highlights that, whilst separation is clearly one of the main triggers for infant crying, evidence that separation calls reflect an acoustically unique type of cry vocalisation in young human infants is lacking (a sentiment echoed by Swain et al., 2007). In fact, evidence shows that whilst newborns separated from their caregiver by being placed in a cot after birth cry substantially more than those kept skin-to-skin with their mother (Christensson et al., 1995), these ‘separation cries’ are spectrographically indistinct in terms of pitch, cry duration and melody contour from the cries of non-separated peers (Michelsson et al., 1996). Because of this, the present report considers the acoustic properties of human infant cries generally rather than trying to distinguish separation calls as a unique type of cry vocalisation.

1.5.2. Evidence linking separation calls to chills

The main evidence that Panksepp (1995) presents explicitly linking chills and separation calls are the results of a small time series study. This shows that participant’s self-reported chills in response to three different music excerpts often coincided with musical crescendos (increases in loudness), which he remarks may symbolically resemble an infant separation cry. Panksepp also claims to have demonstrated a chill response to audio of infant cries in other research, however the exact nature of this research is unspecified and, to date, it remains published. There is in fact a distinct lack of any published research clarifying the cry-like acoustic features associated with chills and piloerection.

Some research has however investigated acoustic associations with chills more generally. In a recent survey, the most prominent musical feature that participants referenced when explaining their chill experiences was the human voice (Bannister, 2020b). This finding makes sense in the context of the separation call hypothesis, after all human vocals seem intuitively more likely to resemble an infant cry than any other instrument. Other researchers have also replicated Panksepp’s claims connecting chills to musical crescendos. A recent time series analysis found a modest cross-correlation between peaks of loudness and chills in response to instrumental music from various cultures (Beier et al., 2022). Another study found that around 20% of chill events (measured using a 20 second symmetrical window) in response to both researcher- and self-selected music coincided with peaks in loudness (Grewe et al., 2007). This finding supports a link between chills and musical crescendos, but also demonstrates that crescendos are far from a ubiquitous elicitor of musically induced chills. Another feature highlighted by this study was the entry of a voice or instrument, which was the feature participants most commonly referenced when asked about what they found pleasant about the music that successfully induced chills. The entry of an instrument could potentially reflect the emergence of a cry sound, though this is very much a tentative interpretation.

Research using audio manipulation provides further insight into the effect of different musical features on chills. In one procedure multiple versions of two chill-inducing song excerpts were created by adding gradual changes in loudness or spectral brightness (Bannister, 2020a). In this case brightness refers to the size of the ratio between high to low frequencies within music, which was manipulated by either amplifying or reducing the frequencies above 2000 Hz within the excerpt. For one of the excerpts- characterised by crescendoing musical dynamics- increased loudness had a moderate, positive effect on chill response frequency. The author interprets this as congruent with contrastive valence theory, with increased loudness reflecting the sound of an approaching threat and thus inducing a vigilance response (auditory looming). This finding can however alternatively be taken as support for Panksepp's (1995) claim that chills result from musical crescendos that symbolise separation calls. Increased brightness was also found to have a substantial negative effect on chill responding for this excerpt, though the significance of this relation is unclear and opposite to the relation found in correlational research (Bannister & Eerola, 2018; Beier et al., 2022).

Contrary to the above findings, no effects of loudness or brightness were found for the other excerpt tested in this study, which contained a guitar solo. This suggests that the effects of musical manipulation are sensitive to underlying musical structure, indicating that chills induced by different kinds of music may result from the activation of distinct psychological processes. This highlights that even if the separation call hypothesis is accurate, sounds representative of separation calls are unlikely to be the only auditory trigger for chills.

Overall, whilst features identified in previous research (such as the human voice, musical crescendos and the entry of an instrument) can be speculated to reflect the properties of separation calls, there isn't currently any evidence specifically justifying claims that any such resemblance underlies chills and piloerection responses. The present research attempts to gain clarity on this by directly testing chills and piloerection in response to actual audio of infant cries, a notable gap in the current literature.

1.5.3. Relevance of pitch

Whilst Panksepp (1995) does not provide a comprehensive breakdown of the features of chill inducing music that resemble separation calls, he does specifically reference the 'high-pitched crescendo' (p.199) as a relevant feature. The idea that pitch is an important feature of chills elicited by separation calls aligns with evidence that the fundamental frequency of infant cries (which roughly translates to perceived pitch) acts as a graded signal of distress (Solitis, 2004). In this case higher cry frequencies indicate greater distress and thus elicit a stronger caregiver response. For example, when presented with a range of pitch manipulated audio recordings of a cry from a 3 month old infant, pitched up recordings were rated by adult participants as substantially more urgent, arousing and distressing than unedited and pitched down recordings (Dessureau, Kurowski & Thompson, 1998). This same relation has been found when unedited recordings of different infant cries with naturally varying pitches are presented to participants (Crowe & Zeskind, 1992). In this case cry pitch was also positively associated with skin conductance level, evidencing an intensified physiological response to high pitched cries.

Evidence also supports the idea that these emotional caregiver responses translate to actual contact behaviours. In one study adult participants were more likely to self-report an intent to engage in sensitive, contact-seeking caregiver behaviours in response to artificially pitched up versions of a cry recording compared to the unedited recording (Out et al., 2010). Field research where real caregiver responses in a nursery were directly observed and coded though a one-way window also found that nursery workers showed more urgent and sensitive caregiver responses to high pitched compared to low pitched cries (Zeskind & Collins, 1987). These are the kinds of contact-seeking responses to infant cries that the separation call hypothesis speculates to be associated with chills, suggesting that the effect of pitch on chills and piloerection is a relevant factor that should be investigated. The present research aims to address this idea directly.

1.6. Affective and social properties of piloerection and chills

1.6.1. Affective valence

Panksepp (1995) claims that musical chills have a greater association with sadness than happiness. He supports this claim with a series of small correlational studies showing that self-reported chills have a stronger (positive) association with participant's sadness ratings in response to music compared to their happiness ratings. He also shows evidence that chills are more common in response to music prospectively identified as sad rather than happy. More recent research supports these findings, showing that the probability of experiencing chills in response to emotionally moving film clips is more associated with sadness than joy (Wassiliwizky et al., 2015). It is however important to note that in all these studies some chills were in fact associated with happiness, these were just less common. These 'happy' chills may potentially reflect a response distinct from the 'sad' chills that Panksepp centres the separation call hypothesis around, as evidenced in more contemporary research (Bannister, 2019; Maruskin, Thrash & Elliot, 2012).

Some research has tried to use more objective methods to establish the emotions related to piloerection and chills. The authors of one study have claimed a link between the physiological correlates of piloerection and sadness (Benedek & Kaernbach, 2011). Specifically, they present findings that piloerection induced by music and audio from film excerpts is associated with increased respiratory depth and short-term increases in heart rate, features they claim physiologically mirror markers of sadness. This physiological resemblance is however ambiguous: a review of autonomic responses shows mixed findings regarding the direction of the relation between sadness and both heart rate and respiratory depth, with the direction of these relations potentially varying for different types of sadness (Kreibig, 2010). Another study using facial electromyography found that both piloerection and self-reported chills in response to spoken poetry were associated with heightened activity of the corrugator supercilii muscle- typically used as an indicator of negative affect- but not the zygomaticus major muscle- typically used as an indicator of positive affect (Wassiliwizky, Koelsch et al., 2017).

The idea that piloerection and chills are more associated with negative than positive affective valence is however not unanimous within the literature. In fact, a recent literature review indicates that more studies actually report a stronger association with positive rather than negative valence, and that multiple studies have found no association at all (McPhetres & Zickfeld, 2022). One possibility is that piloerection and chills are actually characterised by mixed affective valence. Supporting this view, a thematic analysis of results from an online survey found that feelings of mixed emotional valence during chills were more commonly reported than feelings of either unambiguous joy or sadness (Bannister, 2020b). Panksepp (1995) himself acknowledges that chills may result from sadness blended with positive emotion, and often refers to chills in the context of 'bittersweet' or 'nostalgic' sadness.

1.6.2. Being emotionally moved

Some researchers have specifically linked experiences of chills to feelings of being emotionally 'moved'. This is an experience characterised by mixed affective valence: when participants are asked to rate the sadness and joy associated with episodes of being moved, research has found that these emotions often cooccur (Menninghaus et al., 2015). This same research also ties this response to feelings of social bonding. Specifically, death, social separation and social reunion were among the most common themes that participants referenced when asked to describe a specific experience of being emotionally moved. These themes tie into Panksepp's (1995) descriptions of social loss and separation distress. It is however worth noting that participants associated being moved with warmth more than coldness, which doesn't seem to align with the social thermoregulatory claims of the separation call hypothesis (discussed later).

Research using auditory stimuli (including music and audio from films) has found higher ratings of being moved for trials that successfully induced piloerection compared to trials that didn't (Benedek & Kaernbach, 2011). This effect was also stronger than the relation between piloerection and participant's affective valence and arousal ratings. Research into chills has produced similar findings: one study found that participants' ratings of being moved in response to a series of film clips were a better predictor of the probability of chills than sadness or joy ratings (Wassiliwizsky et al., 2015). Another study using musical stimuli also found an association between self-reported ratings of being moved and chills, though this effect was specifically attributed to a 'social' subtype of chills (Bannister & Eerola, 2024). The link between chills and feelings of being emotionally moved is also not a unanimous finding within the published literature: one study found that frequency of chills was not a substantial predictor of participants' ratings of being moved whilst listening to a series of songs (Mori & Iwanaga, 2021).

Despite the somewhat mixed evidence surrounding whether being moved is specifically involved in musical chills, the discourse in this area broadly highlights the relevance of social factors as part of the chill response. Given the ambiguity of the valence associated with piloerection and chills, perhaps understanding the affective properties of these responses may be best achieved by pinpointing specific socio-emotional associations. This is particularly relevant when considering the separation call hypothesis, which conceptualises chills as a social mechanism.

1.6.3. Social loss and separation distress

Panksepp (1995) proposes that chills arise from the activation of ancient affective circuits that establish social behaviour, with separation cries being a particularly potent trigger for this response. In this case, piloerection and chill responses are seen as a manifestation of separation distress, which encompasses feelings of social loss and a desire for social contact. These social feelings are proposed to serve an adaptive function as a trigger to promote social reunion behaviour.

Research has in fact validated a link between experimentally manipulated feelings of social separation and a desire for social contact. One study showed that when asked to list the activities they would like to engage in, participants who had just watched a film clip related to social loss listed almost twice as many social activities compared to participants who watched a neutral documentary film clip, indicating a desire to engage in social contact (Grey, Ishii & Ambady, 2011). This effect was specific to stimuli associated with social loss, no comparable effect was found for participants who watched happy film clips, fear-inducing film clips, or sad film clips related to failure. A more recent fMRI study shows that following 10 hours of social isolation, activity in dopaminergic areas of the brain evoked in response to images of social activities is similar to that evoked during cue-induced food cravings (Tomova et al., 2020). This evidences the ability of social cues to induce ‘social cravings’. Given this, perhaps infant separation cries can act as an elicitor for social craving.

Relating these social processes to the occurrence of chills, Panksepp (1995) anecdotally highlights that the semantic content of the lyrics of chill-inducing songs is commonly related to social loss. In a later publication (Panksepp & Bernatzky, 2002), he also claims that PET research showing increased neural activation in the ventral striatum and the midbrain periaqueductal grey during chills (Blood & Zatorre, 2001) may reflect activation of the brain’s socio-emotional systems. This is however quite a specific and speculative interpretation of these neural findings.

More direct evidence linking chills to social factors does however also exist. One of the themes identified in a thematic analysis of participant’s freely reported experiences during chills was ‘musical relationships and interactions’, which specifically included the presence of social narratives relating to love, social loss and reconciliation (Bannister, 2020b). Another study reported that, when asked freely to list the emotions experienced during sad, chill-inducing and goosebump-inducing stimuli, participants often used terms such as compassionate and sympathetic (Wassiliwizky et al., 2015), indicating an empathetic social response. Interestingly these descriptors were more common than explicit descriptions of being moved despite the stimuli used specifically being selected for their moving properties, suggesting that social responses to chill inducing stimuli are particularly salient to participants.

Looking beyond subjective feelings towards the objective social context of chills, it is notable that responders in Bannister's (2020b) thematic analysis reported experiencing more chills when alone than in the company of others. This fits with the idea that chills are associated with feelings of social separation and a desire for contact. Similarly, research where participants listened to a series of musical excerpts both alone and in a group setting found a relatively large, positive effect of aloneness on chills (Egermann et al., 2011), though this particular study is notably unpowered due to a small sample size. Evidence contradicting this aloneness effect also exists: in a week long study where participants responded to multiple surveys about their chills experiences throughout their daily routine, no overall relation was found between aloneness and musical chills (Nusbaum et al., 2014). There was however significant heterogeneity in this sample, with the authors noting that some participants did get more chills when alone whilst the reverse was true for others. The existence of an aloneness effect on chills and piloerection therefore needs further clarification.

In general, the studies described here highlight the relevance of social aspects in chills and piloerection. More evidence to pinpoint the precise nature of these feelings is however required to support the specific social claims of the separation call hypothesis. The present research addresses this by directly investigating the association of piloerection- and chill-inducing stimuli to reported feelings of separation distress.

1.7. Piloerection, chills and social thermoregulation

1.7.1. Social thermoregulation

It has been suggested that a link between feelings of social separation, piloerection and chills may be rooted in an intersection of neural circuits that connect social behaviour with thermal responses (Panksepp & Bernatzsky, 2002; Panksepp, 1995). This proposed association is grounded in ideas about social thermoregulation, which is a process whereby social contact serves an adaptive function as an energy efficient method for maintaining warmth (IJzerman et al., 2015).

The benefits of social thermoregulation have been demonstrated in non-human mammals. For example, rabbit pups raised alone have been shown to expend more energy on thermogenesis, have lower body temperatures and accrue less fat mass than those raised in groups (Gilbert et al., 2007). Evidence supporting the idea that the thermal benefits of social contact extend to humans also exists. One study showed that in the first two days after birth, newborns either kept skin-to-skin or swaddled and held in the arms of their mother had notably higher skin temperatures (measured on the thigh and foot) compared to those swaddled and left in a nursery (Bystrova et al., 2003). Infants kept skin-to-skin with their mother also cried less- an effect consistent with previous research (Christensson et al., 1995; Michelsson et al., 1996). This could potentially be taken as evidence supporting the idea that human infant cries act as a signal to encourage social thermoregulatory contact.

More recently, some researchers have suggested that due to the adaptive benefits of thermoregulation, social and thermal responses in humans have become more broadly intertwined. Specifically, it has been proposed that feelings of social separation translate to feelings of coldness and thus a desire to feel the warmth associated with social contact, associations that promote social thermoregulatory behaviours (IJzerman et al., 2015). In the context of the separation call hypothesis, these socially elicited feelings of coldness may physiologically manifest as piloerection and chills, responses that people associate with a thermal outcome.

