Vigilance and *Social* Chills with Music: Evidence for Two Types of Musical Chills

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ABSTRACT

It is unclear how music elicits *chills* (emotional experiences accompanied by goosebumps, shivers and tingling sensations), and what psychological mechanisms underlie the response. Crucially, current explanations of chills struggle to encapsulate the variability of results linking the experience to musical features, psychophysiological activity and individual differences, suggesting there may be distinct types of musical chills elicited through different underlying mechanisms. This study aimed to distinguish two types of musical chills: *Vigilance chills*, linked to awe, expectancy and auditory looming, and *social chills*, linked to being moved, empathy and social bonding. Participants listened to four music excerpts containing moments of *contrast* (sudden dynamic changes). Two excerpts were paired with extra-musical information provided before listening, with the other two accompanied by visual animations; the information and animations emphasised either vigilance (i.e. musical structure) or social (i.e. bittersweet moving narrative) aspects, forming vigilance and social conditions for each stimulus. Participants reported chills via button presses, rated experiences of awe and being moved, and had skin conductance and temperature data collected; individual differences in cognitive processing style (empathising and systemising) were also explored. Results show that vigilance conditions elicited higher ratings of awe, and social conditions elicited higher ratings of being moved. Chills during experiences of awe (*vigilance chills*) were accompanied by increased skin conductance and decreased skin temperature compared to chills during experiences of being moved (*social chills*). Cognitive processing styles were unrelated to listener experiences. Findings are discussed in terms of chills theories, reinterpreting previous research, and broader music and emotion frameworks.

Musical chills lack a clear consensual definition and conceptualisation, but are often characterised as subjective responses accompanied by goosebumps, shivers or tingles. Chills are indicators of strong emotion (Gabrielsson, 2011), peak pleasure (Blood & Zatorre, 2001; Ferreri et al., 2019; Salimpoor, Benovoy, Larcher, Dagher & Zatorre, 2011), and arousal (Rickard, 2004). Furthermore, chills have been linked to increases in skin conductance (Craig, 2005; Grewe, Nagel, Kopiez & Altenmüller, 2007), heart rate (Grewe, Kopiez & Altenmüller, 2009; Sumpf, Jentschke, & Koelsch, 2015), and pupil dilation (Laeng, Eidet, Sulutvedt & Panksepp, 2016). Whilst the phenomenon has been associated with individual traits such as openness to experience (Colver & El-Alayli, 2016; McCrae, 2007; Nusbaum & Silvia, 2011), and diverse listening contexts (Egermann et al., 2011; Nusbaum et al., 2014), most research has focussed on links between chills and musical features. This correlational work linked chills to crescendos (Panksepp, 1995), sudden dynamic or textural changes (Sloboda, 1991), entrances of a new voice or instrument (Grewe et al., 2007), unprepared harmonies (Sloboda, 1991), the human voice and lyrics (Bannister, 2020a), loudness, auditory roughness and spectral brightness (Bannister, 2020b; Bannister & Eerola, 2018; Nagel, Kopiez, Grewe & Altenmüller, 2008).

Despite extant research, there is little understanding of how music elicits chills. Currently, there are two emerging theoretical accounts that can be applied to the phenomenon, linked to vigilance or social bonding. The *vigilance theory* posits that music elicits chills via threat-signalling functions of goosebumps (Darwin, 1872), through processes including musical expectations (Huron, 2006) and auditory looming (Ghazanfar, Neuhoff & Logothetis, 2002; Neuhoff, 2001), where sounds with increasing loudness are perceived as approaching oneself. These vigilance processes might involve fear, although this may not be phenomenologically present during chills experiences. This theory explains correlations between chills and dynamic changes, crescendos and unprepared harmonies in music (Grewe et al., 2007; Panksepp, 1995; Sloboda, 1991), but fails to account for effects of lyrics or the human voice (Bannister, 2020a), and chills responses with film, videos and poetry (Bannister, 2019; Benedek & Kaernbach, 2011; Grewe, Katzur, Kopiez, and Altenmüller, 2010; Wassiliwizky, 2015; Wassiliwizky, Koelsch, Wagner, Jacobsen & Menninghaus, 2017a). Alternatively, *social bonding theory* suggests that music elicits chills through thermoregulatory functions of goosebumps, as an artefact of crossovers between thermoregulatory and socio-emotional systems in the brain and in behaviour (Chartrand & Bargh, 1999; IJzerman et al., 2015; IJzerman et al., 2012; Inagaki & Eisenberger, 2013; Kang, Williams, Clark, Gray & Bargh, 2011; Nelson & Panksepp, 1998; Panksepp, 1998; Panksepp & Bernatzky, 2002; Panksepp, Knuson & Pruit, 1998; Zhong & Leonardelli, 2008). Underlying mechanisms may include empathy, social belonging, motor mimicry, synchrony and entrainment; these may result in intensified communal sharing relations and experiences of being moved or *kama muta* (Fiske, Seibt & Schubert, 2017), in which listeners feel social equivalence and sameness with aspects, narratives or personas in music (Robinson & Hatten, 2012). Social bonding theory might explain links between chills and the human voice, lyrics, feeling understood by music, and perceiving social union and interactions in music (Bannister, 2020a; Gabrielsson, 2011); furthermore, this theory better accommodates chills responses reported with films, videos and poetry (Bannister, 2019; Wassiliwizky et al., 2017a); finally, social bonding perspectives encapsulate associations between chills and being moved (Wassiliwizky, 2015; Zickfeld, Schubert, Seibt & Fiske, 2019) or kama muta (Schubert, Zickfeld, Seibt & Fiske, 2018).

Distinct Types of Musical Chills

When appraised separately, vigilance and social bonding accounts fail to encapsulate the variability of results across existing chills research. However, whilst each perspective is insufficient in explaining the phenomenon alone, either theory may be applicable in certain contexts; musical chills may be elicited through vigilance or social processes, depending on the combination of music, listener and situation, with these different processes resulting in psychologically distinct musical chills experiences.

Distinct types of musical chills appear plausible and have been suggested (Levinson, 2006; Panksepp, 1995; Pelowski, Markey, Forster, Gerger & Leder, 2017), given that chills are a highly variable experience across and within individuals, accompanied by diverse feelings, psychophysiological activity, and bodily reactions. Recent work found considerable variability in subjective feelings and emotions accompanying musical chills (Bannister, 2020a), reflecting previous research (Grewe et al., 2010; Halpern, Blake & Hillenbrand, 1986). Inconsistent results are reported across psychophysiological measures accompanying chills: Decreases in skin temperature have been documented (Salimpoor, Benovoy, Longo, Cooperstock & Zatorre, 2009), though null findings are reported elsewhere (Blood & Zatorre, 2001; Craig, 2005); heart rate may increase (Benedek & Kaernbach, 2011; Salimpoor et al., 2009; Sumpf et al., 2015), although Guhn, Hamm and Zentner (2007) reported null results; and skin conductance often increases during chills (Benedek & Kaernbach, 2011; Blood & Zatorre, 2001; Grewe et al., 2007; Salimpoor et al., 2009), though Rickard (2004) reported little correspondence. In neuroimaging approaches, Salimpoor et al. (2011) described an anatomical release of dopamine during musical chills in the nucleus accumbens, compared to moments preceding the response; however, Wassiliwizky et al. (2017a) documented nucleus accumbens activity in moments preceding chills responses with poetry. Additionally, the role of personality traits is unclear: Openness to experience has been linked to chills (Colver & El-Alayli, 2016; McCrae, 2007; Nusbaum & Silvia, 2011), but recent work found no relationship (Starcke, von Georgi, Tiihonen, Laczika & Reuter, 2019); similar inconsistencies exist for neuroticism, agreeableness and extraversion (Maruskin, Elliot & Thrash, 2012; Nusbaum & Silvia, 2011; Sumpf et al., 2015). Chills may co-occur with tears (Wassiliwizky, Jacobsen, Heinrich, Schneiderbauer & Menninghaus, 2017b), although Mori and Iwanaga (2017) suggest that chills and tears reflect distinct types of peak experience. Finally, chills resemble the autonomous sensory meridian response (ASMR; Kovacevich & Huron, 2019), a response linked to certain sounds that can also be accompanied by goosebumps or pleasurable tingling sensations (del Campo & Kehle, 2016); however, ASMR is often linked to relaxation and related functions such as aiding sleep (Barratt & Davis, 2015), which is seemingly at odds with high arousal characteristics of chills (Rickard, 2004).

Distinct chills experiences have been explored by Maruskin et al. (2012), who proposed a distinction between ’goosetingles’ and ’coldshivers’, reflecting approach and avoidance behaviours respectively. Using multimedia items, Bannister (2019) reported three chills categories, namely warm, cold and moving, that were driven by thematic properties of stimuli including depictions of social communion (e.g. a crowd singing together), love (e.g. reunion between pet and owner), emotional distress (e.g. war veteran marching alone at memorial) and empathic concern (e.g. a person comforting an orphaned gorilla); moving chills were further predicted by trait empathy characteristics of participants. However, whilst these two studies provide preliminary evidence for differences across chills responses, neither approach was sufficiently nuanced in their consideration of chills during aesthetic engagements, and little focus was placed on experiences of musical chills.

Crucially, considering recent evidence, inconsistencies across most aspects of musical chills research may be reconciled by conceptualising the phenomenon as several distinct psychological experiences, that share physical reactions like goosebumps. From this perspective, conflicting results may be due to researchers investigating different chills experiences in each study, without explicit awareness. Consequently, comparisons or continuity across existing chills research could be compromised, with substantial implications for extant and future research on the response. Pertinently, vigilance and social bonding theories of chills provide a foundation for investigating these differences as a *two-component theory* of musical chills, distinct from a separation between approach and avoidance chills (Maruskin et al., 2012), and from the chills categories reported by Bannister (2019). Therefore, this study aimed to progress from recent work, by causally distinguishing two broad types of musical chills experiences.

Theoretical Predictions

Two distinct types of musical chills are proposed, labelled *vigilance chills* and *social chills*, derived from vigilance and social bonding theories. In a musical context, it is proposed that these types of chills can be experimentally separated at the levels of *stimulus and experimental manipulations* performed, self-reports of *subjective feeling*, *psychophysiological activity*, and *individual differences* across listeners. What follows is a set of theoretical predictions for each of these factors in relation to musical chills.

Stimulus and Experimental Manipulation

Theoretically, vigilance chills should be elicited by features linked to expectancy and auditory looming, such as crescendos and new or unprepared harmonies. Social chills might best be elicited by the human voice (Bannister, 2020a), lyrical or narrative content, or 'super-expressive' instruments (Juslin, 2001).

Importantly, moments of *contrast* in music might be capable of eliciting either vigilance chills *or* social chills. Contrast encapsulates several features linked to vigilance chills (Grewe et al., 2007a; Panksepp, 1995), but contrast is also pervasive in discussions of narrative, and communicating moments of narrative salience (Burnham, 2000; Graesser, Singer & Trabasso, 1994); this was recently explored by Margulis (2017), with moments of contrast possibly serving as auditory analogies to key moments in narrative, not unlike moving scenes and events linked to chills in film (Wassiliwizky, 2015). Additionally, experiences of kama muta associated with chills have been characterised as a *sudden* intensification of communal sharing relations, which may also be closely linked to moments of musical contrast.

Consequently, selecting musical excerpts with 'built-in' moments of contrast, like a sudden dynamic change, allows for manipulations of the *same* piece of music, to bias listeners towards experiencing vigilance or social chills. When manipulating experiences of music, two approaches have been shown to influence musical emotions in previous work: Firstly, providing extra-musical information prior to listening has been repeatedly shown to affect listener experiences (Miu & Baltes, 2012; Vuoskoski & Eerola, 2015); and secondly, visual information provided alongside music and music performances shows notable effects on experience and perception of emotion whilst listening (Thompson, Graham & Russo, 2005; Thompson, Russo & Quinto, 2008; Vuoskoski, Thompson, Clarke & Spence, 2014). As the current study aimed to provide a broad causal investigation of a *two-component theory* of musical chills, both methodologies were utilised, with each aiming to bias listeners towards experiences of vigilance or social chills.

Subjective Feelings

Vigilance and social chills may be characterised by feelings of awe and being moved respectively. Awe is an emotional state associated with interest and fascination (Izard, 1977), expectancy and surprise (Frijda, 1986), threat and fear (Gordon et al., 2016), humility (Stellar et al., 2018), feelings of the small self (Piff, Dietze, Feinberg, Stancato & Keltner, 2015), and importantly, chills responses (Konečni, 2005; Schurtz et al., 2012). Keltner and Haidt (2003) described awe as involving encounters with *vastness* (something perceived to be larger or grander than oneself), alongside a *need for cognitive accommodation* (adjustment of mental representations to understand the experience). These key aspects of awe characterise the experience in relation to engaging with novel and complex stimuli or events (Campos, Shiota, Keltner, Gonzaga & Goetz, 2013); crucially, the musical features and underlying mechanisms possibly linked to vigilance chills, such as auditory looming and musical expectancy, may reflect listening experiences that can be framed in terms of an encounter with something vast, and something that requires a need for cognitive accommodation. Consequently, awe could serve as an affective signature of vigilance chills with music.

In contrast, social chills may be indicated by experiences of being moved. This concept, associated closely with *kama muta* (Fiske et al., 2017), is a pleasurable, mixed affective response linked to significant life events (Kuehnast, Wagner, Wassiliwizky, Jacobsen & Menninghaus, 2014), reunions (Cova & Deonna, 2014), bittersweet film scenes (Wassiliwizky et al., 2015), and sad music (Vuoskoski & Eerola, 2017); being moved has also repeatedly been associated with chills responses (Bannister, 2020a; Benedek & Kaernbach, 2011; Laeng et al., 2016; Wassiliwizky et al., 2015). Being moved may reflect intensified communal sharing relations (sudden sense of equivalence or sameness between oneself and another person, stimulus or concept); crucially, aspects of music possibly linked to social chills, including the human voice, ‘super-expressive’ instruments, lyrics, or narrative qualities, may reflect experiences of being moved. Therefore, given the links between being moved and chills, being moved may provide an affective signature of social chills with music.

It has been theorised that awe, being moved and chills reflect a similar underlying experience, varying in terms of intensity (Konečni, 2005), although these relationships have yet to be explicitly explored. Indeed, recent work has approached awe as a collective emotion, serving to diminish a sense of self and facilitate assimilation and oneness with broader social systems (Spears et al., 2011); these social underpinnings appear comparable to being moved and kama muta concepts (Fiske et al., 2017;

Menninghaus et al., 2015). However, whilst there is a degree of overlap, there are three reasons to frame awe and being moved as separable experiences. Firstly, whilst awe and being moved are associated with social functions, the responses sit in conceptual opposition to each other; being moved could indicate intensified communal sharing relations, bonding or social *equivalence* (Zickfeld et al., 2019), whereas awe encapsulates social *difference*, subordination to people or stimuli grander or vast beyond oneself, and assimilation into social hierarchies (Keltner & Haidt, 2003). Secondly, common conceptualisations of awe indicate the importance of threat or fear in the response, reflecting the vigilance theory of chills (Gordon et al., 2016; Konečni, 2005; Shiota et al., 2007); but, most accounts of being moved place little to no importance on these factors, suggesting that there are distinct psychological mechanisms underlying the two experiences. Thirdly, recent evidence suggests that experiences with videos linked to awe and kama muta involve distinguishable patterns of physiological activity; for example, responses to awe videos were linked to increased tonic skin conductance and decreased skin temperature when compared with responses to being moved videos (Zickfeld, Arriaga, Santos, Schubert & Seibt, 2020). In short, awe and being moved seem dissociable at the theoretical level, in terms of psychological mechanisms, and with regards to psychophysiological responses.

Whilst awe and being moved are central subjective feeling aspects linked to a *two-component theory* of musical chills, a crucial consideration for this study is using moments of *contrast* in music as malleable periods, in which experiences may be biased towards either vigilance or social chills with experimental manipulations. Importantly, it remains likely that for any listening condition in the experiment, both awe or being moved responses are possible for listeners, and consequently the experimental manipulations are not expected to produce consistent global effects across listeners, especially given the idiosyncratic qualities of music listening and chills (Grewe et al., 2007). Therefore, an analysis of chills experiences across the level of experimental manipulation would be difficult to interpret. An effective solution to address this is to produce a *moved-awe emotional index* scale from awe and being moved ratings, which captures whether experiences more strongly reflect awe, being moved, or balanced responses. This *moved-awe emotional index* would serve as the primary level of analysis, to evaluate the effectiveness of experimental manipulations, to characterise chills reports as vigilance or social chills, to explore how psychophysiological responses differ across these chills categories, and to identify possible effects of individual differences. It was predicted that awe experiences would be stronger when stimuli were manipulated to induce vigilance chills (vigilance condition), and being moved experiences would be stronger when stimuli were manipulated to elicit social chills (social condition).

Psychophysiological Response

There is evidence to suggest that vigilance and social chills responses are separable through skin conductance and skin temperature activity. Increased skin conductance, indicative of arousal, attention and heightened sympathetic nervous system activity (Boucsein, 2012), has been found in experiences linked to vigilance chills. Steinbeis, Koelsch and Sloboda (2006) found that unexpected chords elicited skin conductance increases, with the degree of harmonic violation correlating with amplitudes of the skin conductance response (Koelsch, Kilches, Steinbeis & Schelinksi, 2008); similar results were found through probabilistic modelling of live concert music listening (Egermann, Pearce, Wiggins & McAdams, 2013). Comparable findings are reported for acoustic intensity increases in stimuli, linking auditory looming to increased skin conductance (Bach et al., 2008; Bach, Neuhoff, Perrig & Seifritz, 2009). Music expressive of fear often results in increased skin conductance levels (Khalfa, Peretz, Jean-Pierre & Manon, 2002; Lundqvist, Carlsson, Hilmersson & Juslin, 2009), and loudness has also been correlated with skin conductance (Cheun, Sears & McAdams, 2016; Grewe et al., 2007). In broader work, startle reflexes are accompanied by skin conductance increases (Bradley, Codispoti, Cuthbert & Lang, 2001; Bradley, Lang & Cuthbert, 1993), overall characterising skin conductance increases as a sympathetic nervous system response to sudden changes, incoming threats and unexpected events. Interestingly, there is less evidence to suggest a clear increase in skin conductance derived from social bonding processes, although studies that characterise chills as indicative of being moved also note significant peaks in skin conductance (Benedek & Kaernbach, 2011; Wassiliwizky, 2015).