A link between social separation and coldness has been supported by research. In one study, participants gave lower estimates of room temperature after being asked to recall an experience of social exclusion compared to recalling an experience of social inclusion, implying that feelings of social exclusion can trigger subjective coldness (Zhong & Leonardelli, 2008). In a follow-up, feelings of social exclusion were manipulated using an online group ball tossing exercise (the 'Cyberball' paradigm: Williams & Jarvis, 2006) which was programmed to either exclude or include the participant. Participants were then asked to rate the desirability of a range of foods, and the study found that participants who completed the exclusion condition rated hot food and drink (soup and coffee) as more desirable than participants who completed the inclusion condition. This evidences the idea that beyond feelings of coldness, social exclusion may also lead to a desire to seek warmth. Furthermore, warmth may mitigate the negative effects of social exclusion. In a more recent study, participants who completed the exclusion condition of the Cyberball paradigm reported substantially higher levels of negative affect than those who completed the inclusion condition after holding a cold cup of tea for a confederate, but this difference was not present when participants instead held a warm cup of tea (IJzerman et al., 2012). Another study reported in the same paper found that participants excluded in the Cyberball paradigm showed a decrease in finger temperature over the course of the experiment, whilst no change was observed for the included participants. This can be taken as evidence that social exclusion may literally induce decreases in body temperature, not just a subjective feeling of coldness

Further research also clarifies a bidirectional link between subjective temperature perception and social feelings. In an fMRI study, participants reported greater feelings of social connection when holding a heat pack compared to a room temperature ball, indicating an effect of temperature on social feelings (Inagaki & Eisenberger, 2013). Mirroring this, participants reported feeling warmer when reading loving messages from friends and family compared to neutral, factual messages, indicating an effect of social feelings on perception of warmth. fMRI data showed overlapping activation in the ventral striatum and middle insula during the physically and socially 'warm' conditions, an overlap that was not apparent when compared to pleasant physical touch as a control stimulus. This provides some evidence for a shared neural network involved in both social and thermoregulatory responses.

1.7.2. Evidence linking piloerection and chills to temperature

Preliminary research has found subjective reports of bodily coldness after exposure to a range of non-thermal chill inducing stimuli, though this effect does appear to be specific to chills associated with negative affect (Bannister, 2019; Maruskin, Thrash & Elliot, 2012). In contrast to this, participants have sometimes been shown to report a feeling of warmth in the chest during chills (Bannister, 2020b), a response that may be specific to chills associated with positive affect (Bannister, 2019). It does however appear that chills are at least sometimes associated with a coldness response, providing partial support for a social thermoregulatory account of chills and emotional piloerection.

It may be that the temperature associations of chills vary based on the auditory features of the eliciting stimulus, though this an idea currently unexplored in the literature. Research where participants were presented with a series of sounds played on the violin or flute has however produced some interesting findings, with higher pitched and louder sounds perceived as colder than lower pitched and quieter sounds (Eitan & Rothschild, 2011). These are also features that have been associated with chill-inducing music and potentially, separation calls, though this is very much a speculative comparison to draw based on the current literature.

Whilst there seems to be some link between chills and subjective temperature, research has generally failed to find a link between chills and objective skin temperature. In a study with a musically trained sample, average skin temperature did not vary based on whether participants reported chills whilst listening to music (Blood & Zatorre, 2001), though in this case temperature was averaged across 90 second music excerpts meaning that potential brief changes in skin temperature during chill events would have been missed. In another study using continuous measures of temperature, the author claims that skin temperature maintained consistent throughout the presentation of various musical stimuli despite the presence of both chills and self-reported goosebumps (Craig, 2005). One study has found differences in skin temperature between ‘vigilance’ and ‘social’ chills, with vigilance chills associated with colder temperatures (Bannister & Eerola, 2023). This effect was however small, and it is unclear how the observed temperature differences relate to changes from baseline.

Research investigating piloerection in response to audio-visual stimuli has actually found an increase in skin temperature (though not body temperature measured using a sublingual thermometer) during piloerection (McPhetres, 2023). This aligns with the function of piloerection as an adaptive response to increase bodily temperature (Tansey & Johnson, 2015), highlighting that piloerection in response to non-thermal stimuli does provide an, admittedly small, thermoregulatory benefit. This finding could potentially be interpreted in support of the idea that emotional piloerection has a thermoregulatory function, though an association between piloerection and increased bodily temperature doesn’t align well with the claim that piloerection triggers a desire to seek warmth from social contact. It seems like a change in temperature may be a mechanical outcome of piloerection regardless of the thermal associations of the eliciting stimulus.

Overall, there isn’t currently any strong evidence to suggest that piloerection in response to non-thermal stimuli is a mechanism of social thermoregulation. There is evidence to suggest some link between chills and subjective temperature perception, however the literature in this area is mixed and in need of clarification.

1.8. The present research

The present research addresses the key claims of the separation call hypothesis outlined above by investigating responses to chill-inducing excerpts from songs with acoustic similarities to infant cries, as well as responses to actual audio of infant cries- something absent from the current published literature. Various measures in response to these stimuli have been selected to directly assess specific claims of the separation call hypothesis: (1) claims that cry-like sounds induce piloerection and chills are tested by continuously recording instances of piloerection using body cameras, and by collecting self-reports of chills experiences; (2) claims regarding socio-emotional responses are tested by collecting participants' self-reported feelings of social separation; and (3) social thermoregulatory claims are tested by collecting objective and subjective measures of bodily temperature. Pitch manipulated versions of all the stimuli used in the main study are also presented to test the proposition that pitch is a relevant factor in separation call induced piloerection and chills, and self-reports of emotional arousal and valence are collected to provide a broader overview of affective responses to the stimuli. Appropriate musical stimuli for the main procedure are selected based on the findings of pilot studies.

2 Pilot 1

2.1. Aim and study overview

To determine appropriate musical stimuli for the main study, piloerection inducing excerpts from two music videos containing cry-like auditory features (specifically high pitched crescendos and rising-falling melody contours) were identified. This study uses data collected in the laboratory as part of a larger research project (see McPhetres, Han et al. 2024). Only stimuli and measures relevant to the present research are reported here.

2.2. Participants

This study includes data from 29 participants (22 female, 7 male), ranging from 18 to 50 years in age (*M* = 22.9, *SD* = 6.8). All participants watched the ‘Nessun Dorma’ video, but only 28 watched the ‘Shallow’ video due to time constraints. Participants were recruited from the Durham University community and were either compensated with course credit or cash for their participation.

2.3. Stimuli

Participants watched a variety of video clips, presented in an MP4 format. This included a 3 minute 6 second clip from America’s Got Talent featuring a performance of the song ‘Nessun Dorma’, sang by Emanne Beasha over a backing instrumental. The music video for the song ‘Shallow’ performed by Lady Gaga and Bradley Cooper, which is 3 minutes 36 seconds long, was also included. Audio from the videos was played through headphones, and the videos were presented in a randomised order using E-Prime (v. 3.0).

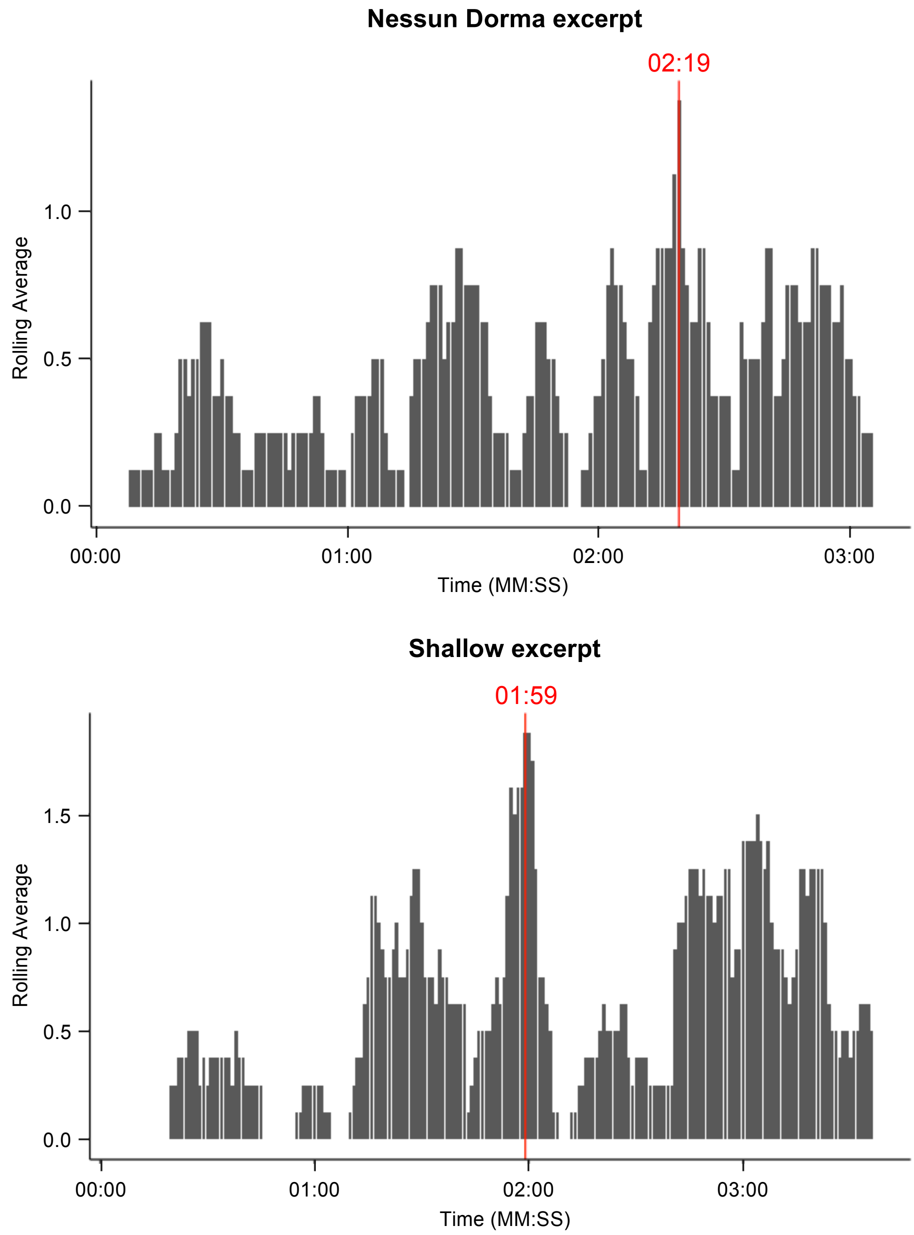
2.4. Measurement of piloerection

Body cameras (each showing roughly 5 cm^2 of skin) were strapped to participants’ dominant upper dorsolateral arm, dominant dorsal calf and to both anterolateral thighs. The camera footage was continuously recorded in OBS Studio (v. 27.1.3) and synced with Acqknowledge (v. 5.0) via an LED cable (OUT103, Biopac Systems UK). Instances of piloerection for each participant were manually coded to a 1 second accuracy using BORIS (v. 8.22, Friard & Gamba, 2016) by two separate observers.

2.5. Outcome

Histograms were generated to determine the most piloerection inducing sections of both the 'Nessun Dorma and 'Shallow' videos (Figure 1). These show time series data for the total number of piloerection events experienced, averaged across the camera locations.

Figure 1.
Histograms depicting the number of total piloerection events over time, averaged across camera locations



Note. The red line marks the peak in piloerection responding; histograms were generated in R (v. 4.2.1, R Core Team, 2022) using the 'ggplot2' package (Wickham, 2016)

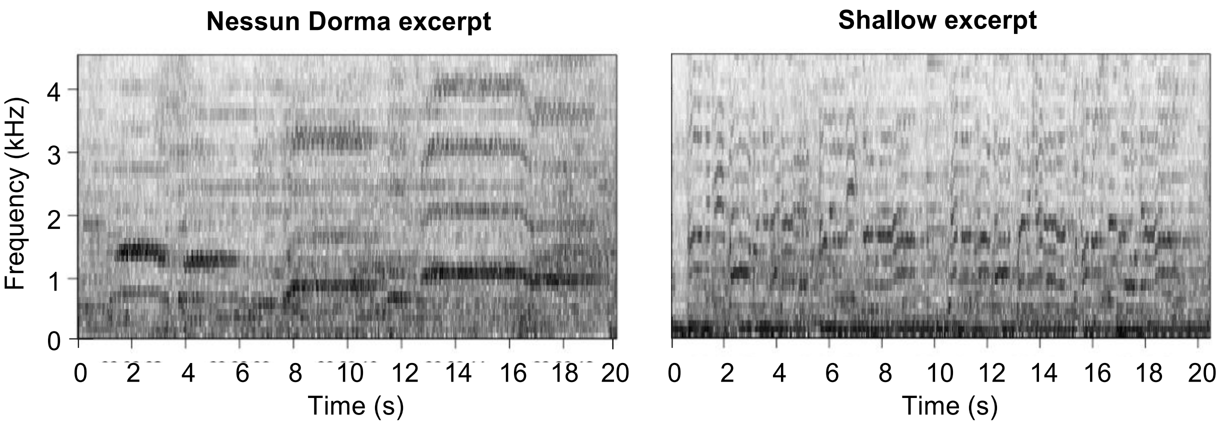
These histograms were used in to inform the selection an excerpt from each song that was particularly effective at inducing piloerection. Specifically, excerpts that incorporated the timepoint containing the highest peak in piloerection responses (marked in red on Figure 1) were selected and cut to be 20 seconds in length. The start and end times of the excerpts were selected to avoid cuts in places that interrupted the flow of the music

A total of 13.79% of participants experienced piloerection during the selected 'Nessun Dorma' excerpt. A total of 21.43% of participants experienced piloerection during the selected 'Shallow' excerpt.

2.6. Auditory features of the selected excerpts

To inspect the auditory properties of the selected excerpts more closely, spectrograms were created (Figure 2). These diagrams provide an overview of the frequencies present within each excerpt over time, with darker areas representing higher amplitude (loudness). Based on these, it is evident that Shallow excerpt contained more complex arrangements of acoustic structures than the Nessun Dorma excerpt.

Figure 2.
Spectrograms depicting the Shallow and Nessun Dorma excerpts

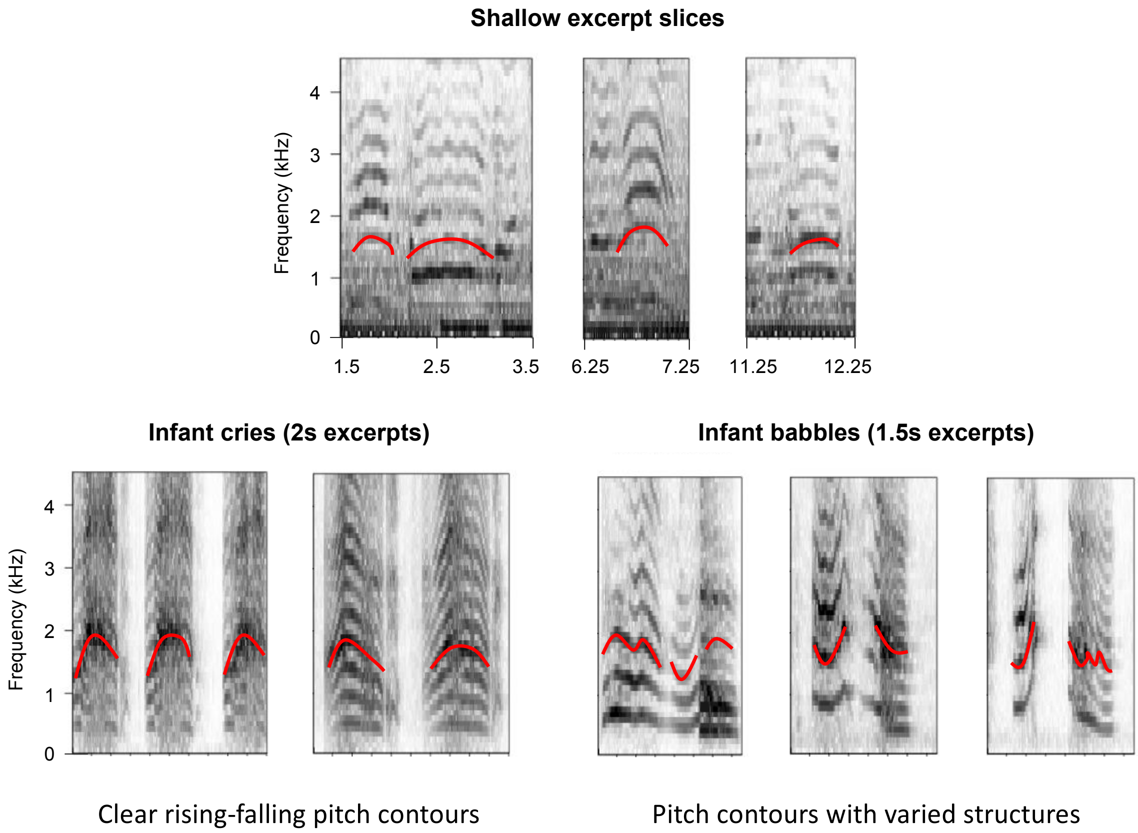


Note. Spectrograms generated in R (v. 4.2.1, R Core Team, 2022) using the packages 'monitoR' (Hafner & Katz, 2018) and 'tuneR' (Ligges et al., 2023)

Closer inspection of the spectrograms shows that the Shallow excerpt contains frequent rising-falling melody contours, a feature characteristic of infant cries (Soltis, 2004). Figure 3 depicts this similarity by showing examples of these melody contours alongside examples of infant cry vocalisations. Examples of infant babbling vocalisations, which do not adhere to this rising-falling structure, are also included for comparison. The melody contours of the Nessun Dorma excerpt have less resemblance to infant cries, instead this excerpt contains prolonged vocalisations of individual notes, which have long and flat structures (see Figure 1). The structures may however speculatively be said to reflect the ‘prolonged wail’, which Panksepp (1995, p.200) has previously described in relation to separation calls.