Literature on skin temperature suggests that vigilance chills could be accompanied by decreases in skin temperature for two immediate reasons. Firstly, fear or vigilance responses, associated with unexpected events, incoming threats and sudden changes, have been linked to skin temperature decreases (Collet, Vernet-Maury, Delhomme & Dittmar, 1997; Ekman, Levenson & Friesen, 1983); comparable findings were reported in response to fear music compared to happy music (Baumgartner, Esslen & Jäncke, 2006; Krumhansl, 1997). Secondly, the biological mechanisms of skin temperature are linked to sympathetic nervous system activation, such that when sympathetic nervous system activity increases in response to unexpected events or possible threats (resulting in skin conductance increases), vasoconstriction also occurs, resulting in lower temperatures in extremities such as the skin (Vos et al., 2012; Wallin, 1981); in short, the biological mechanisms suggest that increases in skin conductance due to heightened sympathetic nervous system activity should be accompanied by decreases in skin temperature. Crucially, there is also growing evidence to suggest that social chills might be accompanied by increased skin temperature. For instance, social isolation, elicited in a computerised ball toss paradigm, has been linked to skin temperature decreases (IJzerman et al., 2012; see also Zhong & Leonardelli, 2008); additionally, experiences of social closeness have been associated with increases in body temperature (Inagaki & Eisenberger, 2013; Inagaki & Human, 2019).

Given the existing literature and evidence around skin conductance and skin temperature, it was predicted that vigilance and social chills with music may be accompanied by distinct patterns of physiological activity, with vigilance chills accompanied by increased skin conductance and decreased skin temperature compared to social chills. These predictions resemble recent findings linking responses to kama muta videos with increased skin temperature and decreased skin conductance compared to experiences with awe videos (Zickfeld et al., 2020).

Individual Differences

One intuitive framework for linking vigilance and social chills to possible individual differences is the empathising-systemising distinction of cognitive processing styles (Baron-Cohen & Wheelwright, 2004), proposing that individuals can be categorised into three main ‘brain types’ that reflect variations in cognitive processing preferences: Systemisers prefer to process stimuli in terms of rules, patterns and syntax; empathisers tend to process stimuli at the socio-emotional and empathic level; and balanced types present tendencies for both processing styles and reflect much of the neurotypical population (Greenberg, Warrier, Allison & Baron-Cohen, 2018). Chills have recently been linked to trait empathy (Bannister, 2019), complimenting existing relationships between being moved and empathy (Eerola et al., 2016); however, there are no clear explorations of systemising tendencies and chills in previous research, though recent work has suggested that these cognitive styles are related to aspects of musical engagement, such as preferences (Greenberg et al., 2015). Despite this, these empathising-systemising styles map intuitively on to the vigilance and social chills distinction, and were included as an exploratory variable in the current study; preliminary predictions were that empathising would be linked to being moved and more chills during social stimulus conditions, and systemising would be associated with awe and more chills during vigilance stimulus conditions.

Outline of the Current Study

To accommodate the varied results across research on musical chills, the current conceptualisation of the response describes two distinct types of chills in response to music, linked to either vigilance or social bonding mechanisms. These experiences may be separable at the levels of stimulus and experimental manipulation, subjective feeling, physiological response, and individual differences.

The central aim of this study was thus to provide empirical evidence for a *two-component theory* of musical chills. The formalised hypotheses were as follows:

- **H1**: Stimuli manipulated to emphasise structure or social narrative would elicit stronger experiences of awe (vigilance chills) and being moved (social chills) respectively, reflected by a *moved-awe emotional index*.
- **H2**: Chills reported within experiences of awe would be characterised by increases in skin conductance and decreases in skin temperature. Chills reported within experiences of being moved would be characterised by increases in skin temperature, with no prediction made for skin conductance.
- **H3**: Empathisers would report stronger being moved responses, and more chills in response to social stimulus conditions. Systemisers would report stronger awe experiences, and more chills in response to vigilance stimulus conditions.

Methods

Ethics Statement

This study was fully approved by the Durham University Department of Music Ethics Committee (institutional approval reference: MUS-2019-01-11T10:48:25), and all aspects of this research were executed in line with the institution's ethical and governance guidelines. All participants in the study were aged 18 or older, and all provided written informed consent after being presented with participant information sheets, outlining the experimental procedure and the processing, storage and security of data in line with the General Data Protection Regulation.

Design

A listening experiment was designed using four pieces of music, split into two blocks of listening. In the first, participants listened to two different pieces of music, with extra-musical information provided about the piece before listening; this information either emphasised the overall dynamic structure of the piece (vigilance condition), or described an emotional narrative that reflected the structural development of the music (social condition). In the second block, participants listened to the other two music excerpts, accompanied by a visual animation; this would either be a circle that increased or decreased in size and motion velocity to reflect the dynamic intensity of the music (vigilance condition), or an animation that communicated a bittersweet, moving story (social condition). To control for order effects or fatigue, stimulus presentation order was randomised within each experimental block. However, the experimental block order was kept constant (extra-musical information followed by visual accompaniment); this was to control for confounding variables such as visual imagery that might persist if experimental blocks were reversed.

The dependent variables were the frequency of chills reports via button presses, skin conductance and skin temperature during chills reports, and the *moved-awe emotional index* calculated from awe and being moved ratings. The independent variables were the vigilance or social conditions for each of the four stimuli. Finally, individual differences were assessed in terms of the empathising-systemising distinction. The experiment followed a within-subjects design, where participants listened to all four stimuli, but received one vigilance and social condition in the first block, and one of each in the second block (see **Figure 1**).

Participants

In total, 44 participants took part in the experiment (mean age = 27.56, SD = 7.44, range = 20-55). Of the sample, 17 were male, 27 were female, 36 reported being a student, and 40 reported playing a musical instrument. Participants were recruited through institutional mailing lists, social media, and poster advertisements across the University campus. A pre-screening process confirmed that all participants had experienced chills with music previously. This sample size was derived from existing correlational and causal studies of musical chills (Bannister, 2020b, N = 40; Bannister & Eerola, 2018, N = 24; Craig, 2005;

N = 32; Egermann et al., 2011, *N* = 14; Grewe et al., 2007, *N* = 38; Rickard, 2004, *N* = 21; Salimpoor et al., 2009, *N* = 32). Sample descriptives are available in the **Supplementary Material**.

Materials and Measures

Stimuli

Four stimuli were utilised in the experiment: *Glósóli* by Sigur Rós (duration: 6 minutes, 18 seconds), *Prayer* by Ernst Bloch (duration: 5 minutes), the fourth movement of *Pines of Rome* by Ottorino Respighi (duration: 5 minutes, 35 seconds), and a video game music excerpt from Final Fantasy IX called *Behind the Door,* composed by Nobuo Uematsu (duration: 2 minutes, 5 seconds). These stimuli were selected to contain a key moment of structural contrast (e.g. sudden dynamic change), and for their documented efficacy to elicit chills and emotions both in previous research (Bannister, 2020a; Bannister & Eerola, 2018; Juslin, Barradas & Eerola, 2015; Juslin, Harmat & Eerola, 2014), and across social media forums such as Quora, YouTube and Reddit. Additionally, stimuli were chosen on the basis that they would be unfamiliar; using a familiarity scale of one (unfamiliar) to five (very familiar) after each piece, this was confirmed in the experiment (Prayer: *M* = 1.39, *SD* = 0.84; Pines of Rome: *M* = 1.58, *SD* = 0.95; Glósóli: *M* = 1.95, *SD* = 1.31; Behind the Door: *M* = 1.40, *SD* = 0.72). For stimulus descriptions and sources, see the **Supplementary Material.**

Stimulus Manipulations

In the first experiment block, the pieces Prayer and Pines of Rome were used, preceded by text descriptions that emphasised the structural development in the music (vigilance), or social and narrative elements (social). These full texts are provided in the **Supplementary Material**.

For the second block, the pieces Glósóli and Behind the Door were used, presented alongside a visual animation. For vigilance conditions, an animation was created using Adobe AfterEffects; for both pieces this was a white circle on a black background, to avoid priming of emotion concepts via colour (Curwen, 2018; Ou, Luo, Woodcock & Wright, 2004). This circle increased or decreased in size, thickness and motion in relation to the general dynamic contour throughout the piece; during the moment of dynamic climax in both pieces, the dimensions of the circle would be displaced and distorted, resulting in a rapidly rotating and large noise-like circle, intended to visually emphasise structural developments in music linked to vigilance mechanisms. To create social conditions, short animations were utilised. For Glósóli, an animated film called *The OceanMaker* was used; for Behind the Door, an excerpt from the film *Storks* was used; both animations were edited to fit the scenes with the musical structure. These animations represent positively (reunion after separation) or negatively moving (self-sacrifice for the greater good) scenarios linked to being moved (Wassiliwizky, 2015), and these moments were synchronised with key moments of contrast within the music; both joyfully and sadly moving scenarios were depicted in the social conditions to fully encapsulate current conceptualisations of being moved (Menninghaus et al., 2015; Tokaji, 2003). Descriptions and sources for these animations are provided in the **Supplementary Material**.