Figure 3.

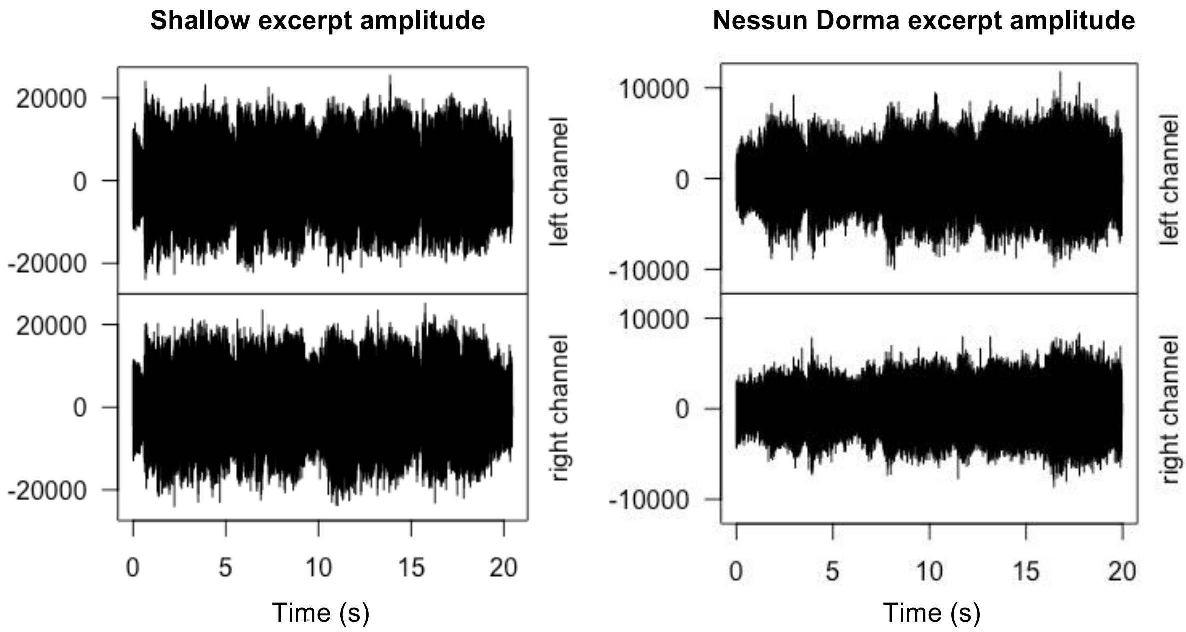
Shallow excerpt compared to spectrograms of infant cries and babbling vocalisations



Note. Red lines included for illustrative purposes to approximate the pitch trajectory; spectrograms depicting infant cry and babbling vocalisations were generated using audio files downloaded from https://bigsoundbank.com/ (Sardin, n.d.)

Whilst lacking cry-like pitch contours, the Nessun Dorma excerpt is prototypical of the high pitched crescendos described by Panksepp (1995). As can be seen in Figure 1, high frequencies are prominent within the music. In addition, amplitude plots shown in Figure 4 demonstrate the overall crescendo of sounds within this excerpt. High frequencies are also prominent within the Shallow excerpt, though this clip features a comparatively more consistent amplitude.

Figure 4.
Amplitude plots of the Shallow and Nessun Dorma excerpts



Note. Spectrograms generated in R (v. 4.2.1, R Core Team, 2022) using the packages 'monitoR' (Hafner & Katz, 2018) and 'tuneR' (Ligges et al., 2023)

In summary, both excerpts have structural similarities to infant separation cries. Specifically, this relates to rising-falling melody contours present in the Shallow excerpt and the high pitched crescendos present in the Nessun Dorma excerpt.

3. Pilot 2

3.1. Aim and study overview

A laboratory study was conducted to identify a control stimulus. To do this, instances of piloerection and chills were recorded whilst participants listened to a selection of songs, with the goal of selecting an excerpt from the song least effective at inducing these responses.

3.2. Participants

Nine undergraduate students (8 female, 1 male) were recruited from the Durham University psychology department. Participants signed up through an online portal called SONA and were compensated with course credit for their time. Age of participants ranged from 18 to 21 years (*M* = 19.0, *SD* = 1.0).

3.3. Stimuli

Participants listened to four songs from a range of genres. These songs were selected by the principal researcher as, upon a cursory inspection, they either seemed to lack notable musical crescendos, or maintain a relatively low pitch throughout the song. This contrasts with the cry-like stimuli identified in Pilot 1, although all songs included a human vocal to make them broadly comparable to Pilots 1 excerpts. Details of the songs are provided in Table 1.

Table 1.
A summary of the musical stimuli shown to participants

Song name	Artist	Song length (s)
Karma Police	Radiohead	263
One Dance	Drake	244
Sweetest Thing	U2	195
The Girl From Ipanema	Astrud Gilberto and Stan Getz	170

The songs were played through a set of Sennheiser HD 201 headphones in a random order using E-Prime (v.3.0). They were presented in an MP4 format with a blank black screen, which turned to white at the end of the song. This decision to not present the songs with accompanying music videos was made since, unlike Pilot 1, the data collection methods for this study were chosen with the specific auditory claims of the separation call hypothesis in mind.

3.4. Measures

3.4.1. Piloerection

An LED lit body camera was strapped to participants' dominant upper dorsolateral arm. Compared to the multi-camera setup used in Pilot 1 (and later the main study), this setup allowed participants to be tested in shorter 30-minute sessions and reduced the time needed to code the data. Given previous research showing a large correlation between the occurrence of piloerection across various body locations (McPhetres, Han et al., 2024), the single-camera setup was not expected to have a substantially detrimental impact on detection of piloerection.

Data from the camera was recorded using OBS Studio (v. 27.1.3) and Acqknowledge (v. 5.0), in the same manner as Pilot 1. Piloerection was initially coded to a 1 second accuracy using BORIS (v. 8.22, Friard & Gamba, 2016), and this information was then used to code piloerection as a binary value (did not occur = 0, did occur = 1) for each song.

3.4.2. Subjective chills

After each song participants were asked whether they had experienced chills, which were defined to participants at the start of the procedure as 'an emotional response accompanied by gooseflesh, shivers and/or tingling sensations' (taken from Bannister, 2020b, p.298). Participants answered either 'yes' or 'no'.

3.5. Outcome

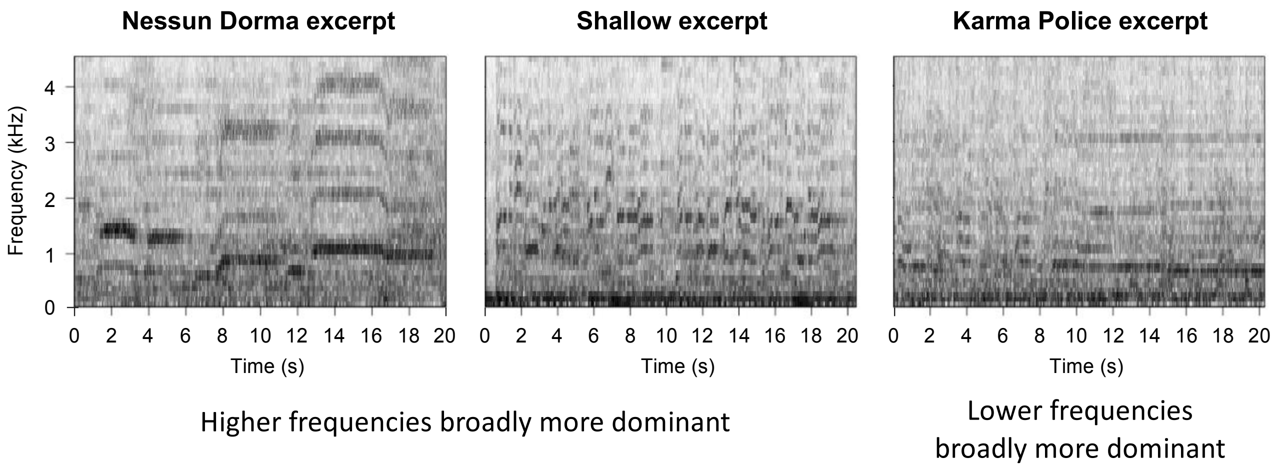
The number of participants who experienced chills and piloerection during each song is shown in Table 2. *Karma Police* was associated with chills for the fewest participants, followed by *The Girl from Ipanema* then *Sweetest Thing* and *One Dance*. Only *The Girl from Ipanema* and *One Dance* were associated with any instances of piloerection.

Table 2.
Percentage of participants who experienced piloerection and chills whilst listening to each song

	Piloerection	Chills
Karma Police	0.00%	22.22%
One Dance	25.00%	44.44%
Sweetest Thing	0.00%	44.44%
The Girl from Ipanema	12.50%	33.33%

As it was the least effective song at inducing chills, *Karma Police* was selected for use in the main study. To match the musical excerpts selected in Pilot 1, a 20 second excerpt of the song was selected. This excerpt reflects the musical climax towards the end of the song and features a prolonged vocal similar to the Nessun Dorma excerpt. It is also notable that high frequencies seem to be less dominant in this excerpt compared to those selected in Pilot 1, as depicted in Figure 5.

Figure 5.
Spectrograms comparison of music excerpts selected from Pilot 1 and Pilot 2



Note. Spectrograms generated in R (v. 4.2.1, R Core Team, 2022) using the packages 'monitoR' (Hafner & Katz, 2018) and 'tuneR' (Ligges et al., 2023)

4. Main Study: Methods

4.1. Aim and study overview

To test the claims of the separation call hypothesis (Panksepp, 1995, 2009), participants' reactions to cry-like stimuli (the music excerpts from Pilot 1 and actual audio of infant cries) were compared to control stimuli (the Karma Police excerpt from Pilot 2 and audio of infant babbling vocalisations). Specifically, measures of piloerection and chills, feelings of separation distress and coldness were tested, alongside more general affective measures of arousal and valence. Two versions of each stimulus were presented (one pitch manipulated and the other unedited) to test the proposition that high pitch is a relevant factor for inducing the 'separation responses' described by the theory.

4.2. Participants

Forty-three participants, 32 females and 11 males, were recruited between November 2023 and March 2024. The age of participants ranged from 18 to 24 years (M = 20.16, SD = 1.34). A power simulation with 1000 resamples indicates that a sample of this size with 14 within person repetitions, should have 87.6% power to detect effects of R^2 = .022 or higher.

The study was advertised to psychology students using an online portal called SONA, and to the wider Durham University community via a centrally distributed online newsletter. Individuals with severe hearing impairments and those who completed the pilot studies were excluded from participating. Participants were compensated with either course credit or £10 cash for their time

4.3. Stimuli

Participants were presented with a series of audio excerpts. This included the 20 second music excerpts identified from Pilot 1 (*Nessun Dorma* and *Shallow*) and Pilot 2 (*Karma Police*). Audio clips featuring actual infant vocalisations were also presented. This included cry vocalisations from a one-month-old (*Cry 1*) and a two-month-old (*Cry 2*) human infant, along with babbling vocalisations from a three-month-old (*Babble 1*) and a four-month-old (*Babble 2*) infant. These recordings of infant vocalisations were all downloaded in an MP3 format from https://bigsoundbank.com/ (Sardin, n.d.), and were recorded in studio conditions using a Tascam DR-40 recorder and a Sennheiser ME66 microphone. Representative 12s excerpts of each these recordings were created using the ‘cut’ tool in Audacity (v. 3.3.3). In some instances, this involved trimming the gaps where there was a long period of silence between vocalisations.

Pitch manipulated versions of all the audio excerpts were also created in Audacity (v. 3.3.3) using the ‘change pitch’ tool with the ‘use high quality stretching’ feature selected. This allowed the frequencies within the audio excerpt to be altered without changing the length of the excerpt. For the excerpts with cry-like features (expected to induce high rates of piloerection and chills) the pitch was manipulated down. This was done to decrease the resemblance of these excerpts to descriptions of separation calls, and subsequently to test whether this manipulation decreases piloerection and chill responding. For control excerpts without cry-like features (expected to induce low rates of piloerection and chills), the pitch was manipulated up. This was done to increase resemblance of these excerpts to descriptions of separation calls, and to test whether this manipulation increases piloerection and chill responding.

For the purposes of analysis, these stimuli are grouped according to three different categories: trial type (expected or control), sound type (music or cry) and pitch type (low pitch or high pitch). These categories are explained in more detail below and are depicted in Figure 6.

Figure 6.

The stimuli used for the main study, separated into trial type, pitch type and sound type

TRIAL TYPE \ PITCH TYPE	**Low Pitch** *Lesser* separation responses expected	**High Pitch** *Greater* separation responses expected
Expected (**Music**, **Cry**) *Greater* separation responses expected	**Shallow- 75% pitch** **Nessun Dorma- 75% pitch** **Cry 1- 75% pitch** **Cry 2- 75% pitch**	**Shallow- original** **Nessun Dorma- original** **Cry 1- original** **Cry 2- original**
Control *Lesser* separation responses expected	Karma Police- original Babble 1- original Babble 2- original	Karma Police- 125% pitch Babble 1- 125% pitch Babble 2- 125% pitch

Note. 'Expected' refers to stimuli with cry-like auditory features whilst 'control' refers to stimuli without these features; purple text denotes the cry-like music excerpts whilst red text denotes excerpts featuring actual infant cries

4.3.1. Trial type

The *expected* stimulus group refers to the audio excerpts that structurally reflect separation calls. This includes the Nessun Dorma and Shallow excerpts, which have cry-like musical features and have previously been associated with piloerection, and the actual infant cry vocalisations, which are a direct representation of separation calls.

The *control* stimulus group refers to the audio excerpts that do not structurally reflect separation calls, and that act as counterparts to the expected stimuli. This includes the Karma Police excerpt, which lacks cry-like features and has been associated with low rates of piloerection and chills. This piece of music therefore provides a control to the Nessun Dorma and Shallow excerpts. Also included in this group are audio excerpts of infant babbling vocalisations, a vocalisation that is easy to distinguish from infant crying. These babbling excerpts provide a control to the cry excerpts and are included to establish whether cry vocalisations have a unique effect of the present measures beyond the effect of other infant vocalisations.

4.3.2. Sound type

This category exclusively includes the stimuli that structurally reflect separation calls. The *music* stimulus group refers to the cry-like music excerpts (Nessun Dorma and Shallow). The *cry* stimulus group refers to the actual infant cry vocalisations (Cry 1 and Cry 2).

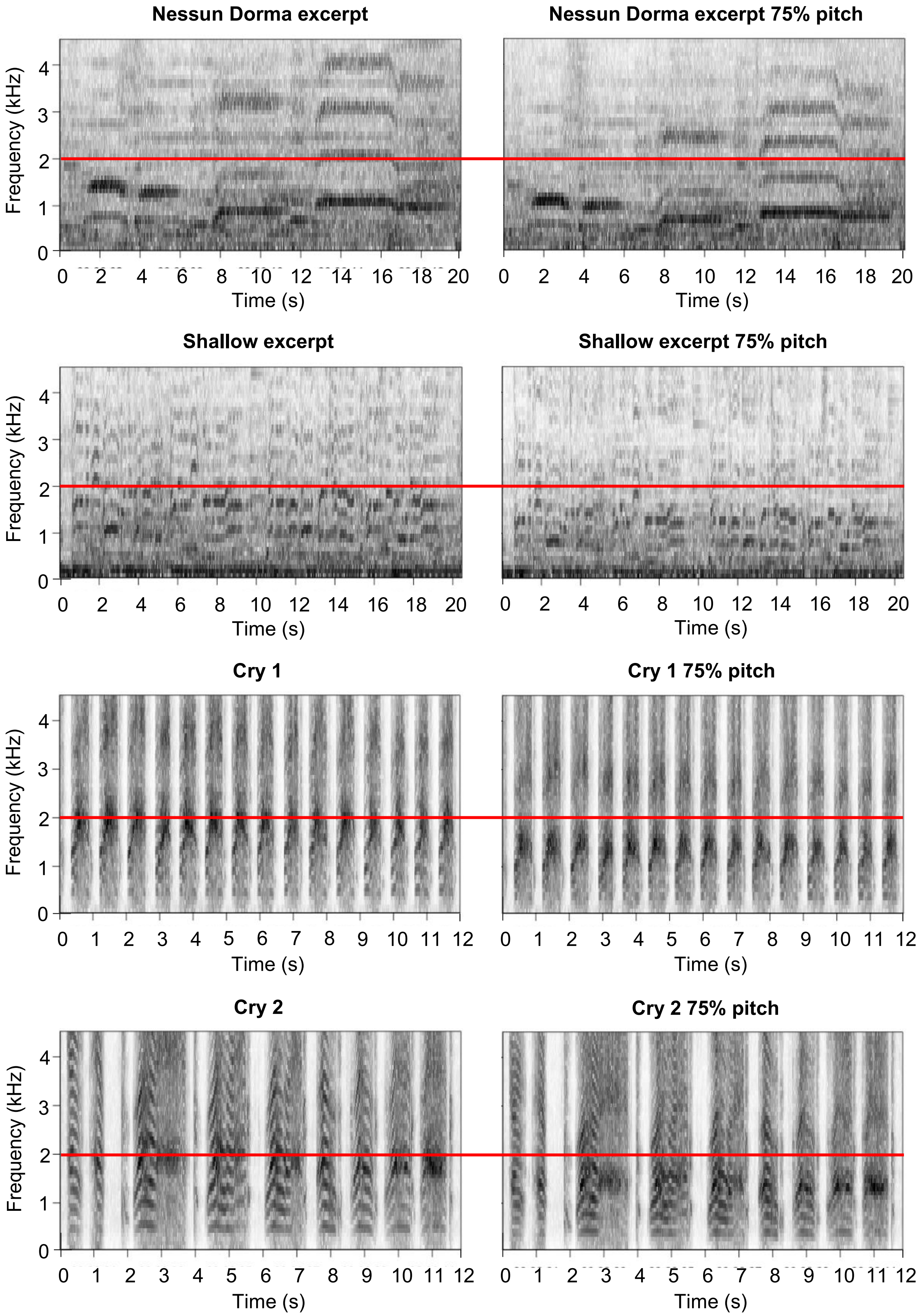
4.3.3. Pitch type

The *low pitch* stimulus group refers to the unedited control stimuli, and versions of the expected stimuli that have been pitched down to 75% frequency (to less closely resemble a separation call).

The *high pitch* stimulus group refers to the unedited expected stimuli, and versions of the control stimuli that have been pitched up to 125% frequency (to more closely resemble a separation call).

The effects of pitch manipulation on the expected stimuli are depicted using spectrograms in Figure 7, whilst the effects on the control stimuli are depicted in Figure 8.

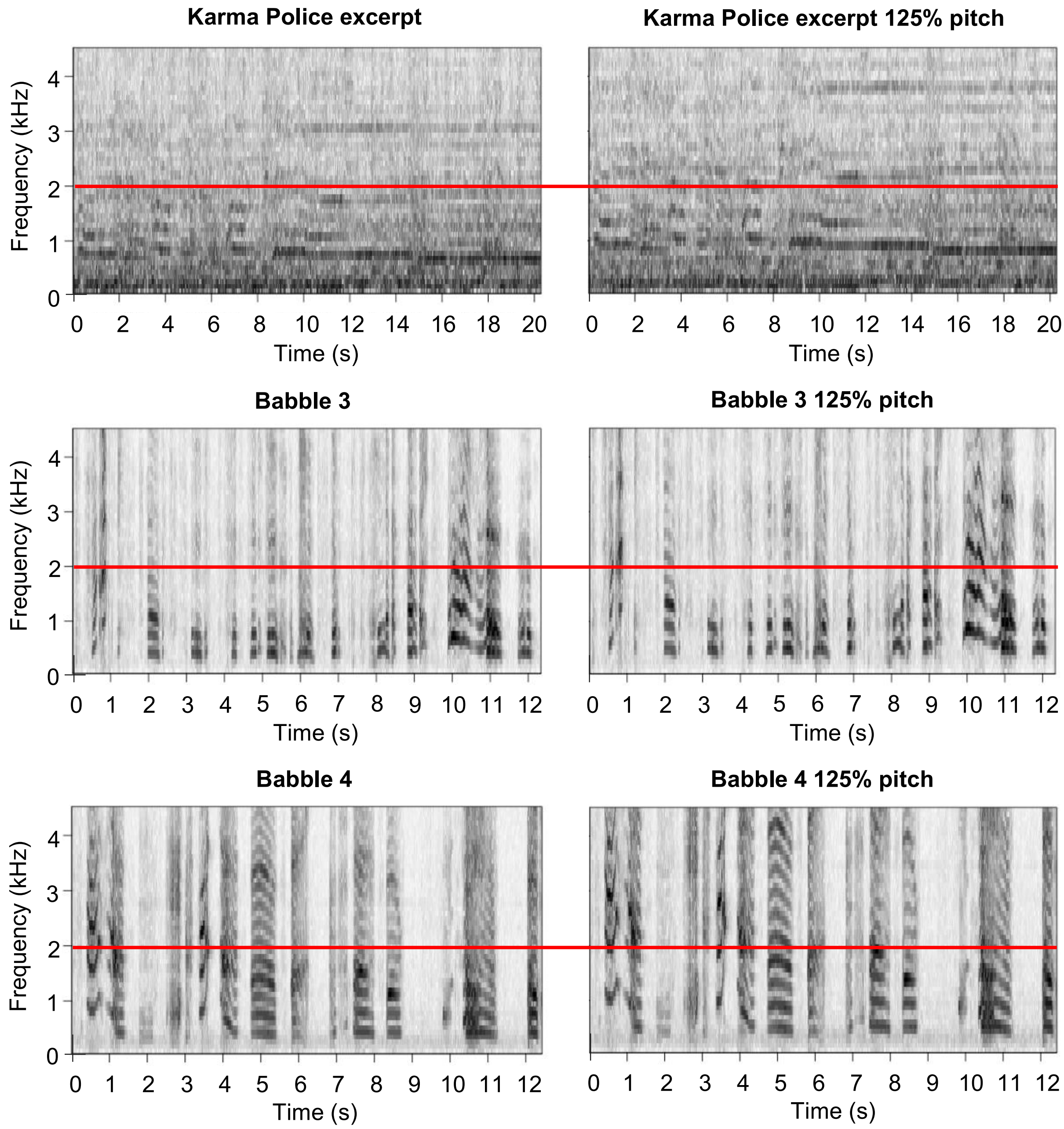
Figure 7.
Spectrograms depicting the original and pitched-down 'expected' excerpts



Note. The red lines provide a reference point at 2kHz; spectrograms were generated in R (v. 4.2.1, R Core Team, 2022) using the packages 'monitoR' (Hafner & Katz, 2018) and 'tuneR' (Ligges et al., 2023)

Figure 8.

Spectrograms depicting the original and pitched-up 'control' excerpts



Note. The red lines provide a reference point at 2kHz; spectrograms were generated in R (v. 4.2.1, R Core Team, 2022) using the packages 'monitoR' (Hafner & Katz, 2018) and 'tuneR' (Ligges et al., 2023)

4.4. Measures

4.4.1. Piloerection

Footage from four body cameras strapped to participant's dominant upper dorsolateral arm, dominant dorsal calf and their left and right anterolateral thighs was continuously recorded using the same method as the pilot studies. This footage was later coded for piloerection by two independent observers whenever bumps in the skin were seen to emerge symmetrically around the hair follicle, and whenever twitches in skin were observed between the hair follicles. First, footage from each of the camera locations was inspected separately, and timepoints for the start of each observed piloerection event were recorded to a 1-second accuracy using BORIS (v. 8.22; Friard & Gamba, 2016). Timepoints from these different locations were then combined and used to code the occurrence of piloerection during each audio excerpt as a binary value (did not occur = 0, did occur = 1). This method resulted in 97.4% agreement between observers. Before analysis, the lead researcher revisited the camera footage of the few disputed trials and made the final decision about how these should be coded.

4.4.2. Subjective chills

Participants were directed to press a hand button (connected to a Biopac MP160 AMI100D unit; BIOPAC Systems UK) whenever they experienced chills during the experiment. A reminder to press the button for this purpose was displayed on the screen before the presentation of each excerpt. Chills were defined to participants as ‘an emotional response accompanied by gooseflesh, shivers and/or tingling sensations’ (from Bannister, 2020b, p.298).

4.4.3. Separation distress

After each audio trial, participants were asked to rate their levels of loneliness (1 = not at all lonely, 5 = extremely lonely) and desire for social contact (1 = very much prefer to spend time with someone, 5 = very much prefer to spend time alone) using 5-point scales. These questions were adapted from prior research into social isolation and social craving (Stijovic et al., 2023; Tomova et al. 2020).

4.4.4. Objective bodily temperature

Continuous temperature measures were recorded through AcqKnowledge v 5.0 using Biopac equipment (BIOPAC Systems, UK). Skin temperature was measured via a skin temperature thermistor (TSD202B) taped next to the body camera on participants’ upper dorsal arm. Another of these sensors was taped to the back of the camera on participants’ arm to record the ambient temperature, used as a control variable. These sensors were then wired to a BioNomadix transmitter strapped around participants chest, and the signals were recorded using a Biopac MP160 SKT2-R unit. Body temperature was measured using a sublingual thermometer (TSD202F) covered in a plastic sheath. This thermometer was wired directly to a Biopac MP160 SKT100c unit.

Before analysis, temperature data for each audio condition was pre-processed and written out using Mindware BSA (v 3.2.9) This involved omitting any data segments for audio trials where temperature varied by more than 1°C, indicating a loss of signal.

4.4.5. Subjective bodily temperature

After each audio excerpt, participants were asked to rate how they would describe their body temperature during the excerpt using a 5-point scale (1 = very cold, 5 = very hot). This question was adapted from previous piloerection research (McPhetres, 2023).

4.4.6. Emotional arousal and valence

After each audio excerpt, participants were asked to rate their emotional arousal (1 = not at all intense, 5 = extremely intense) and valence (1 = very negative, 5 = very positive) during each excerpt using 5-point scales. The valence question was also adapted from previous piloerection research (McPhetres, 2023).

4.5. Procedure

Participants attended an in-person lab session at Durham University's psychology department. After confirming consent to participate in the study, participants were connected to body cameras and temperature sensors, as previously described. All these physiological measures were recorded and synced using Acqknowledge (v. 5.0) for the duration of the study. Participants then sat in front of a monitor and started a procedure run using e-prime (v. 3.0).

Participants first reported their age and gender and were then directed to wear a pair of Sennheiser HD 201 headphones. After this, participants watched a 2 minute 30 second video of a walk through the woods (a stimulus used in previous research: McPhetres, Han et al., 2024) which allowed time for the temperature sensors to acclimate. Baseline measures of temperature were collected from the last minute of the video. Participants then listened to each of the audio excerpts in a random order whilst using a button to report instances of chills. After every excerpt, participants answered each of the self-report questions, also presented in a random order. A timer was used to ensure that a period of at least one minute was left after one audio excerpt ended before the next began. After watching all the excerpts participants were debriefed and received compensation. The procedure typically lasted between 45 and 60 minutes.

4.6. Hypotheses

Based on the claims of the separation call hypothesis, it is expected that stimuli resembling the cry-like properties of separation calls (e.g. high pitched crescendos and rising-falling melody contours) will induce a specific pattern of ‘separation responses’. Specifically, it is predicted that these stimuli will be associated with an increased likelihood of chills/piloerection, increased levels of separation distress, and increased levels of both objective and subjective bodily coldness.

It is also expected that actual audio of infant cries will be associated with stronger separation responses relative to cry-like music excerpts, as these are a direct representation of separation calls.

Finally, pitch manipulations are expected to differentially affect the stimuli by increasing or decreasing resemblance to prototypically high-pitched separation call. Decreasing the pitch of the cry and cry-like stimuli (which already resemble separation calls) should decrease separation responses whilst increasing the pitch of the control stimuli (which are originally dissimilar to separation calls) may potentially increase these responses. Put differently, the high-pitched versions of the stimuli are expected to be associated with stronger separation responses than the low-pitched versions of the stimuli.

5. Main Study: Results

5.1. Data overview

Data was collected for 43 participants and with one exception, the participants listened to all 14 audio conditions. Due to a glitch when running eprime, one participant only listened to 13 of the audio conditions (missing *Babble 1- 125% pitch*). This means that data was collected across 601 trials. Data from all these trials was available for each of the self-reported measures, however due to technical issues, some trials were missing piloerection or temperature data.

5.1.1. Piloerection data loss

Due to malfunction in camera recording, two participants were missing full piloerection data, and another participant was missing data from two trials (the *Karma Police- original* and *Nessun Dorma- original* excerpts). This leaves data from 571 of the 601 trials.

A further seven participants were missing data from one of the four cameras due to specific hardware issues. In four cases this affected the calf camera and in three this affected the arm camera. Prior research has demonstrated that participants experience largely equal rates of piloerection across the four camera locations selected for this study (McPhetres, Han et al., 2024) so this is not expected to have a substantial detrimental impact on the present findings.