Importantly, whilst experimental manipulations are not fully counterbalanced across stimuli (e.g. Glósóli is not paired with any text descriptions), this was considered an appropriate compromise in the current work for three reasons: Firstly, all stimuli have been linked to chills or shown experimentally to be effective elicitors, suggesting that stimulus and manipulation combinations are unlikely to affect the overall elicitation of chills in listeners; secondly, all stimuli were specifically selected to contain a key moment of *contrast* linked to chills (sudden dynamic change), and consequently it was anticipated that similar underlying mechanisms would be engaged by the music itself, allowing for an emphasis of the experimental manipulations and reduction in impact of any counterbalancing; finally, as this experiment was a theory-driven approach to establishing an initial and broad distinction between musical chills types, it was determined that maximising resources and data collection in the current design was optimal for this first iteration, to establish a foundation for future work on musical chills that enables informed and detailed investigations into interactions between stimulus and experimental manipulations, and identifying psychological mechanisms underlying these experiences.

Self-Reports

After each stimulus, participants rated experiences of awe and being moved, utilised as indicators of vigilance and social chills respectively. For awe, items were extracted from the Awe Experience Scale (AWE-S; Yaden et al., 2019), a recently developed, internally consistent instrument correlated with existing tools previously used to indirectly assess awe (e.g. Shiota, Campos & Keltner, 2003). The AWE-S is comprised of a six-factor structure, with three factors traditionally related to awe (Keltner & Haidt, 2003; Shiota et al., 2007), and deemed appropriate for the theoretical basis of vigilance chills, labelled *physical sensations*, *perceived vastness* and *need for accommodation*. In total, 13 items were used from the AWE-S (Likert-type, 1-7), three pertaining to bodily activity and 10 to subjective feelings.

For being moved, items were taken from the KAMMUS-2 instrument (Zickfeld et al., 2019), a scale recently utilised and validated across different languages and contexts, consisting of five factors. Of these, three were utilised for the current experiment, which were *physical sensations, appraisals* (i.e. feelings of social connection) and *motivations* (e.g. for social connection), encapsulating feelings of communion, love and wanting to express social closeness with others; these reflect subjective feelings of kama muta linked to chills (Fiske et al., 2017), and changes in motivation and goal-orientation also associated with chills (Fukui & Toyoshima, 2014). Inclusion of the physical activity factor was motivated by balancing across ratings for awe and kama muta, and by evidence suggesting that chills can co-occur with various sensations (Algoe & Haidt, 2009; Maruskin et al., 2012; Wassiliwizky et al., 2017b) that may indicate meaningful differences in experience (Nummenmaa, Hari, Hietanen & Glerean, 2018). Overall, 11 items were utilised from the KAMMUS-2 (Likert-type, 1-7), three linked to bodily activity and 8 to subjective feelings.

Importantly, items from both rating instruments were omitted from the experiment, as they referred to typical sensations associated with prevailing definitions of chills experiences provided to participants (e.g. goosebumps, shivers and tingling sensations).

Participants also rated their experiences in terms of familiarity with the stimulus (Likert-type, 1-5), enjoyment (Likert-type, 1-7), and emotional intensity (Likert-type, 1-7). Regarding individual differences, cognitive processing styles of empathising and systemising were assessed, using the empathising quotient (EQ; Baron-Cohen & Wheelwright, 2004) and revised systemising quotient (SQ-R; Wheelwright et al., 2006). The EQ is comprised of 60 statements, containing 20 distractor items. For each statement, participants can score a maximum of two points and a minimum of 0, resulting in a possible score range of 0 to 80; higher scores reflect stronger empathising approaches. The SQ-R contains 75 statements, with no distractor items. The maximum score per statement is two, and the minimum is 0, with a possible score range of 0 to 150; higher scores reflect stronger systemising tendencies. Across instruments, participants respond to statements with a strongly agree, agree, disagree or strongly disagree, regarding the extent to which statements reflect how participants sees themselves.

Physiological Activity

Skin conductance and skin temperature were recorded in the experiment. Skin conductance data were collected using two electrodes (Ag/AgCL) attached to the distal phalanx of the index and middle fingers of the non-dominant hand. Skin temperature data were collected by attaching a thermistor, a small wire aligned with the palmar surface of the small finger of the non- dominant hand, with the end of the wire taped to the fingertip. Physiological data were sampled at the rate of 32Hz, and measurements were performed using the NeXus-10 MKII hardware and BioTrace software. Due to occasional technical difficulties with hardware, no physiological data were collected for three participants, data were only collected for three of four stimuli in 10 participants, and data were only collected for two of four stimuli in three participants.

Chills Measurement

To measure chills experiences, participants reported the onset of chills in real time by pushing a button. Previous work often utilises physiological activity to validate self-reported chills experiences, by assessing whether button presses are accompanied by significant increases in skin conductance (Craig, 2005; Egermann et al., 2011; Grewe et al., 2007). However, given the aim of investigating distinct types of musical chills, with physiological activity used as a distinguishing feature, these validation methods were not replicated, and button presses from participants were mostly retained for analysis. To control for abnormal behaviours in button presses that might influence results (e.g. overuse of the button, accidental pressing), button presses from a participant were omitted from analysis if they were within seven seconds of the preceding button press; this value was based on the average duration of chills experiences from previous work (Bannister, 2020b; Craig, 2005). Through this process, 36.3% of chills reports were omitted from the analysis.

Procedure

Participants were tested separately, randomly assigned to one of two experimental groups. In group one, participants received vigilance conditions for Pines of Rome and Glósóli, and social conditions for Prayer and Behind the Door; this was reversed for group two (see **Figure 1**). Participants first familiarised themselves with the procedure and data protection standards, presented in a participant information screen; next, written informed consent was obtained through completion of a consent form, with a series of statements initialised and the form signed by participants. Before the experiment, participants completed demographic questions, whilst electrodes and thermistor were connected to their non-dominant hand. As a safety and control measure, the experimenter played a short piece of music to participants, representing the maximum level of loudness to be encountered in the experiment; the volume of this music was set between experimenter and participant, aiming for the music to be as loud as possible without causing discomfort. Participants then moved through the first experimental block, providing self-reports after each stimulus, and indicating chills in real time by pushing a button. After a break, participants moved through the second block, with the same procedure as the first. To conclude, participants completed the EQ and SQ-R instruments. Participants were paid £5 for participation. Data were fully anonymised throughout the collection and analysis procedures; the experiment took roughly 45 minutes to complete, and was delivered using *OpenSesame*.

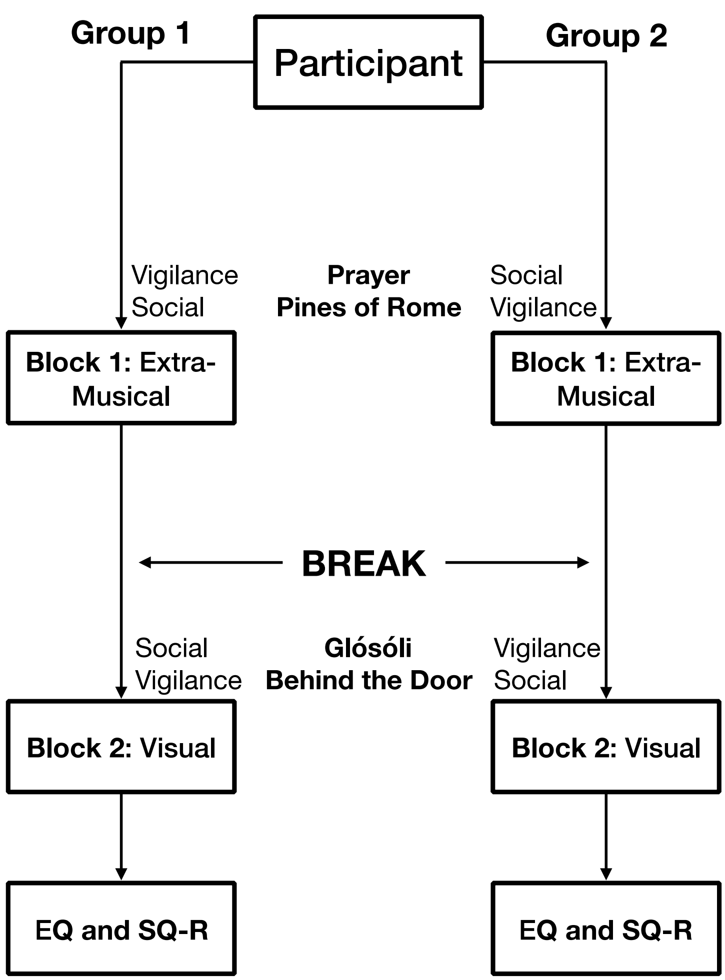

Figure 1: Procedural outline of the experiment; stimulus orders within each experimental block were

counterbalanced across participants.