5.1.2. Temperature data loss

Skin temperature data from one participant was excluded due to the sensor detaching during the procedure, and body temperature data from a different participant was excluded due to movement artifacts. This leaves data from 587 of the 601 trials for both these measures.

Ambient temperature data for two participants was unavailable, in one case because of movement artifacts and in the other because of a lack of equipment availability due to a resource allocation error. This leaves data from 573 of the 601 trials.

5.2. Analysis procedure

The data was analysed using mixed effects models, a method selected as it allows analysis of multi-level data whilst being highly robust to distributional variation (Schielzeth et al., 2020). The analyses were performed in R (v. 4.2.1, R Core Team, 2022) using the 'lmerTest' (Kuznetsova et al., 2017) and 'r2glmm' (v 0.1.2, Jaeger, 2017) packages. All models used fixed slopes with random intercepts for participant ID. Following previously established guidelines (Barr et al., 2014), more complex models which used either random slopes or random intercepts for each audio trial were tested, but in these cases there was either an insufficient number of total trials to support the analysis, or the addition was flagged as redundant. Copies of the R scripts used can be found on the Open Science Framework: https://osf.io/nydtq/?view_only=83598c61f87840dca277937556e10ce2.

5.3. Piloerection and chills

5.3.1. Descriptive statistics.

The percentages of participants who displayed piloerection and reported chills during each trial are shown in Table 3. The hypothesis predicts that occurrence of piloerection and chills should be greater in response to the: expected compared to control trials, cry compared to music trials and high pitch compared to low pitch trials. A cursory look at the data shows that the occurrence of piloerection was generally much less frequent than the occurrence of chills. The expected trials did induce more chills than the control trials, though this doesn't appear to be the case for piloerection. Both measures were also more frequent in response to the music compared to the cry trials, and the direction of the differences between pitch conditions was not consistent. Interestingly, the babbling clips elicited piloerection at similar frequency to the clips in the expected trials. In addition, the Karma Police excerpt elicited chills at a similar frequency to the clips in the expected trials.

Table 3.
Percentage of participants who experienced piloerection and chills during each trial

Audio Excerpt	Piloerection		Chills	
	Low Pitch	High Pitch	Low Pitch	High Pitch
Expected				
Cry 1	0.00%	0.00%	23.26%	20.93%
Cry 2	0.00%	2.44%	18.60%	23.26%
Nessun Dorma	2.44%	5.00%	27.91%	32.56%
Shallow	4.88%	7.32%	37.21%	27.91%
Control				
Babble 1	2.44%	7.50%	11.63%	11.90%
Babble 2	2.44%	0.00%	9.30%	9.30%
Karma Police	2.50%	4.88%	23.26%	23.26%

5.3.2. Piloerection.

To examine the differences in piloerection responding between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed. Originally analysis was attempted using binomial family generalised linear mixed effects models. Attempts to run these models however flagged issues of convergence due to low variance within the grouping variables. Because of this, standard linear mixed effect models were used instead. Ambient temperature was also controlled to ensure that one primary cause of piloerection was accounted for.

The first model (top half of Table 4) examined the differences between the control and expected trials. This was done using a regression equation predicting piloerection with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model (R^2 = .013) did not indicate any effect of trial or pitch type, suggesting that the sounds reflecting separation calls were not more effective at inducing piloerection than controls, and that piloerection was not sensitive to pitch manipulation.

Table 4.
Effects of trial, sound and pitch type on piloerection

Predictor	*β*	*SE*	*t*	*df*	*p*	*semi part. R^2*
Control / Expected Model						
Trial Type	-0.004	0.016	-0.272	501.135	.786	< .001
Pitch Type	-0.017	0.018	-0.970	501.068	.333	.002
Trial Type * Pitch Type	-0.002	0.023	-0.095	501.038	.924	< .001
Ambient Temperature	-0.007	0.011	-0.626	46.929	.535	.007
Cries / Music Model						
Sound Type	0.052	0.021	2.512	269.101	.013	.018
Pitch Type	-0.013	0.021	-0.626	269.024	.532	.001
Pitch Type * Sound Type	-0.013	0.029	-0.458	269.064	.647	.001
Ambient Temperature	-0.011	0.011	-0.925	42.896	.360	.015

Note. '*' denotes that p < .05, '**' denotes that p < .01

The next model (bottom half of Table 4) examined whether the cries or cry-like music were more likely to induce piloerection, and whether these interacted differently with pitch. This was done using a regression equation predicting piloerection with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model ($R^2 = .047$) indicates that occurrence of piloerection was more probable during music (4.91% occurrence) compared to cry trials (0.61% occurrence, $\beta = 0.052$), explaining 1.8% of the variance in the data. No effect of pitch type was found, again suggesting that piloerection was not sensitive to pitch manipulation.

5.3.3. Chills.

To examine the differences in chill responding between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using binomial family generalised linear mixed effect models. Ambient temperature was included as a control variable.

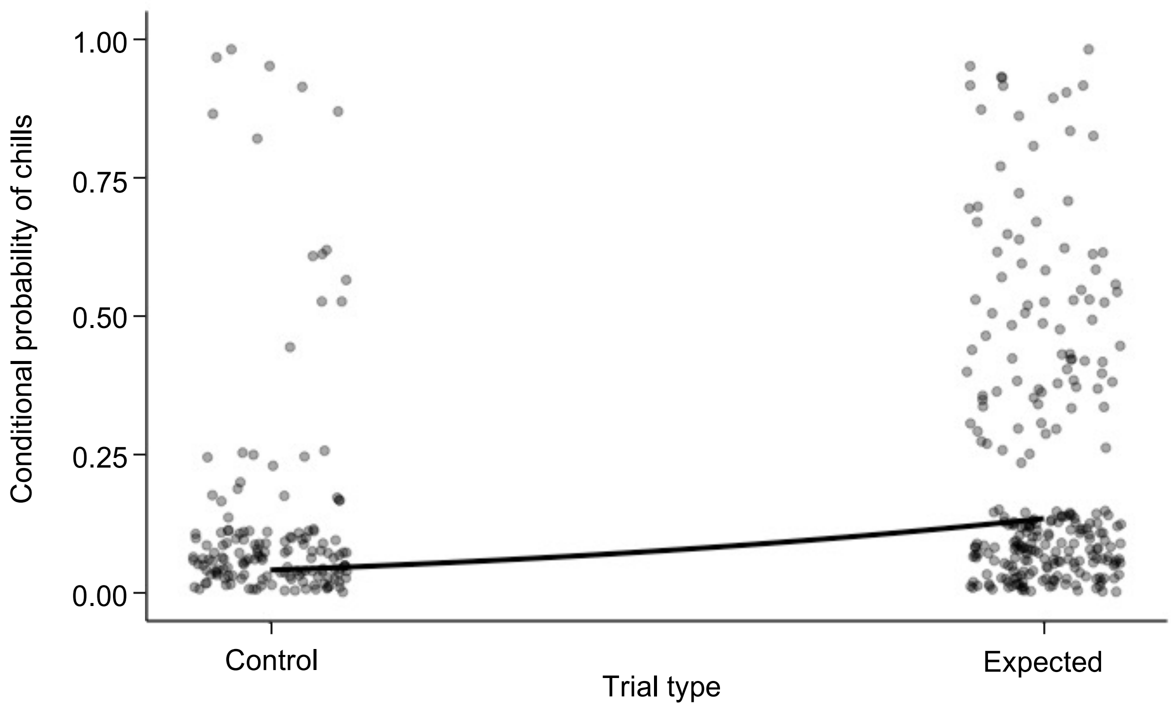
The first model (top half of Table 5) examined the differences between the control and expected trials. This was done using a regression equation predicting chills with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model ($R^2 = .042$) indicates that chills were 3.3 times more likely to be reported during the expected compared to the control trials, explaining a modest 1.6% of the variance in the data (effect depicted in Figure 9). This particular finding is unsurprising given the piloerection/chills criteria used to select the music excerpts used as expected and control stimuli. There was however no effect of pitch type or an interaction, suggesting that chills were not sensitive to pitch manipulation.

Table 5.
Effects of trial, sound and pitch type on chills

Predictor	*Odds Ratio*	*p*	*semi part. R^2*
Control / Expected Model			
Trial Type	3.309	.002**	.016
Pitch Type	0.905	.823	< .001
Trial Type * Pitch Type	1.164	.782	< .001
Ambient Temperature	0.826	.461	.005
Cries / Music Model			
Sound Type	2.417	.065	.010
Pitch Type	0.884	.803	< .001
Pitch Type * Sound Type	1.394	.620	.001
Ambient Temperature	0.852	.588	.004

Note. '*' denotes that p < .05, '**' denotes that p < .01

Figure 9.
Conditional probability of chills by trial type (control / expected)

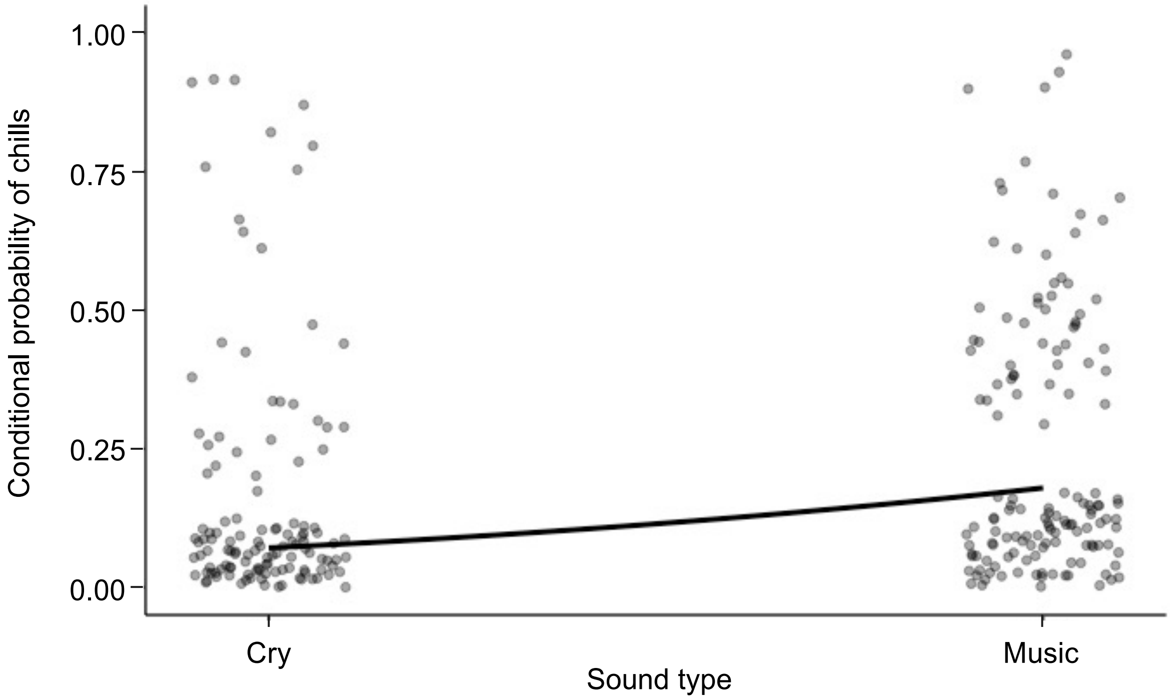


Note. Points indicate partial residuals controlling for pitch and ambient temperature

The next model (bottom half of Table 5) examined whether the cries or cry-like music were more likely to induce chills, and whether these interacted differently with pitch. This was done using a regression equation predicting chills with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model ($R^2 = .032$) indicates that chills were 2.4 times more likely to be reported during music compared to cry excerpts (effect depicted in Figure 10). This effect explains 1.0% of the variance in the data but falls short of a 5% significance level. No effect of pitch was found or an interaction, again suggesting that piloerection was not sensitive to pitch manipulation.

Figure 10.

Conditional probability of chills by sound type (cry / music)



Note. Points indicate partial residuals controlling for pitch and ambient temperature

5.4. Separation distress

5.4.1. Descriptive statistics.

The average loneliness and desire for social contact ratings given after each trial are shown in Table 6. The hypothesis predicts that loneliness and desire for social contact (reverse coded) should be greater in response to the: expected compared to control trials, cry compared to music trials and high pitch compared to low pitch trials. An initial look at the data indicates that loneliness ratings were similar across all trial types, although the *Shallow- 75% pitch* excerpt stands out as having a slightly higher loneliness rating. The expected trials look to have been given higher ratings on the desire for social contact scale (indicating a greater preference for aloneness over social interaction) compared to the control trials, a difference that is largely driven by comparatively high ratings for the cry excerpts rather than by the music excerpts. For the control trials, the pitched-up excerpts elicited higher (aloneness) ratings on the desire for social contact scale than the original, low pitch excerpts. For the expected trials, the direction of the differences in desire for social contact between pitch conditions is however inconsistent.

Table 6.
Loneliness and desire for social contact ratings for each trial

Audio Excerpt	Loneliness (1-5)		Desire for social contact (1-5)	
	Low Pitch	High Pitch	Low Pitch	High Pitch
Expected				
Cry 1	1.60	1.49	3.23	3.14
Cry 2	1.60	1.63	3.19	3.23
Nessun dorma	1.35	1.49	2.86	2.86
Shallow	1.79	1.49	2.93	2.72
Control				
Babble 3	1.47	1.45	2.74	2.86
Babble 4	1.53	1.56	2.77	2.91
Karma police	1.56	1.53	2.86	2.91

Note. For loneliness: 1 = not at all lonely, 5 = extremely lonely; for desire for social contact: 1 = very much prefer to spend time with someone, 5 = very much prefer to spend time alone

5.4.2. Loneliness.

To examine the differences in loneliness between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using linear mixed effect models. Ambient temperature was included as a control variable.

The first model (top half of Table 7) examined the differences between the control and expected trials. This was done using a regression equation predicting loneliness with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model (R^2 = .009) did not indicate any effect of trial or pitch type, suggesting that the sounds reflecting separation calls were not more effective at inducing loneliness than controls, and that loneliness was not sensitive to pitch manipulation.

Table 7.
Effects of trial, sound and pitch type on loneliness

Predictor	*β*	*SE*	*t*	*df*	*p*	*semi part. R^2*
Control / Expected Model						
Trial Type	0.003	0.063	0.044	529.210	.965	< .001
Pitch Type	-0.001	0.067	-0.008	528.994	.994	< .001
Trial Type * Pitch Type	-0.055	0.088	-0.625	528.990	.532	.001
Ambient Temperature	-0.026	0.050	-0.526	55.183	.601	.007
Cries / Music Model						
Sound Type	-0.074	0.080	-0.917	283.810	.360	.002
Pitch Type	0.036	0.080	0.447	283.832	.655	.001
Pitch Type * Sound Type	0.038	0.114	0.331	283.839	.741	< .001
Ambient Temperature	-0.044	0.054	-0.828	48.424	.412	.016

Note. '*' denotes that p < .05, '**' denotes that p < .01

The next model (bottom half of Table 7) examined whether the cries or cry-like music were more likely to induce loneliness, and whether these interacted differently with pitch. This was done using a regression equation predicting loneliness with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model ($R^2 = .021$) did not indicate any effect of sound or pitch type, suggesting that cry sounds were not more effective at inducing loneliness than cry-like music excerpts, and again suggesting that loneliness was not sensitive to pitch manipulation.

5.4.3. Desire for social contact.

To examine the differences in desire for social contact between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using linear mixed effect models. Ambient temperature was included as a control variable.

The first model (top half of Table 8) examined the differences between the control and expected trials. This was done using a regression equation predicting desire for social contact with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model ($R^2 = .035$) did not indicate any effect of trial or pitch type, suggesting that the sounds reflecting separation calls were not more effective at inducing desire for social contact than controls, and that desire for social contact was not sensitive to pitch manipulation.