Data Analysis

All data analysis was performed in R; To analyse repeated-measures numerical data (self-report ratings, psychophysiological activity), linear mixed effects models were constructed to assess overall effects, implemented using the *lme4* package (Bates, Mächler, Bolker & Walker, 2015). To assess the statistical significance of fixed effects fitted in these models, likelihood ratio tests were performed, comparing full statistical models with reduced models (i.e. no specified fixed effects); planned post-hoc contrasts (Tukey corrected) were also carried out to understand specific differences in data across the level of comparison. Effect sizes of the models were estimated using marginal R^2 values following calculations from Nakagawa and Schielzeth (2013), computed in R using the *MuMIn* package (Barton, 2018).

Self-Report Transformations

For EQ and SQ-R instruments, data were scored following negative or positive scoring structures, with distractor questions omitted.

For awe and being moved, responses were averaged for each stimulus, across 13 items from the AWE-S, and 11 items from the KAMMUS-2. As both instruments have recently been developed independently, it was unclear how rating patterns for both would be compared; in an early diagnosis, a principal components analysis of the subjective feeling scales (see the **Supplementary Material**) reported that both instruments showed reasonable separation given some conceptual overlaps between the two states (Fiske et al., 2017; Konečni, 2005; Menninghaus et al., 2015; Piff et al., 2015; Preston & Shin, 2017; Spears et al., 2011; Stellar et al., 2018), but the distribution of awe scores was generally higher compared to being moved, suggesting a different behavioural range of reporting. To allow for more intuitive comparisons across 13 awe items and 11 being moved items, AWE-S and KAMMUS-2 average ratings were normalised within each instrument, across participants; the same procedure was performed for EQ and SQ-R data, accommodating different scoring totals.

To accommodate the possibility that all listening conditions may elicit *either* vigilance or social chills responses, the likelihood that experimental manipulations would not produce global effects for idiosyncratic chills responses (Grewe et al., 2007), and the possible similarities between awe and being moved (Konečni, 2005), a continuous *moved-awe emotional index* scale was produced, by subtracting normalised mean being moved ratings from awe ratings for each participant and stimulus, (a method adapted from recent empathising-systemising research, e.g. Greenberg et al., 2018). This index followed a normal distribution, serving as the main dependent variable for subjective feeling that more clearly encapsulated and distinguished experiences of awe or being moved from those that were emotionally balanced. In this scale, negative values indicate stronger experiences of being moved, whilst positive values indicate stronger experiences of awe; scores tending towards zero reflect balanced experiences. The same procedure was carried out for empathising-systemising scores, producing a *cognitive style* scale; these scores were normally distributed, with negative values on this scale indicate strong empathising characteristics, and positive values reflect systemising tendencies. Crucially, given current limitations around understanding the conceptual scope of chills (Bannister, 2019), subjective reports from participants provide primary information around the phenomenon. Importantly, it was proposed that if the experimental conditions (vigilance vs. social) could predictably bias experiences towards awe and being moved respectively, then the *moved-awe emotional index* scores would serve as the foundation for categorising listening experiences as awe or being moved, and in turn provide a proxy for vigilance or social chills experiences; this *moved-awe emotional index* would also function as the primary level of comparison in which to assess differences in psychophysiological differences across chills reports, and the role of cognitive processing styles.

Chills Categorisation

To investigate differences in psychophysiological data across chills reports, one strategy could be to average psychophysiological data across button presses for each participant and stimulus, and correlate these values with the *moved-awe emotional index* scale; however, this strategy is sensitive to varying magnitudes of *moved-awe emotional index* scores, which may not be appropriate when considering distinct chills experiences and complexities of physiological activity patterns (Khalfa et al., 2002), and a level of dissociation between subjective feeling and physiological response (Grewe, Nagel, Kopiez & Altenmüller, 2007b).

Alternatively, an additional analysis strategy less sensitive to varying magnitudes of ratings was to categorise listening experiences, by splitting the *moved-awe emotional index* scale into three equal proportions: scores in the 33rd percentile or lower were judged to reflect being moved experiences, scores in the 67th percentile or higher were classified as awe experiences, and all scores in between were assumed to indicated balanced affective experiences (see **Figure 2**). From this operation, chills reported within being moved experiences were classified as *social chills,* chills reported within awe experiences were categorised as *vigilance chills*, and chills reported during balanced experiences were also considered to be *balanced* chills responses. At this level of categorisation, psychophysiological data could be compared across three chills categories (vigilance, balanced and social). This categorisation procedure was adapted from similar methodologies in previous work (Greenberg et al., 2018; Wheelwright et al., 2006).

Psychophysiology

Skin conductance and skin temperature data were firstly detrended, to correct gradual linear decreases over time. Skin conductance data were then pre-processed and decomposed into phasic (SCR) and tonic (SCL) components (see Bannister & Eerola, 2018), using the continuous decomposition analysis method performed with the '*Ledalab*' package in MATLAB (Benedek & Kaernbach, 2010). The phasic SCR served as a higher resolution measure of event-related response, and tonic SCL indicated slower trends in activity (Boucsein, 2012).

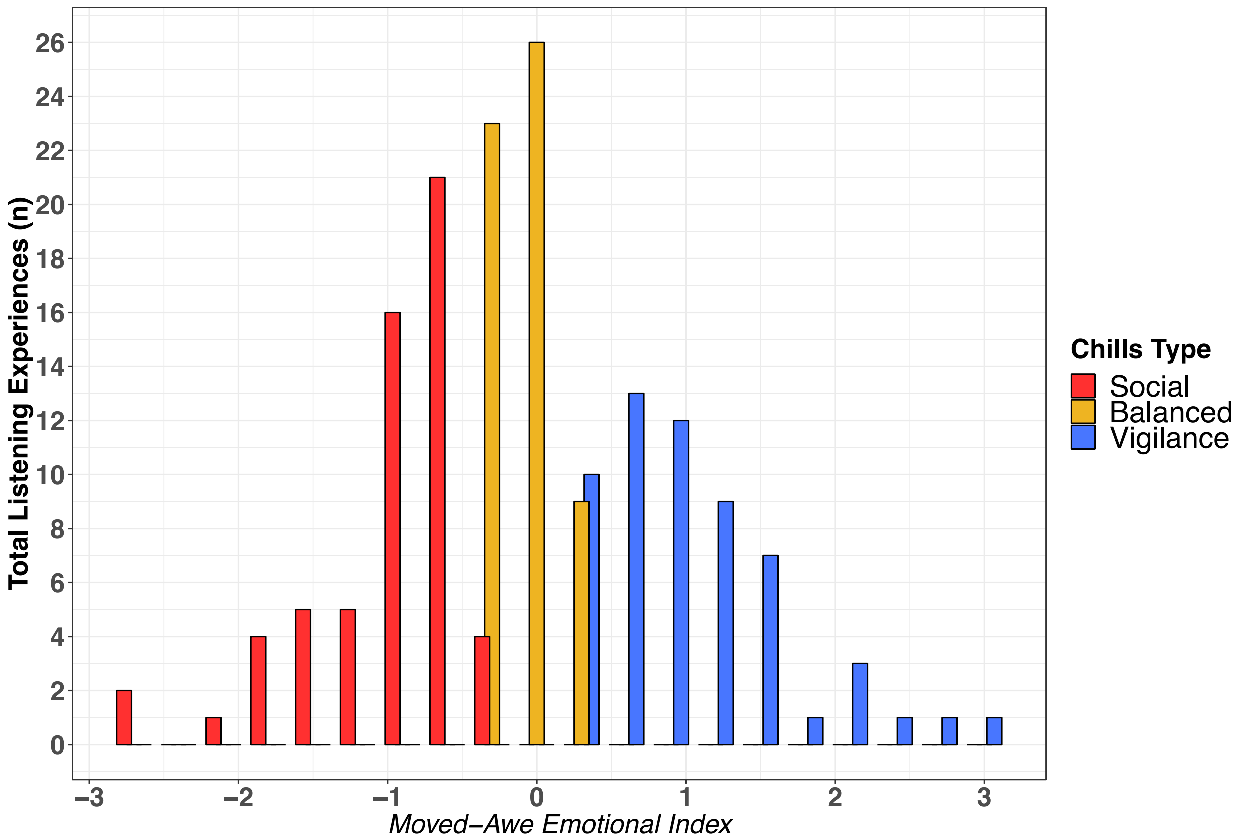

Figure 2: Visualisation of the categorisation procedure for listening experiences from the *moved-awe emotional index* scores; these categories were separated according to the 33rd and 67th percentile values in the distributions. The y-axis indicates how many listening experiences received a corresponding *moved-awe emotional index* score on the x-axis.

Phasic SCR, tonic SCL and skin temperature were utilised as possible indicators of vigilance or social chills. Measures were normalised within each participant to account for individual differences in physiological activity (Khalfa et al., 2002). To characterise chills responses of participants, the 4 second epoch following each button press chills report was compared to the 4 second epoch directly preceding the same button press; for all measures, the mean change in signal from pre- to post-button press was analysed. An epoch of 4 seconds was targeted in accordance with a two to four second delay of skin conductance activity following behavioural responses (Boucsein, 2012). The pre- to post-button press comparison was preferred over comparisons to a baseline epoch of physiological activity as previously utilised (Grewe et al., 2007a), given that the current focus was not on validating chills experiences, but on data that may reflect more closely the specific, temporal, differing qualities of chills responses; for example, by comparing to a baseline, some chills may be accompanied by 'increased' skin conductance or temperature, when the button press is accompanied by no such localised change as expected.

Results

Descriptive Statistics

The following descriptive statistics consider the frequency of chills reports across stimuli and conditions. For an overview, see **Table 1;** descriptive data are also presented in relation to the experimental manipulation *modality* (e.g. text information or visual animation) in **Table 2.**

Table 1: Descriptive statistics across stimuli and conditions for chills frequency, familiarity (1-5), enjoyment (1-7), intensity (1-7), awe (1-7), being moved (1-7), and aggregated *moved-awe emotional index* scores.

Condition	Stimulus	Total Chills (*N*)	Mean Chills Per Minute	Familiarity	Enjoyment	Intensity	Awe	Being Moved	***Moved-Awe Emotional Index***
Vigilance	*Prayer*	80	0.72	1.36	5.68	4.86	2.56	2.77	**-0.22**
	Pines	96	0.81	1.71	4.61	3.38	2.52	1.68	**0.65**
	Glósóli	105	0.75	1.81	4.59	3.13	2.42	1.76	**0.25**
	Door	49	1.06	1.40	5.00	3.86	2.30	1.98	**0.01**
Social	*Prayer*	96	0.91	1.42	5.42	4.52	2.24	2.59	**-0.34**

	Pines	69	0.56	1.45	5.27	4.27	2.65	2.49	**0.10**
	Glósóli	130	0.93	2.09	5.31	5.00	3.05	2.75	**0.18**
	Door	67	1.46	1.40	4.68	4.36	2.25	2.79	**-0.65**

With 44 participants experiencing four stimuli each (total = 176 experiences), 692 chills responses were reported via button presses, suggesting that the stimuli used and participants recruited resulted in an effective paradigm for eliciting chills in experimental settings. Of the 44 participants, only five reported no chills throughout the experiment, and the mean number of chills reported in a piece was 3.97 (*SD* = 4.25, range = 0 - 20).

At the level of condition, social conditions resulted in more chills per minute (*M* = 0.96) compared to vigilance conditions (*M* = 0.84), with the social condition of Behind the Door reflecting the highest chills rate (*M* = 1.46). To assess whether chills frequency differed significantly across listening conditions (vigilance, social), linear mixed effects models were constructed; the dependent variable was chills per minute (to accommodate differing stimulus durations), the fixed effect was listening condition, and individual participants and the four pieces (Pines of Rome, Prayer, Glósóli, Behind the Door) were fitted as random effects. At the level of vigilance and social conditions, no significant difference was found for chills frequency (x^2 = 2.27, *df* = 1, *p* = .13); across all stimulus and condition combinations (total = 8), Tukey post-hoc contrasts suggested that there were no significant differences in chills per minute values.

The level of modality was also considered, comparing across extra-musical information or visual animation approaches with a linear mixed effects model (modality as fixed effect, participant and four pieces as random effects); no significant differences in chills per minute values were found across modality (x^2 = 2.16, *df* = 1, *p* = .14). These results suggest that chills were elicited similarly across stimuli, vigilance and social conditions, and the different modality approaches.

As a final analysis, linear mixed effects models were used to assess the frequency of chills reports in relation to the reported gender of the listener, and ratings of familiarity with the stimuli. Firstly, there were no differences in frequency of chills reports chills across gender (x^2 = 1.57, *df* = 1, *p* = .20);

secondly, frequency of chills did not differ across familiarity ratings (x^2 = 0.18, *df* = 4, *p* = .99), with most stimuli being unfamiliar to participants.

Table 2: Descriptive statistics across experimental modality and condition for chills frequency, familiarity (1-5), enjoyment (1-7), intensity (1-7), awe (1-7), being moved (1-7), and aggregated *moved-awe emotional index* scores.

Modality	Condition	Total Chills (*N*)	Mean Chills Per Minute	Familiarity	Enjoyment	Intensity	Awe	Being Moved	***Moved-Awe Emotional Index***
Information	*Vigilance*	176	0.77	1.53	5.16	4.13	2.54	2.24	**0.20**
	Social	165	0.73	1.44	5.34	4.39	2.45	2.54	**-0.11**
Visual	*Vigilance*	154	0.91	1.61	4.79	3.50	2.36	1.87	**0.13**
	Social	197	1.19	1.75	5.00	4.68	2.65	2.77	**-0.23**

Vigilance and Social Chills

Stimulus Manipulation

To assess the first hypothesis (**H1**), subjective feeling data were firstly compared across vigilance and social stimulus conditions. Following the analysis strategy, aggregated *moved-awe emotional index* scores were utilised (see **Figure 2**). In assessing these values across vigilance or social stimulus conditions and modality with a linear mixed effects model (condition and modality fitted as fixed effects, individual participants and individual pieces fitted as random effects), a significant effect of condition was found (*ß* = -0.34, *SE* = 0.12, *t* = -2.84, *p* = .004), with vigilance conditions resulting in more positive scores, and social conditions leading to more negative scores; no effect of modality was found (*ß* = 0.10, *SE* = 0.41, *t* = 0.24), and no significant interaction between modality and condition was found (*ß* = 0.04, *SE* = 0.24, *t* = 0.20). These findings support the first hypothesis, where by framing the same musical stimulus with a vigilance or social focus (using extra-musical information or visual animations), stronger experiences of awe and being moved can be elicited respectively and predictably. Consequently, *moved-awe emotional index* scores were a validated, continuous proxy for indicating vigilance or social chills responses reported within listening experiences, and as a foundation for categorising experiences as being moved (*social chills*), awe (*vigilance chills*), or balanced (*balanced chills*), as reflected in **Figure 2**.

Across being moved, awe and balanced listening experiences, linear mixed effects models were used to explore any differences in ratings of familiarity with the stimulus, enjoyment and emotional intensity (ratings as dependent variable, three experience categories as fixed effect, and individual participants and pieces as random effects). With Bonferroni correction for multiple comparisons, no differences in ratings were found for familiarity (x^2 = 0.56, df = 2, p = .75) or enjoyment (x^2 = 1.47, df = 2, p = .47), but for emotional intensity a significant difference across experience categories was found (x^2 = 8.52, df = 2, p = .014); post-hoc Tukey comparisons revealed that this difference was driven by higher emotional intensity ratings during experiences classified as being moved, compared to experiences of awe (*ß* = 0.78, z = 2.90, p = .01).

Psychophysiological Response

To address the second hypothesis (**H2**), namely that vigilance chills are accompanied by higher skin conductance and lower skin temperature levels compared to social chills, physiological activity was first correlated with *moved-awe emotional index* scores, to assess relationships between skin conductance or temperature with differing magnitudes of awe and being moved. An average physiological value was calculated across all chills reports for each participant, within each stimulus, and Spearman rank correlations were performed between this aggregated data and emotion ratings. Results revealed no clear relationships between moved-awe emotional index and tonic skin conductance (r_s = .08, p = .24), phasic skin conductance (r_s = -.11, p = .81), or skin temperature (r_s = -.04, p = .35). These results suggest that changes in physiological activity were insensitive to differing magnitudes of *moved-awe emotional index* ratings.

To accommodate the possibility that physiological activity is not strictly correlated with the magnitude of awe or being moved experiences, physiological activity was compared across the three chills categories derived from the *moved-awe emotional index* scores, namely *vigilance*, *balanced* and *social* categories (see **Methods**). For all psychophysiological measures, a linear mixed effects model was constructed (chills type fitted as fixed effect, with individual participant and stimulus fitted as random effects). Regarding tonic SCL, the model captured significant effects of chills type (x^2 = 269.55, *df* = 2, *p* <.0001, R^2 = .04); planned post-hoc comparisons, predicting that SCL would be higher in vigilance chills compared to social chills, suggested that this was the case (*ß* = -0.13, *SE* = 0.009, *z* = 13.78, *p* <.0001). When assessing phasic SCR during chills, a significant effect of chills type was found (x^2 = 49.68, *df* = 2, *p* <.0001, R^2 = .01); however, in contrast to tonic SCL, phasic SCR was significantly higher in social chills compared to vigilance chills (*ß* = -0.43, *SE* = 0.06, *z* = -6.55, *p* <.0001). Finally, regarding skin temperature, significant effects of chills type were found (x^2 = 149.55, *df* = 2, *p* <.0001, R^2 = .02); post-hoc planned comparisons, predicting that skin temperature would be higher in social chills compared to vigilance chills, suggested that this prediction was correct, although this difference was marginally significant (*ß* = -0.007, *SE* = 0.003, *z* = -2.00, *p* = .044), and should be interpreted with caution.