Table 8.
Effects of trial, sound and pitch type on desire for social contact

Predictor	*β*	*SE*	*t*	*df*	*p*	*semi part. R^2*
Control / Expected Model						
Trial Type	0.114	0.081	1.408	526.541	.160	.003
Pitch Type	-0.082	0.087	-0.945	526.260	.345	.002
Trial Type * Pitch Type	-0.149	0.115	-1.301	526.260	.194	.003
Ambient Temperature	0.052	0.074	0.698	58.168	.488	.015
Cries / Music Model						
Sound Type	-0.365	0.101	-3.612	282.399	< .001**	.032
Pitch Type	0.037	0.101	0.367	282.427	.714	< .001
Pitch Type * Sound Type	0.060	0.143	0.421	282.438	.674	< .001
Ambient Temperature	0.035	0.079	0.445	51.070	.658	.006

Note. '*' denotes that p < .05, '**' denotes that p < .01

The next model (bottom half of Table 8) examined whether the cries or cry-like music were more likely to induce desire for social contact, and whether these interacted differently with pitch. This was done using a regression equation predicting desire for social contact with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model (R^2 = .032) indicates that desire for social contact was greater following music compared to cry excerpts (*β* = -0.365). This explains 3.2% of the variance in the data. No effect of pitch was found, again suggesting that desire for social contact was not sensitive to pitch manipulation.

5.5. Temperature

5.5.1. Descriptive statistics.

The average bodily temperature values recorded during each trial, and the average subjective temperature ratings given after each trial are shown in Table 9. The hypothesis predicts that both the objective and subjective measures of temperature should be lower in response to the: expected compared to control trials, cry compared to music trials and high pitch compared to low pitch trials. A cursory look at the data indicates that differences in skin and sublingual body temperature readings were very small across all the trial types. For the expected trials, the pitched-down excerpts were associated with lower subjective ratings of bodily temperature than the original, high pitch excerpts. For the control excerpts, the direction of the differences in subjective temperature between pitch conditions is inconsistent. Subjective temperature ratings also appear to be somewhat higher for the music compared to cry excerpts, though these differences are small.

Table 9.
Average measures of bodily temperature during each trial

Audio Excerpt	Skin Temp (°C)		Body Temp (°C)		Subjective Temp (1-5)	
	Low Pitch	High Pitch	Low Pitch	High Pitch	Low Pitch	High Pitch
Expected						
Cry 1	30.85	30.85	35.58	35.59	2.70	2.86
Cry 2	30.89	30.80	35.62	35.61	2.58	2.63
Nessun dorma	30.80	30.85	35.62	35.59	2.72	2.79
Shallow	30.83	30.83	35.60	35.63	2.81	3.00
Control						
Babble 1	30.82	30.78	35.61	35.61	2.93	2.83
Babble 2	30.79	30.84	35.60	35.60	2.70	2.70
Karma Police	30.84	30.87	35.63	35.63	2.70	2.84

Note. For subjective temperature: 1 = very cold, 5 = very hot

5.5.2. Skin temperature.

To examine the differences in skin temperature between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using linear mixed effect models. Ambient temperature was included as a control variable.

The first model (top half of Table 10) examined the differences between the control and expected trials. This was done using a regression equation predicting skin temperature with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model (R^2 = .090) did not indicate any effect of trial or pitch type, suggesting that the sounds reflecting separation calls were not more effective at inducing changes in skin temperature than controls, and that skin temperature was not sensitive to pitch manipulation. Changes in ambient temperature (β = -0.046), included as a control variable, explain 8.8% of the variance in the data.

Table 10.
Effects of trial, sound and pitch type on skin temperature

Predictor	*β*	*SE*	*t*	*df*	*p*	*semi part. R^2*
Control / Expected Model						
Trial Type	-0.014	0.020	-0.671	515.882	.503	.001
Pitch Type	-0.025	0.022	-1.165	515.484	.245	.002
Trial Type * Pitch Type	0.025	0.029	0.886	515.492	.376	.001
Ambient Temperature	-0.046	0.030	-1.517	182.892	.131	.088
Cries / Music Model						
Sound Type	0.001	0.026	0.028	276.900	.977	< .001
Pitch Type	0.020	0.026	0.756	276.955	.450	.001
Pitch Type * Sound Type	-0.040	0.037	-1.058	276.974	.291	.003
Ambient Temperature	-0.026	0.035	-0.759	103.683	.450	.024

Note. '*' denotes that p < .05, '**' denotes that p < .01

The next model (bottom half of Table 10) examined whether the cries or cry-like music were more likely to induce changes in skin temperature, and whether these interacted differently with pitch. This was done using a regression equation predicting skin temperature with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model (R^2 = .029) did not indicate any effect of sound or pitch type, suggesting that cry sounds were not more effective at inducing changes in skin temperature than cry-like music excerpts, and again suggesting that skin temperature was not sensitive to pitch manipulation. Here, changes in ambient temperature (β = -0.026) explain 2.4% of the variance in the data, an effect that falls short of 5% significance.

5.5.3. Sublingual body temperature.

To examine the differences in sublingual body temperature between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using linear mixed effect models. Ambient temperature was included as a control variable.

The first model (top half of Table 11) examined the differences between the control and expected trials. This was done using a regression equation predicting sublingual body temperature with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model (R^2 = .294) did not indicate any effect of trial or pitch type, suggesting that the sounds reflecting separation calls were not more effective at inducing changes in sublingual body temperature than controls, and that sublingual body temperature was not sensitive to pitch manipulation. Changes in ambient temperature (β = 0.067) however explain a very large 29.3% of the variance in the data.

Table 11.
Effects of trial, sound and pitch type on sublingual body temperature

Predictor	β	*SE*	*t*	*df*	*p*	semi part. R^2
Control / Expected Model						
Trial Type	-0.011	0.020	-0.566	508.661	.571	.001
Pitch Type	-0.006	0.021	-0.294	508.016	.769	< .001
Trial Type * Pitch Type	-0.004	0.028	-0.138	508.001	.891	< .001
Ambient Temperature	0.067	0.022	3.070	71.420	.003**	0.293
Cries / Music Model						
Sound Type	0.012	0.027	0.458	271.354	.648	.001
Pitch Type	-0.008	0.027	-0.317	271.378	.751	< .001
Pitch Type * Sound Type	0.012	0.038	0.324	271.401	.746	< .001
Ambient Temperature	0.059	0.023	2.575	50.923	.013*	.199

Note. '*' denotes that p < .05, '**' denotes that p < .01

The next model (bottom half of Table 11) examined whether the cries or cry-like music were more likely to induce changes in sublingual body temperature, and whether these interacted differently with pitch. This was done using a regression equation predicting sublingual body temperature with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model (R^2 = .201) did not indicate any effect of sound or pitch type, suggesting that cry sounds were not more effective at inducing changes in sublingual body temperature than cry-like music excerpts, and again suggesting that sublingual body temperature was not sensitive to pitch manipulation. Here, changes in ambient temperature (β = 0.059) explain 19.9% of the variance in the data.

5.5.4. Subjective temperature perception.

To examine the differences in subjective temperature perception between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using linear mixed effect models. Ambient temperature was included as a control variable.

The first model (top half of Table 12) examined the differences between the control and expected trials. This was done using a regression equation predicting subjective temperature with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model ($R^2 = .007$) did not indicate any effect of trial or pitch type, suggesting that the sounds reflecting separation calls were not more effective at inducing changes in subjective temperature perception than controls, and that subjective temperature was not sensitive to pitch manipulation.

Table 12.
Effects of trial, sound and pitch type on subjective temperature perception

Predictor	*β*	*SE*	*t*	*df*	*p*	*semi part. R²*
Control / Expected Model						
Trial Type	0.030	0.066	0.451	529.173	.652	< .001
Pitch Type	-0.007	0.070	-0.098	529.071	.922	< .001
Trial Type * Pitch Type	0.103	0.093	1.104	529.047	.270	.002
Ambient Temperature	0.004	0.033	0.118	44.463	.907	< .001
Cries / Music Model						
Sound Type	0.171	0.093	1.841	283.997	.067	.010
Pitch Type	-0.073	0.093	-0.788	284.005	.431	.002
Pitch Type * Cry Type	-0.073	0.131	-0.558	284.007	.577	.001
Ambient Temperature	0.004	0.035	0.109	41.800	.914	< .001

Note. '*' denotes that p < .05, '**' denotes that p < .01

The next model (bottom half of Table 12) examined whether the cries or cry-like music were more likely to induce changes in subjective temperature perception, and whether these interacted differently with pitch. This was done using a regression equation predicting subjective temperature with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model ($R^2 = .022$) indicates that participants felt subjectively colder during the cry compared to the music trials ($\beta = 0.171$). This explains 1.0% of the variance in the data however falls short of a 5% significance level. No effect of pitch was found, again suggesting that subjective temperature was not sensitive to pitch manipulation.

5.6. Arousal and valence

5.6.1. Descriptive statistics

The average emotional arousal and valence ratings given after each trial are shown in Table 13. The hypothesis predicts that arousal should be higher and that valence should be more negative in response to the: expected compared to control trials, cry compared to music trials and high pitch compared to low pitch trials. A cursory look at the data shows that arousal ratings were generally higher for the expected compared to the control trials. For the control trials, the original, low pitch excerpts elicited slightly greater arousal ratings than the pitched-up control excerpts. For the expected trials, the direction of the differences between pitch conditions is however inconsistent. Arousal ratings also appear generally larger for cry compared to music trials. Valence ratings for the expected trials are also generally more negative than for the control trials, a difference that is largely driven by comparatively negative ratings for the cry excerpts rather than by the ratings for the music excerpts. The direction of differences in valence ratings between pitch conditions is inconsistent.

Table 13.
Emotional arousal and valence ratings for each trial

Audio Excerpt	Arousal (1-5)		Valence (1-5)	
	Low Pitch	High Pitch	Low Pitch	High Pitch
Expected				
Cry 1	2.77	2.60	1.70	1.70
Cry 2	2.81	2.65	1.79	1.65
Nessun dorma	2.26	2.35	3.58	3.88
Shallow	2.35	2.67	3.37	3.84
Control				
Babble 1	2.28	2.21	3.53	3.33
Babble 2	2.23	1.95	3.26	2.63
Karma police	2.19	1.91	3.51	3.44

Note. For arousal: 1 = not at all intense, 5 = extremely intense; for valence: 1 = very negative, 5 = very positive

5.6.2. Emotional arousal

To examine the differences in emotional arousal between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using linear mixed effect models. Ambient temperature was included as a control variable.

The first model (top half of Table 14) examined the differences between the control and expected trials. This was done using a regression equation predicting arousal with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model (R^2 = .085) indicates that emotional arousal was higher during the expected compared to the control trials (β = 0.555), explaining a reasonably high 6.2% of the variance in the data. Emotional arousal was also higher during the low pitch compared to the high pitch trials (*β* = 0.238), explaining 1.1% of the variance within the data.

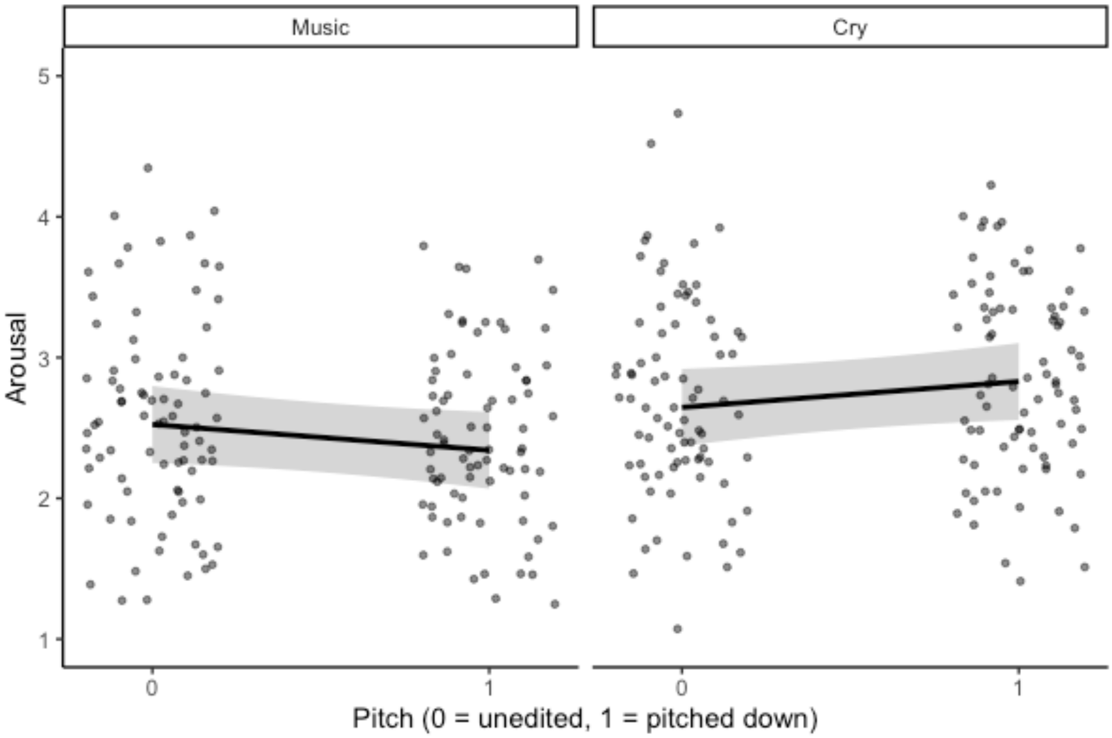
Table 14.
Effects of trial, sound and pitch type on emotional arousal

Predictor	*β*	*SE*	*t*	*df*	*p*	*semi part.* R^2
Control / Expected Model						
Trial Type	0.555	0.092	6.005	529.147	< .001**	.062
Pitch Type	0.238	0.099	2.411	528.973	.016*	.011
Trial Type * Pitch Type	0.238	0.131	1.825	528.965	.069	.006
Ambient Temperature	-0.008	0.064	-0.131	50.477	.896	< .001
Cries / Music Model						
Sound Type	-0.122	0.119	-1.024	283.860	.307	.003
Pitch Type	0.183	0.119	1.546	283.878	.123	.006
Pitch Type * Sound Type	-0.367	0.168	-2.184	283.884	.030*	.013
Ambient Temperature	0.035	0.072	0.482	46.556	.632	.005

Note. '*' denotes that p < .05, '**' denotes that p < .01

The next model (bottom half of Table 14) examined whether the cries or cry-like music had a greater association with arousal, and whether these interacted differently with pitch. This was done using a regression equation predicting arousal with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model (R^2 = .051) indicates an interaction between the effects of trial type and pitch on emotional arousal (*β* = -0.367). This explains 1.3% of the variance in the data. A simple slopes analysis shows that for the music trials the unedited excerpts were rated as more arousing than the pitched-down excerpts (*β* = -.183, p = .124), whilst the reverse relation was found for the cry trials (*β* = .183, p = .123). This interaction is depicted in Figure 11.

Figure 11.
Interaction between sound type and pitch on emotional arousal



Note. Points indicate partial residuals controlling for ambient temperature

5.6.3. Emotional valence

To examine the differences in emotional valence between the control and expected trials, the cry and music trials and the high pitch and low pitch trials, regression analyses were computed using linear mixed effect models. Ambient temperature was included as a control variable.