These results partially support the second experimental hypothesis, with chills reported within stronger experiences of being moved accompanied by higher skin temperature and lower tonic SCL levels compared to chills reported within stronger awe experiences. Phasic SCR is a notable exception, although it must be noted that by visualising the average phasic SCR time-series (see **Figure 3**), there was a substantial peak in activity found in experiences of awe compared to being moved, but this occurred before the reported onset of chills; after the button press, phasic SCR activity appears more comparable across vigilance and social chills. Furthermore, correlational analyses suggest that physiological activity is insensitive to the intensity of awe or being moved experiences. Finally, whilst significant differences were reported, the estimated effects of chills type on physiological activity, evidenced through both marginal R^2 calculations and standardised beta coefficients, seem small; however, there are likely many other biological and experiential factors that determine physiological responses across individuals, and considering the use of unfamiliar stimuli in the current experiment, the results remain notable.

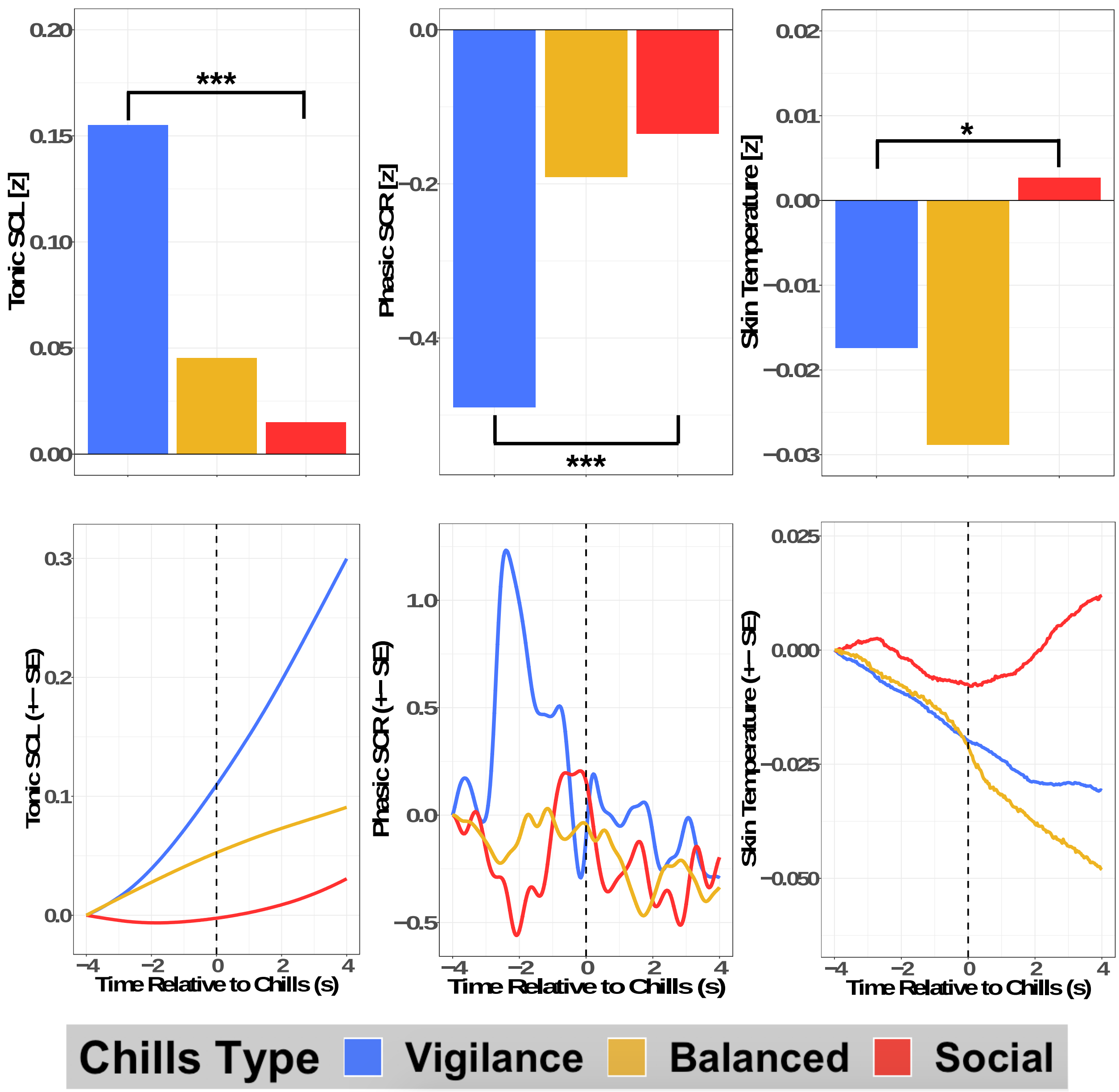

Figure 3: Visualisation of mean differences in physiological activity (tonic SCL left, phasic SCR centre, skin temperature right) across chills types; top row represents mean differences from 4 seconds before and 4 seconds after chills reports, and bottom row represents average time-series activity ranging from 4

seconds before to 4 seconds after chills reports (shaded area reflects average standard error of values). Note: *** = p <.001, * = p <.05.

Individual Differences

The final hypothesis (**H3**) concerned the possible role of individual differences, mainly the empathising and systemising cognitive processing styles. It was predicted that systemisers would report stronger awe experiences, and empathisers would report more being moved responses, in turn reflecting the tendency to experience vigilance or social chills with music. Furthermore, it was predicted that systemisers would report more chills in vigilance conditions, with empathisers experiencing more chills in social conditions. To assess links between empathising-systemising and emotion ratings, spearman rank correlations were performed using the overall cognitive style scale (see **Methods**), with negative scores indicating stronger empathising tendencies, and positive scores reflecting systemising tendencies. However, no relationship was found between cognitive style and moved-awe emotional index scores (r_s = .06, p = .18). To explore how cognitive style affected reported chills experiences in vigilance or social conditions, interaction effects were assessed between stimulus conditions and cognitive style on frequency of chills, reported in a general linear mixed effects model with poisson distribution; however, reflecting correlation results, there was no clear interaction between stimulus condition and cognitive style scores in determining frequency of reported chills (x^2 = 0.31, df = 2, p = .85), indicating no immediate relationship between the empathising-systemising distinction and experiences of vigilance or social chills with music.

Discussion

The phenomenon of musical chills has been conceptualised as an indicator of peak pleasure or emotional arousal whilst listening (Rickard, 2004; Salimpoor et al., 2011), linked to musical features, individual differences, and listening contexts. Theories have been proposed to explain chills, including mechanisms of vigilance, expectancy and auditory looming, or the role of empathy and social bonding processes. These perspectives are problematic and lack explanatory power when considered in isolation, due to several confounds in existing research: Firstly, chills are linked to plethora of musical and psychoacoustic features that can be understood from several theoretical perspectives; secondly, chills are associated inconsistently with psychophysiological and neurophysiological activity; thirdly, chills are not reliably predicted by individual personality traits of listeners; and finally, is it unclear how chills are best distinguished from reactions including tears and the autonomous sensory meridian response (ASMR). Consequently, a contemporary view suggests that chills may be more accurately characterised as a collection of phenomenologically distinct responses (Bannister, 2019, 2020a; Bannister & Eerola, 2018; Levinson, 2006; Maruskin et al., 2012; Panksepp, 1995; Pelowski et al., 2017), with varied underlying psychological mechanisms. The present study formalised and developed this approach, and empirically tested a specific distinction between *vigilance chills*, linked to threat-signalling goosebumps, vigilance and awe, and *social chills* experiences, linked to thermoregulatory goosebumps, social bonding, empathy and being moved. It was predicted that these distinct chills responses could be distinguished at the level of stimulus manipulation, subjective feelings, psychophysiological activity, and individual differences of listeners.

The current results support the existence of distinct musical chills responses: When the same musical stimuli are paired with extra-musical information or visual accompaniment emphasising structural developments in the music, emotional experiences are more strongly characterised as awe, whereas information or visual accompaniment emphasising narrative and social components results in stronger being moved states. When using reports of awe and being moved, through a *moved-awe emotional index*, to categorise chills into either *vigilance, balanced* or *social* types, it was found that vigilance chills demonstrate increased tonic skin conductance and decreased skin temperature compared to social chills. Interestingly, phasic skin conductance appeared to increase after social chills were reported by participants, compared to vigilance chills; however, this may be explained by the visualisation in **Figure 3**, showing that vigilance chills demonstrate a substantial peak in phasic skin conductance prior to the chills report, with social chills showing no clear peaks. This peak leading up to chills has been reported several times (Salimpoor et al., 2009), sometimes labelled a 'pre-chill' (Wassiliwizky et al., 2017a), and may reflect anticipatory or expectation mechanisms involved in some chills responses; this might explain why the phasic skin conductance peaks were apparent before vigilance chills reports but not social chills, possibly supporting the current study predictions more closely than results suggest. Regarding individual differences however, no clear relationships were found between chills experiences and systemising or emphasising scores; this might be because most neurotypically developing individuals are classified as having a balanced cognitive style (Greenberg et al., 2018), but future work on this topic could consider utilising an empathising-systemising measurement tool designed specifically for music (Kreutz et al., 2006).

The present data are some of the first to offer broad empirical evidence of a *two-component theory* of musical chills, and of systematic and predictable variations in musical chills responses, reflecting contemporary investigations on the phenomenon and musical experience more broadly. For example, the vigilance and social chills distinction resembles the 'goosetingles' and 'coldshivers' suggested by Maruskin et al. (2012); social bonding could be associated with approach behaviours, with vigilance processes linked to avoidance, although both may result in pleasure and enjoyment in aesthetic contexts, suggesting that that the chills distinction proposed by Maruskin et al. (2012) is not sufficiently nuanced to encapsulate aesthetic engagements. Additionally, current data might be conceptually comparable to a tentative distinction proposed between aesthetic 'chills', linked to resonance, flow and being moved, and aesthetic 'thrills', linked to awe and fear (Pelowski et al., 2017). Finally, these findings resonate somewhat with recent work on musical beauty (Omigie et al., 2019), that reported evidence of different types of beauty linked to interest (e.g. processing of musical structure) or empathy (e.g. connecting with social personas or narratives), although it is currently difficult to directly equate concepts of interest and empathy with vigilance and social perspectives of chills.

Implications for Chills Research, Theory, and Underlying Mechanisms

The current experiment also has substantial implications for interpreting previous literature, performing future investigations, evaluating theoretical accounts of chills, and understanding underlying psychological mechanisms of music and emotion.

Firstly, the possibility of distinct musical chills experiences may result in significant reinterpretations and reassessments of previous investigations of the phenomenon. Most studies have approached musical chills without exploring their emotional qualities, which have been shown to vary substantially (Bannister, 2020a). Additionally, many studies utilise certain working definitions of chills, such as noting key physical reactions including goosebumps, shivers and tingling; however, tingles are currently difficult to capture objectively (Tihanyi et al., 2018), and only goosebumps have been objectively tied to self-reported chills responses (Benedek & Kaernbach, 2011; Craig, 2005; Wassiliwizky et al., 2017b), meaning that the definitional scope of chills requires serious discussion and debate. These factors, alongside previously noted inconsistencies across all aspects of musical chills research, suggest a problematic possibility, namely that extant research on chills has been assessing different types of experiences without explicit awareness. A scenario in which researchers investigate ‘musical chills’ that are psychologically distinct from those targeted by other researchers poses an obvious issue in interpreting and understanding correlational and causal data on the topic (Bannister & Eerola, 2018; Grewe et al., 2007a; Sloboda, 1991). The current data emphasise the need to better define the conceptual scope of musical chills, identify systematic variations across these responses, and apply this novel research perspective to existing and future investigations.

Secondly, this study has ramifications for existing theoretical accounts of musical chills. Vigilance theory, formalised here but postulated by Huron (Huron, 2006; Huron & Margulis, 2010), suggests that chills are elicited through fear, vigilance, surprise and expectations, resulting in threat-signalling goosebumps and awe in pleasurable aesthetic contexts. A more recent, developing account is that of social bonding theory (Bannister, 2019, 2020a; Panksepp, 1995, 1998), in which musical chills are elicited through social bonding and empathic processes leading to intensified communal sharing relations, resulting in thermoregulatory goosebumps and being moved whilst listening (Fiske et al., 2017; IJzerman et al., 2015). These perspectives were the foundations for the proposed chills distinction tested in the current experiment, with data supporting both theories through the manipulations of listening conditions, subjective feelings and physiological activity. Given the lack of causal research on musical chills, these findings represent novel evidence for the role of various psychological processes underlying the response, and whilst it is crucial to further elucidate the distinctions between musical chills, future investigations should also focus on extensively testing and characterising these theoretical accounts. For example, a pivotal question for understanding how music elicits chills is to what degree there is any mutual exclusivity between vigilance and social bonding processes during emotional responses whilst listening. The current experiment assessed vigilance and social chills as separable experiences based on various factors, but there are notable overlaps that will need to be examined further. For example, there is the conceptual overlap of awe and kama muta as two emotional states linked to prosocial processing (Fiske et al., 2017; Konečni, 2005; Menninghaus et al., 2015; Piff et al., 2015; Preston & Shin, 2017; Spears et al., 2011; Stellar et al., 2018); there is also a duality surrounding moments of contrast in music (e.g. sudden dynamic changes), which seem capable of engaging vigilance and social mechanisms, depending on the circumstances and experimental approach. A further important question concerns whether the present *two-component theory* of musical chills can be applied across other aesthetic engagements, such as with visual art (Pelowski et al., 2017) or film (Hanich, Wagner, Shah, Jacobsen & Menninghaus, 2014). This possibility seems intuitive, given that chills occur in many aesthetic circumstances, and both the vigilance theory and social bonding theory described in this work are not domain-specific, derived instead from broader adaptive processes. However, it could be that certain art domains, depending on their overall qualities, are more biased towards eliciting particular chills experiences (for example, consider music that develops through time, and visual art that may not); to comprehensively understand the chills phenomenon, it will be important to further test theories and ideas across aesthetic engagements.

Finally, through better situating and characterising theoretical accounts in the musical chills context, there may be broader substantial impacts for understanding psychological mechanisms of music and emotion (Juslin, 2013). Indeed, the current study raises important considerations for possible underlying mechanisms of music and emotion. In the BRECVEMA framework (Juslin, 2013; Juslin et al., 2010; Juslin & Västfjäll, 2008), eight mechanisms have been proposed, ranging from brain stem reflexes, through rhythmic entrainment and emotional contagion, to visual imagery and episodic memory; however, these mechanisms are rarely causally tested, and it is difficult to identify these processes when they are each linked to several emotions or broad constructs such as arousal. Crucially, investigating musical chills in relation to theoretical accounts and processes underlying the response provides a unique emotional case study that helps to inform these broader frameworks. For example, social bonding and empathic mechanisms have been partially referenced through emotional contagion (Juslin & Västfjäll, 2008), but have rarely been considered more directly in current research; consequently, little is known as to how emotions might be elicited by aspects such as the human voice, lyrics and 'super-expressive' instruments (Bannister, 2020a; Juslin, 2001). By inducing chills through emphasising social and narrative aspects of music, these mechanisms may be characterised and tested. Therefore, there is significant potential in developing these causal approaches to musical chills, such as developing sophisticated inferences regarding causal processes underlying music and emotion.

Limitations and Conclusions

There are several limitations to the current experiment. Firstly, it is difficult to bridge the gap between self-reported experience and individual chills reports from participants. Whilst subjective feelings were utilised as a proxy for categorising chills experiences, future research should aim to develop methodologies that more directly assess the moment-to-moment emotional qualities of the chills reported; for example, continuous measurements of experience may be employed (Bannister & Eerola, 2018). Secondly, the current study utilised two different methods of stimulus manipulation, with the visual accompaniment method creating audio-visual stimuli; discerning the emotional effects of audio, video and interactions between the two is complex, and presently there is reduced clarity regarding the effects of music specifically. However, the method was included to diversify approaches to eliciting and separating vigilance and social chills, and given that the music used was consistent between vigilance and social animations, there is confidence that the visuals manipulated chills experiences by emphasising and combining with the qualities of the music. Using two manipulation methods was deemed a well-suited approach for the current study, performed as an investigation into a broad distinction between different musical chills experiences, and a first step to producing evidence for a *two-component theory* of the phenomenon. However, now that there is evidence for a predictable distinction between musical chills experiences, it will be crucial for future work to explore and evaluate the specific mechanisms and interactions between the music excerpts and manipulations such as providing extra-musical information (Miu & Baltes, 2012; Vuoskoski & Eerola, 2015) and using accompanying visual stimuli (Thompson et al., 2005; Thompson et al., 2008; Vuoskoski et al., 2014), in both chills research and broader work on music and emotion.

To conclude, the present experiment tested a novel hypothesis describing two types of musical chills, labelled vigilance chills and social chills; this was motivated by extensive inconsistencies in previous chills literature, and the inability of existing theories of the phenomenon to encapsulate the range of extant findings. Following evidence-based empirical predictions, this study confirmed the likelihood of distinct chills experiences, derived from two underlying theories based on vigilance or social bonding. Vigilance chills appear to be accompanied by feelings of awe, increased tonic skin conductance levels and decreased skin temperature; in contrast, social chills are linked to experiences of being moved, less pronounced skin conductance increases, and increases in skin temperature. In addition, these types of chills, when characterised by feelings of awe or being moved, can be predictably elicited through stimulus manipulations that emphasise structural or social aspects of music. Consequently, it may be essential to substantially reinterpret previous musical chills research, given the possibility that these studies have investigated psychologically distinct responses without being explicitly defined. Finally, the current experimental paradigm serves as a promising foundation for further assessing the prevailing theoretical accounts of musical chills, and for informing broader research on underlying mechanisms of music and emotion.

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Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

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