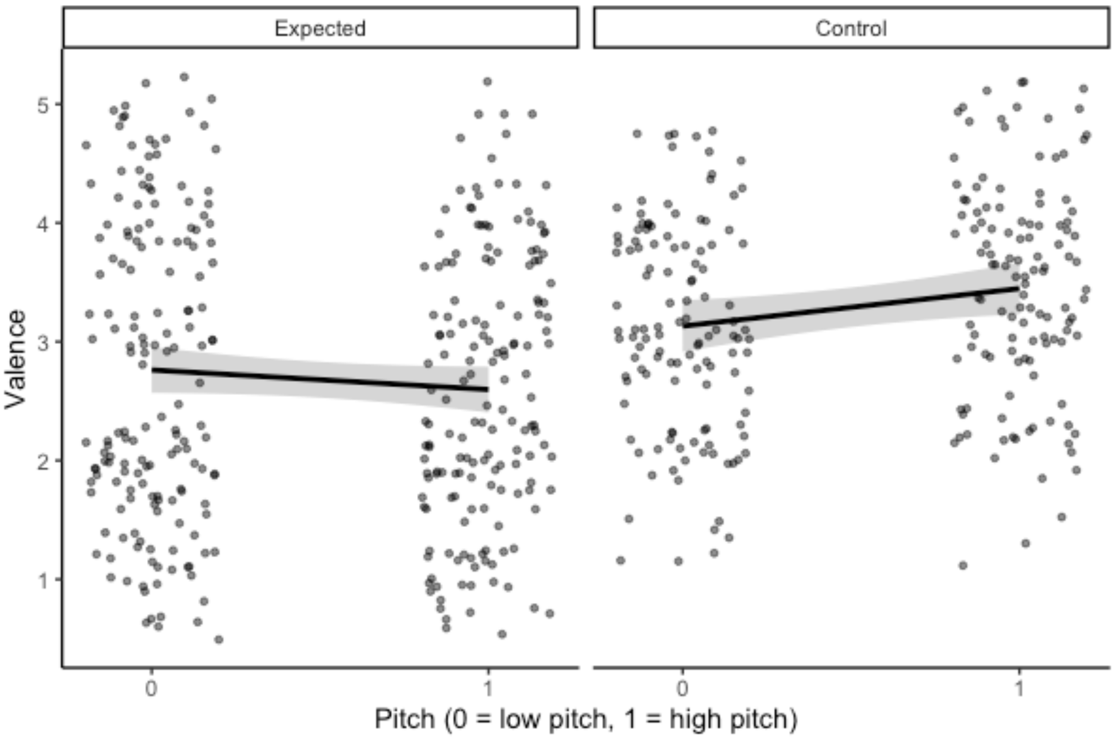
The first model (top half of Table 15) examined the differences between the control and expected trials. This was done using a regression equation predicting valence with trial type (control vs expected), audio manipulation (high vs low) and their interaction. This model (R^2 = .094) indicates an interaction between the effects of trial type and pitch on emotional valence (β = -0.481). This explains 1.4% of the variance in the data. A simple slopes analysis shows that for the expected trials the lower pitched audio excerpt variants were rated as having more positive valence than their higher pitched variants (β = -.165, p = .177), whilst the reverse relation was found for the control trials (β = .316, p = .025). This interaction is depicted in Figure 12.

Table 15.
Effects of trial, sound and pitch type on emotional valence

Predictor	*β*	*SE*	*t*	*df*	*p*	*semi part. R^2*
Control / Expected Model						
Trial Type	-0.369	0.132	-2.803	529.188	.005**	.016
Pitch Type	0.316	0.141	2.242	529.127	.025*	.010
Trial Type * Pitch Type	-0.481	0.186	-2.581	529.060	.010*	.014
Ambient Temperature	-0.013	0.041	-0.305	40.897	.762	< .001
Cries / Music Model						
Sound Type	2.158	0.110	19.694	283.984	< .001**	.553
Pitch Type	0.048	0.110	0.441	283.990	.660	.001
Pitch Type * Sound Type	-0.426	0.155	-2.750	283.992	.006**	.024
Ambient Temperature	-0.031	0.035	-0.887	40.981	.380	.005

Note. '*' denotes that p < .05, '**' denotes that p < .01

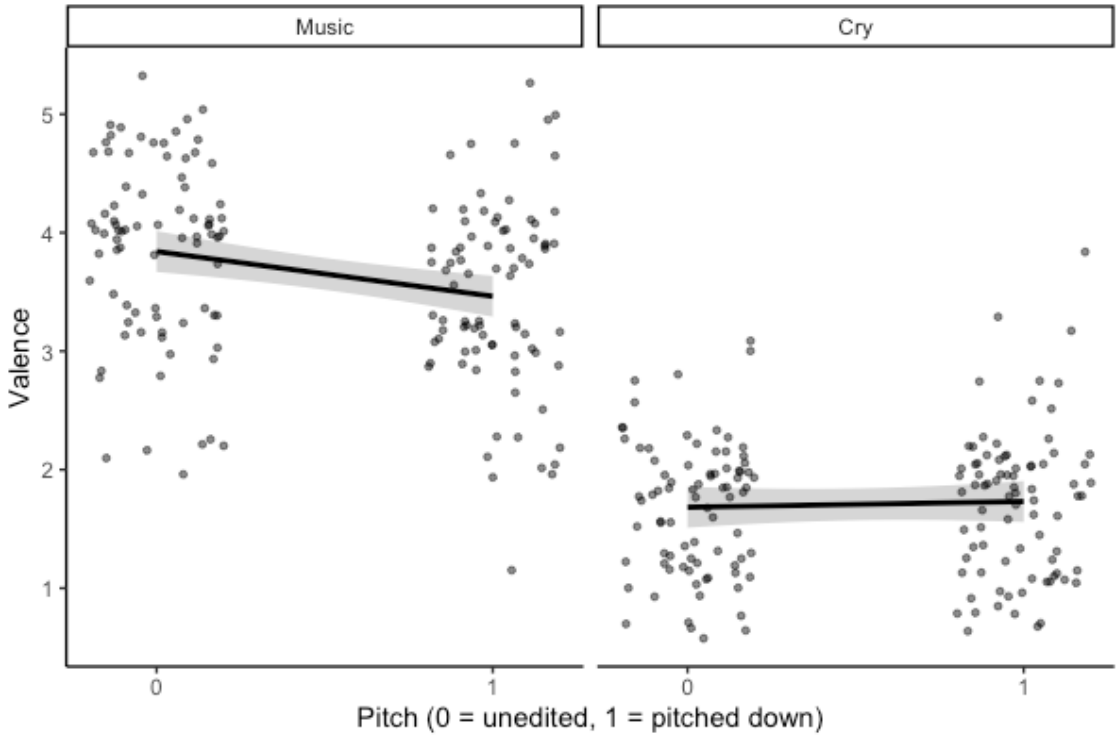
Figure 12.
Interaction between trial type and pitch on emotional valence



Note. Points indicate partial residuals controlling for ambient temperature

The next model (bottom half of Table 15) examined whether the cries or cry-like music were associated with more negative valence, and whether these interacted differently with pitch. This was done using a regression equation predicting valence with sound type (cry vs music), audio manipulation (high vs low) and their interaction. This model (R^2 = .673) indicates an interaction between the effects of trial type and pitch on emotional valence (β = -0.426). This explains 2.4% of the variance in the data. A simple slopes analysis shows that for the music trials the unedited excerpts were rated as having more positive valence than the pitched-down excerpts (β = - .378, p = .001), whilst for the cry trials the unedited and pitched down excerpts had similar valence ratings (β = .048, p = .660). Averaging across pitch conditions, the music excerpts were rated to have a much more positive valence compared to cry excerpts (*d* = 2.225). These relations are depicted in Figure 13.

Figure 13.
Interaction between sound type and pitch on emotional valence



Note. Points indicate partial residuals controlling for ambient temperature

6. Discussion

In this study, we examined key predictions of the separation call hypothesis (Panksepp, 1995) by exposing participants to infant cries and music with cry-like auditory features while observing physiological and psychological separation response patterns. Overall, the findings call into question key aspects of the separation call hypothesis. Actual recordings of infant cries (directly representing separation calls) were less effective at inducing piloerection and chills than cry-like music excerpts. The cry and cry-like stimuli were also no more associated with feelings of social separation or bodily coldness than control stimuli. In addition, attempts to manipulate resemblance of the presented audio excerpts to separation calls by modifying pitch had little effect on any of these measures.

6.1. Directly refuting the claims of the separation call hypothesis

6.1.1. Piloerection and chills don't seem to occur in response to sounds that resemble infant separation calls

Contrary to claims that infant cry vocalisations are a trigger for piloerection, levels of piloerection were consistently very low in response to all the stimuli presented in the main study, including actual audio of infant cries. The cry/cry-like audio excerpts were also not found to be more effective at eliciting piloerection than the control excerpts. Whilst the cry/cry-like audio excerpts were associated with greater chance of experiencing chills than the control excerpts, the music excerpts were more effective at eliciting both piloerection and chills than the cry excerpts (albeit with somewhat small effect sizes). The direction of these relations do not align with the idea that chills occur in response to music because of auditory features that resemble cry vocalisations.

Stimulus pitch manipulation also had very little effect on the occurrence of piloerection and chills, suggesting that high frequencies may not be an important factor in eliciting these responses. Given previous evidence that pitch is an important factor influencing human responsiveness to cry sounds (Crowe & Zeskind 1992; Dessureau, Kurowski & Thompson, 1998; Out et al., 2010; Zeskind & Collins, 1987) and the emphasis Panksepp (1995, 2009) places on high pitched crescendos when describing the separation call hypothesis, this finding could be seen as a challenge the idea that piloerection and chills are elicited by cry-like auditory features. It is however relevant to highlight that, opposite to findings previously reported in the cry-responsiveness literature (Dessureau, Kurowski & Thompson, 1998), the present study indicates greater emotional arousal in response to pitched-down cry vocalisations compared to comparatively higher pitched, unedited cry vocalisations. Given this, perhaps a relation between higher pitch and cry responsiveness is not as relevant as previously thought.

6.1.2. Separation calls don't seem to trigger separation distress

Claims that cry and cry-like stimuli induce feelings of separation distress were also unsupported. No substantial differences in reports of loneliness were found between any of the different types of auditory stimuli presented. Differences in desire for social contact between the cry/cry-like and the control stimuli were also not found. A modest difference in desire for social contact following the infant cry excerpts compared to music excerpts was found, with the former associated with a lesser desire for social contact. The direction of this finding is however contrary to the expectations set out by the separation call hypothesis, conflicting with the claim that cry vocalisations function as a signal to elicit a desire to engage in social contact behaviours.

6.1.3. Separation calls don't seem to trigger a social thermoregulatory response

Findings relating to temperature also conflict with the social thermoregulatory claim that separation calls elicit a feeling of coldness that motivates contact seeking. No differences in objective or subjective bodily temperature were observed between the cry/cry-like and the control stimuli. Instead, the only substantial predictor was the ambient temperature, which explained a large amount of variance within the objective measures of bodily temperature. The output of the analysis did indicate that participants may have felt somewhat colder during the cry compared to the music excerpts, but this difference was small and fell slightly short of a 5% significance level. Based on this, it is possible that the cry sounds did induce some feelings of subjective coldness, but this effect does not seem to generalise to cry-like music. Based on this, music resembling separation calls do not appear to be associated with either a literal or a subjective coldness.

6.1.4. The emotional correlates of infant cries and music excerpts are dissimilar

More generally, it is also notable that the emotional valence associated with the cry vocalisations were dissimilar to those associated with cry-like music excerpts: emotions experienced during the infant cry excerpts were rated to be far more negative than those experienced during the music excerpts. Pitch manipulation was also indicated to have directionally distinct effects on both arousal and valence ratings for cry vocalisations compared to cry-like music excerpts, further differentiating responses to these two different types of stimuli. The reason behind these differing relations with pitch is unclear, though it is notable that the association found between pitched-down cries and greater emotional arousal is contrary to prior research (Dessureau, Kurowski & Thompson, 1998).

6.2. Limitations of the present research design

The use of a unitary measure of chills may have affected the present findings. Chills are quite a vaguely defined concept that have been associated with a heterogenous range of different experiences- evidence that been used to propose different subtypes of chills (Bannister, 2019; Bannister & Eerola, 2023; Maruskin, Thrash & Elliot, 2012). As such, it is possible that the chills reported in the present study don’t reflect a discrete response that is consistent across participants. This could potentially account for the comparatively stronger chill response to the music compared to the cry stimuli: it could be speculated that the chills reported in response to the cry stimuli only reflected one specific type of chills (induced by separation calls), whilst the chills reported in response to the musical stimuli reflect a more varied range of experiences (including separation call elicited chills). Whilst this line of reasoning could potentially be used to argue that the chills findings in the present study are in fact consistent with the separation call hypothesis, it cannot explain the findings relating to reports of separation distress and temperature, which were also inconsistent with the theory.

In addition, due to the nature of the physiological equipment used, participants had to be tested in a laboratory setting whilst the experimenter was in the same room. Due to the social nature of the separation call hypothesis, there is a possibility that this abnormal social environment may have affected participant’s reactions to the presented audio excerpts. This is particularly relevant for participant’s self-reported levels of separation distress. Effort was however made to give participants a sense of aloneness, with the participant and experimenter separated by a privacy screen.

It is also possible that the participants selected for the present sample were not as sensitive in their responses to infant crying as others may have been. Specifically, previous research has shown heightened responsiveness to infant crying from parents compared to non-parents. Evidence of this heightened responsiveness include fMRI research showing stronger activation in limbic brain regions (Seifritz et al., 2003) and research showing enhanced hormonal responding to infant cries for fathers compared to non-fathers (Fleming et al., 2002). Another study also suggests that parents show different patterns of cardiac activity in response to infant cries compared to non-parents (Out et al., 2010). Whilst participants were not specifically asked about their parental status, it is likely that the parent demographic was underrepresented the sample used for the main study, which mainly consists of university students in their late teens or early twenties. Other research has however indicated that infant cry response patterns are at least to some extent universal, with both parents and non-parents showing unique pattern of brain activity in response to infant cry recordings compared to recordings of adult cries (Young et al., 2016). Because of this, if chills are part of an innate response to infant cries, some responsiveness would be expected even in a sample of non-parents.

Additionally, it was only feasible to present participants with a small selection of musical stimuli due to the capacity limits of the equipment used to synchronise stimulus presentation to continuous measurements (STP100C module for a Biopac MP160 unit). This is relevant because when asked to describe the kinds of music most likely to elicit chills, participants' responses vary across a wide range of genres, for example classical, pop, jazz, electronic and folk music (Bannister, 2020b). Whilst research directly addressing individual differences in the musical elicitors of chills and piloerection is sparce, it seems likely that peoples' individual musical preferences affect the kinds of music that elicits these responses. Limitations in the variety of musical stimuli that could be presented to participants means that it was not possible to cater to participants individual tastes in music. Whilst this may have affected responsiveness to the musical selections used in the present study, this wouldn't have affected responsiveness to infant cries, which under the claims of the separation call hypothesis should be expected to trigger an innate chill response across the population.

The small stimulus selection presented in the present study is also relevant given previous research suggesting that the nature of chill responses- in this case the effect of audio manipulation on chills- is sensitive to underlying musical structure (Bannister, 2020a). Whilst effort was made to select stimuli that appropriately captured the cry-like musical structures referenced by Panksepp (1995), this selection was still somewhat subjective due to a lack of clarity about how to accurately identify these structures. As such, it remains possible that different cry-like musical selections may have activated different psychological processes and therefore produced different results. A lack of clarity regarding relevant musical structures however also reflects a broader conceptual issue with the separation call hypothesis itself.

6.3. Conceptual implications for the separation call hypothesis

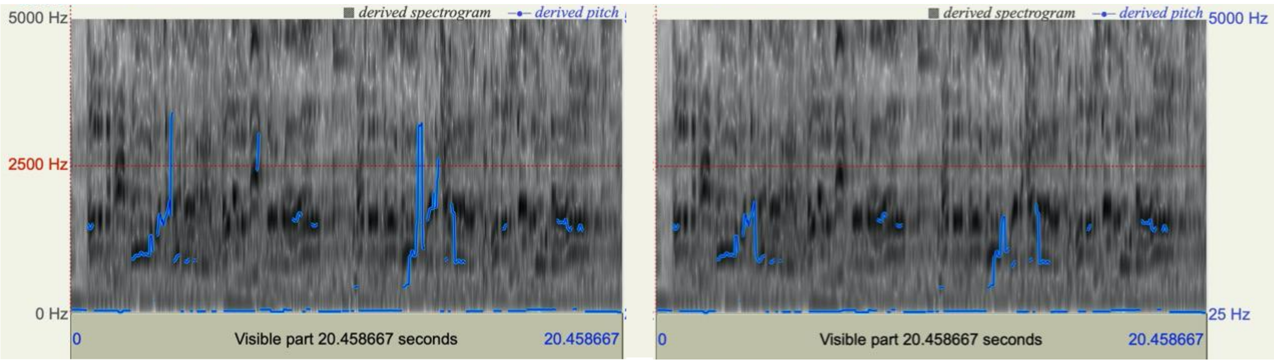
The vagueness of claims made by separation call hypothesis became very apparent when designing the present research procedure. Whilst this theory sets out the idea that emotional piloerection and musical chills are induced by sounds that resemble the separation calls of mammalian infants, the specific cry-like auditory features of these sounds are never clearly defined within the literature.

When describing separation calls Panksepp (1995) focuses on frequency, specifically referencing prolonged wails with ‘a fundamental frequency of around 500 Hz’ and ‘successive harmonics up to 4500 Hz’ (p.200). These precise descriptions regarding the frequency of infant cries don’t however translate well to the kinds of chill eliciting music identified in the literature. These music pieces almost always feature varied instrumentation, making them much more acoustically complex than infant separation calls, which consist of isolated vocalisations.

Whilst attempts were made using the auditory analysis program Praat (v. 6.3.11) to quantify the fundamental frequencies contained within the music excerpts selected for the present research, these values were erratic, sometimes varying by more than 1000 Hz within a few seconds. The fundamental frequency values computed by Praat also varied dramatically depending on the analysis window used (shown in Figure 14). This meant that it was not possible to generate precise frequency values to describe the music excerpts.

Figure 14.

Screenshots from Praat (v.6.3.11) showing the dramatic differences in fundamental frequency estimations based on the analysis window used



Fundamental frequency range = 25 to 4000 Hz   Fundamental frequency range = 25 to 2000 Hz

Note. Estimated fundamental frequency is represented by the blue lines

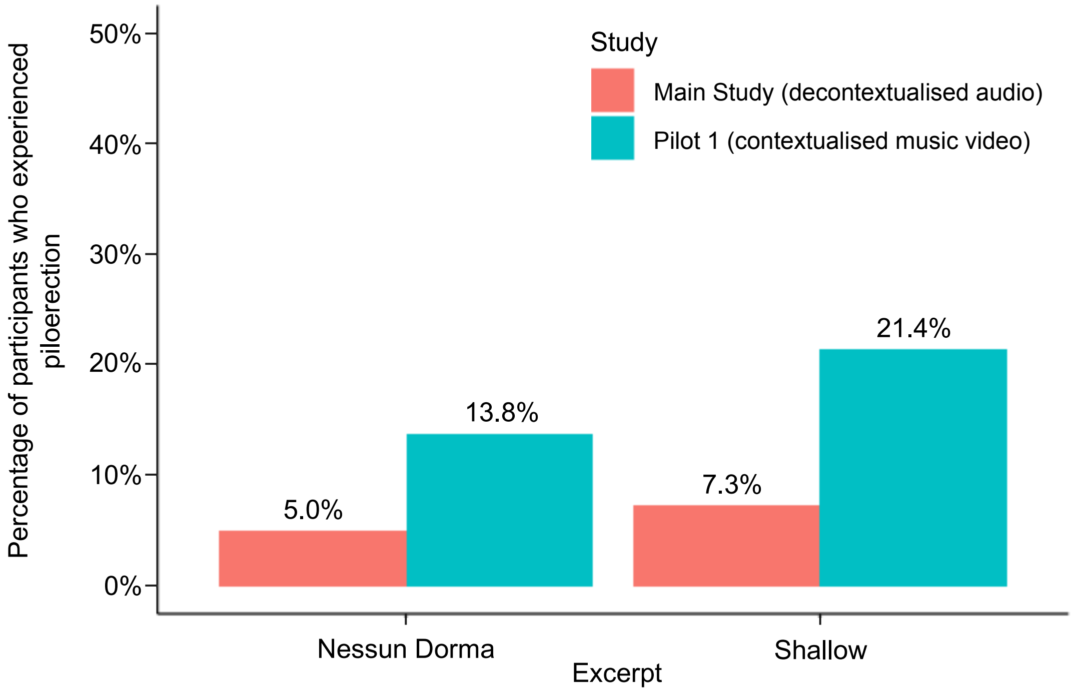
Because of these difficulties comparisons to separation calls had to rely on more descriptive observations about the acoustic properties of the music visualised using spectrograms, such as the appearance of the melody contours and the apparent dominance of high frequencies within the excerpt. These comparisons are speculative in nature. This highlights a conceptual issue with the separation call hypothesis as theory of piloerection and chills. The fact that there is no clear benchmark by which to compare music excerpts to separation calls renders the claim chills are elicited by musical features that resemble separation calls largely unfalsifiable. This calls into question the scientific basis of the separation call hypothesis itself.

6.4. The importance of context for piloerection and chills

The separation call hypothesis ultimately implies that piloerection and chills occur as precise reaction to specific auditory triggers rather than as a complex, multifaceted response. This is an idea that has been challenged previously, with one study noting that reports of chills whilst listening to classical music rarely lined up closely between participants to the same timepoints within the music (Grewe et al., 2007). The present findings further contradict this idea: the isolated audio excerpts presented in the main study were shown to be notably less effective at inducing piloerection compared to the contextualised, audio-visual versions of the same excerpts presented in Pilot 1, as depicted in Figure 15.

Figure 15.

Bar plot showing the differences between the number of participants who experienced piloerection between Pilot 1 and the Main Study



There are two potential explanations which may individually or jointly account for the stark differences in the occurrence of piloerection between Pilot 1 and the main study, both emphasising the importance of context. First, the musical context leading up to the selected excerpts may have been important in facilitating the experiences of piloerection identified in Pilot 1. Second, the visual accompaniment to the music that was present in Pilot 1 but not the main study may have provided additional sensory context that enhanced piloerection responding.

The relevance of musical context is something highlighted by vigilance accounts of piloerection and chills, such as contrastive valence theory (Huron, 2006; Huron & Margulis, 2010). This theory specifically suggests that new and surprising sounds should induce piloerection and chills, an idea supported by evidence showing associations of these responses with novelty. In a study where participants retrospectively recalled their experiences during shivers (a concept roughly analogous to chills), new or unprepared harmonies and sudden and dynamic textural changes were the most commonly referenced musical features associated with this response (Sloboda, 1991). A more recent experimental study similarly found that the entrance of a new vocal or instrument was the musical feature most associated with chills (Grewe et al., 2007). It is reasonable to infer that the impact of these musical changes depends on the prior musical context, which is necessary to establish a precedent for how the music is expected to continue. The extent to which piloerection and chills rely on novelty- and the extent to which this relation depends on prior musical context- are however things that should be established conclusively through further research.

The impact of a multisensory context on the occurrence of piloerection and chills is something explored less in the present research base. It has however been established that these responses are not unique to music, or more generally to auditory stimuli. For example, research has demonstrated that both piloerection and chills can be triggered by non-musical video clips (Maruskin, Thrash & Elliot, 2012; McPhetres, Han et al., 2024; Wassiliwizky et al., 2015; Wassiliwizky, Jacobson et al., 2017), the written word (Bannister, 2019, Wassiliwizsky, Koelsch et al., 2017) and tactile stimulation (Grewe et al. 2010; McPhetres, Han et al., 2024). One research study also demonstrated that different types of visual accompaniment can influence the feelings associated with chills, and even found a small influence on physiological correlates- specifically skin conductance and temperature (Bannister & Eerola, 2023). The potential that visual accompaniment may enhance the effectiveness of music at inducing piloerection and chills is however not something that appears to have been explicitly addressed in the current literature. This is an interesting avenue for future research that could be tested using a relatively straightforward research design.

6.5. Potential dissociation of piloerection and chills from emotional experience

Prior psychological research largely interprets piloerection and the physical sensations encompassed under the concept of chills as physiological manifestations of emotion. According to the separation call hypothesis, these responses reflect feelings of social separation-related sadness elicited by infant cries. Panksepp (1995) explicitly assumes that rather than being independent responses to similar stimuli, chills and social sadness must be causally related- though he admits an uncertainty about the direction of this relation.

Alternate theories similarly characterise piloerection and chills as emotional responses: peak arousal theory (Benedek & Kaernbach, 2011, Grewe, Kopiez & Altenmüller, 2009) connects these responses to peaks of emotional intensity whilst contrastive valence theory (Huron, 2006; Huron & Margulis, 2010) connects them to fleeting emotional contrasts. There is also a body of literature specifically associating chills with the emotion of being moved (Benedek & Kaernbach, 2011; Wassiliwizsky et al., 2015; Zickfeld et al., 2019). These theories overtly suggest that emotion is a directly relevant feature of piloerection and chills, with descriptions often implying that the former causally precedes the latter.

These approaches to conceptualising piloerection and chills are consistent with prior efforts to map emotions onto specific patterns of autonomic activation (Kreibig, 2010). Piloerection and chills don’t however appear to map onto specific emotions in a one-to-one fashion: both responses have been linked to a variety of different emotional correlates, and findings relating to these emotional correlates are often inconsistent within the literature (McPhetres & Zickfeld, 2022). One of the ways contemporary research has attempted to address these inconsistencies is by mapping different emotional correlates onto different chills subtypes (Bannister, 2019; Bannister & Eerola, 2023; Maruskin, Thrash & Elliot, 2012). Inconsistencies in the emotional correlates of piloerection and chills may however instead be a sign that these responses simply can’t be fitted to discrete emotional experiences. This would be consistent with a constructivist view of emotion, which suggests that emotions are actually indiscrete conceptual categories which encompass a heterogenous range of context dependant autonomic responses (Siegel et al., 2018).

In support of a constructivist account of emotion, a review of over 200 studies covering a range of different physiological responses indicated substantial autonomic variation within commonly used emotion categories such as happiness, sadness, anger and fear (Siegel et al., 2018). Effect sizes for many physiological responses were also similar across multiple emotion categories. This suggests that emotions are not associated with consistent and unique patterns of physiological activation. Framed differentially, this also implies that specific physiological events (such as piloerection, and potentially bodily chills sensations) cannot be directly mapped onto emotional experiences.

In line with this constructivist research, experimental evidence implying that chills are somewhat dissociated from emotion does exist. This includes a study where participants listened to manipulated versions of three songs, which each had sections of the music previously established to be chill inducing removed (Bannister & Eerola, 2018). As expected, a modest decrease in self-reported chill frequency and chill intensity (reported continuously throughout the study) was found for the chill-removal versions compared to the original versions of the songs. In contrast to this, ratings of a range of emotional descriptors did not differ significantly between the original and manipulated versions, implying that the emotional responses to the music were not directly associated with the chill responses. This chill excerpt removal technique provides an interesting methodology that is worth considering in future research, providing a way to illuminate the stimulus properties that trigger piloerection and chills without having to rely on self-report and emotional inferences.

Beyond the already established fact that neither piloerection nor chills can be attributed to a singular emotional experience, it is still premature to make any firm claims about the emotional nature (or lack thereof) of these responses, with piloerection in particular having a very sparce research base to draw from. Further attempts to establish clear emotional subtypes of piloerection and chills may help clarify this. If such efforts are unsuccessful, this would indicate that these responses should be defined independent of emotional inferences.

6.6. Piloerection and chills aren't interchangeable

Piloerection as described in the present literature has been greatly intertwined with the concept of chills. This is likely because identifying piloerection is a time-consuming task that requires specialist equipment and observer training, whilst subjective chills can be measured with less effort using self-report. Because of this, it has been convenient to make inferences about piloerection based on chills research.

An implicit relation between these two responses is apparent given that piloerection is often referenced as one of the defining features of chills. The present research however highlights that piloerection and chills aren't interchangeable measures. Prior research has suggested that objective piloerection occurs at roughly half the frequency of chills (Craig, 2005; Sumpf, Jentschke & Koelesh, 2015). Findings from the present study indicate an even greater disparity: objective piloerection was recorded in response to 3.0% of the available audio trials whilst chills were reported in response to 21.5% of the audio trials, a seven-fold difference. This indicates that self-reported chills are substantially more common than objective piloerection.

This disparity may reflect the fact that piloerection is an objective phenomenon that can be directly observed, whilst chills are a broader, more nebulous concept that rely on identification via self-report. Because of this, it is difficult to pin down a homogenous description of what different people's experiences of chills represent. The extent to which chills reflect a physiological response is even unclear. Chills have largely been defined in the current literature using descriptions of physical, bodily reactions. For example, the definition from Bannister (2020b) specifically mentions 'gooseflesh, shivers and/or tingling sensations' (p.298) as the features that characterise chills. This implies the existence of an objective physiological response without describing the specifics of this response. Chills are however ultimately measured subjectively and cannot be definitively identified using physiological measures: whilst chills are known to sometimes coincide with physiological responses such as piloerection and skin conductance responses, they can also be reported independently of these features (Beier et al., 2022; Benedek & Kaernbach, 2011; Craig, 2005; Grewe et al., 2007; Sumpf, Jentschke & Koelesh, 2015).

This lack of conceptual specificity highlights that there are limits to how informative subjective chills are as a research measure. Perhaps more research investigating piloerection, a more objective and isolated phenomena, will help bring some greater clarity to the literature. A greater understanding of human piloerection in response to non-thermal stimuli may even lay the foundations to clarify the direction research into the broader concept of chills should take. It is however important to note that with the current technology available, future research investigating piloerection should do so using manual observation methods. Participant's self-reports of piloerection have been shown to be largely inaccurate (McPhetres, Han et al., 2024), and the main automated software that is currently available for identifying piloerection from camera footage (Gooselab: Benedek et al., 2010) has been shown to produce data that is highly confounded by movement artifacts (McPhetres, Sun & Watroba, 2024).

6.7. Conclusion and directions for future research

Considered within the context of an already unconvincing evidence base, the present findings call into question many elements of the separation call hypothesis as an explanation of piloerection or chills. These findings also highlight relevant questions about the nature of these responses that warrant further investigation. This includes the potential impact of preceding musical context and the impact of visual (or other sensory) accompaniment to music on piloerection and chill responding. It is also relevant for future research to clarify whether distinct emotional correlates of piloerection and chills can be pinpointed. If this is not the case, this would indicate that emotional inferences about the nature of piloerection are perhaps better avoided. Finally, a larger research base investigating objective measures of piloerection is clearly needed to better understand the psychological component of this physiological response.

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