Emotional responses in Papua New Guinea show negligible evidence for a universal effect of major versus minor music

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Abstract

Music is a vital part of most cultures and has a strong impact on emotions^{1–5}. In Western cultures, emotive valence (happiness and sadness) is strongly influenced by major and minor melodies and harmony (chords and their progressions)^{6–13}. Yet, how pitch and harmony affect our emotions, and to what extent these effects are culturally mediated or universal, is hotly debated^{2,5,14–20}. Here, we report an experiment conducted in a remote cloud forest region of Papua New Guinea, across several communities with similar traditional music but differing levels of exposure to Western-influenced tonal music. One hundred and seventy participants were presented with pairs of major and minor cadences (chord progressions) and melodies, and chose which of them made them happier. The experiment was repeated by 60 non-musicians and 19 musicians in Sydney, Australia. Bayesian analyses show that, for cadences, there is strong evidence that major induced greater reported happiness than minor in every community except one: the community with minimal exposure to Western-like music. For melodies, there is strong evidence that those with higher mean pitch (major melodies) induced greater happiness than those with lower mean pitch (minor melodies) in only one of the three PNG communities and in both Sydney groups. The results show that the emotive valence of major and minor is strongly associated with exposure to Western-influenced music and culture, although we cannot exclude the possibility of universality.

In Western cultures, major harmony and melodies are perceived or felt to be happy, while their minor versions are perceived or felt to be sad^{6–13}. Although several possible origins have been proposed¹⁰, there is no consensus over exactly how harmony and pitch affect our emotions and to what extent these effects are culturally mediated or universal^{2,5,14–20}. Experiments conducted with Western participants have shown that emotions induced by psychoacoustic features related to the pitch content of the musical signal – such as roughness, harmonicity, spectral entropy, and mean pitch – are relevant not only for familiar musical examples, but also for unfamiliar microtonal stimuli^{21–23}. Although this suggests that harmony and melody may have the capacity to communicate universally, mixed results have been obtained from four prior experimental investigations in remote communities without easy access to mass media: Mafa, Cameroon²⁴; Mebenzélé Pygmies, Congo¹⁸; Tsimane', Bolivia¹⁹; Khow and Kalash, Pakistan²⁵.

The first of these cross-cultural studies used short piano pieces composed to express the emotions 'happy', 'sad', and 'scared'. These emotional categories were recognized by Mafa participants above chance, and tempo and mode (major/minor) correlated with their responses. However, the pieces co-varied across a number of musical features and the independent effect of mode (e.g., after controlling for tempo) was not reported. The second study used orchestral classical and film music and found no similarities between pleasantness ratings made by Canadian and Mebenzélé participants, and no effect of major/minor on the latter group. In the third study, which presented intervals and chords, US participants' pleasantness ratings were predicted by traditional Western music-theoretical characterizations of consonance or dissonance: the Tsimane' participants' ratings were not. The fourth study examined dimensional ratings of valence, energy and dominance as well as of four basic emotions (joy, anger, sadness and fear) of short Western and non-Western musical harmonizations in different styles with participants from the UK and from two remote communities in Pakistan (the Khow and Kalash): mode significantly impacted valence ratings of the UK participants, but not of the Kho and Kalash participants.¹

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¹As explained by Athanasopoulos et al.²⁵, the tribe is referred to as Khow, whereas the people are named Kho.

Although only the first of these four studies hints at the presence of a universal effect of major/minor on perceived emotion, it is notable that none of them has taken a Bayesian approach. Where traditional frequentist methods are mostly only able to reject, or fail to reject, a null hypothesis, Bayesian analyses are required to quantify evidence for the absence of an effect²⁶.

The experiment reported here was conducted across a number of remote and self-sufficient communities in Papua New Guinea (PNG). None of the communities has regular access to mass media. According to our analyses and local knowledge, traditional indigenous music is similar across these communities (see ‘Appendix’). In each trial, their task was to choose which of two chord progressions, or which of two melodies, induced the greater feeling of happiness. Hence, like the Mafa study²⁴ and the Khow/Kalash study, the question asked of our PNG participants is about a basic emotion (happiness), but unlike any of the previously discussed studies, it refers to felt emotion rather than perceived emotion; that is, it locates the emotion in the participant rather than in the music or its performer. This is important because responses about perceived musical emotions can differ from those related to felt emotions²⁷. Despite years of research on the association between major/minor and basic emotions such as happiness, there is still no consensus on its origin. Here, we aim to further explore possible mechanisms of this association in communities with varied exposure to Western music. Furthermore, by taking a Bayesian approach it is possible to assess evidence in favour of each effect as well as evidence for its practical absence²⁶.

Some of the chord progressions and melodies were in a major key, some in a minor key (the quantifications of major and minor are elaborated later). In every community, except the one with minimal exposure to Western-like music, we find strong evidence that major harmony induces greater happiness than minor, although less decisively than for Sydney participants. For melodies there is a very strongly evidenced effect of major and minor in one of the PNG communities, and in Sydney. The estimates are not sufficiently certain, however, to rule out a universal effect of major and minor in either cadences or melodies.

Theoretical background

We can theorize at least two broad classes of culture-dependent mechanisms that mediate the effect of musical features (such as major versus minor) on emotion^{28,29}. The first is *familiarity*. Stimuli that an individual has heard many times before – notably, over a lifetime of experience – are typically preferred and signify positive valence, perhaps because familiar events have greater perceptual fluency so take up fewer cognitive resources. Clearly, this is a culture-dependent mechanism because the musical sounds common in one culture may be uncommon in another (although due to cultural globalization, musical experiences are becoming rapidly homogenized hence the urgency for experiments such as reported here)³⁰.

The second is *associative conditioning*. Given consistent spatio-temporal pairings between musical features and valenced events, those musical features may become imbued with the associated valence¹⁷. For example, a person familiar with movies using Western music will more frequently hear major harmony in positively valenced scenes and minor harmony in negatively valenced scenes than the other way round.

An example of a musical feature that may influence emotion via a culture-independent mechanism is the mean pitch of the tones in a piece (which would differ between major and minor versions). Mean pitch has been found to influence emotional responses to music^{10,12,22,31–33}, often showing a positive relationship with valence^{9,22,33,34}. This could be due to an innate bias – in both animal sounds and human vocalizations, high pitches are often associated with friendliness or submission, whereas low pitches are related to threat or aggression^{35,36}. In two recent studies^{22,33}, the association between pitch height and valence has been found for Westerners listening to chords from an unfamiliar microtonal (Bohlen-Pierce)³⁷ tuning system, which is suggestive that pitch height’s effect is independent of a listener’s musical culture²². However, these findings are not sufficient to establish whether this effect is truly universal. It may simply be that a culturally learned association between pitch height and valence is carried over from the familiar musical system to the unfamiliar system.

Similar arguments hold for the emotional implications of major and minor harmony, which differ in psychoacoustic properties such as harmonicity, spectral entropy, and roughness. All else being equal, major chords have higher harmonicity and lower spectral entropy than minor chords, which should support the former’s perceptual fluency because, regardless of their familiarity, they are intrinsically sim-

pler^{38,39}. Hence, these are possible routes for a culture-independent effect of major/minor on valence. Recent studies have demonstrated that each of these three psychoacoustic features predict the perceived valence of chords in an unfamiliar tuning system^{22,23}; but, as before, this may just be a carry-over from culturally learned associations between major and minor chords and valence.

Experiments in Papua New Guinea and Australia

In this study, we focus on how the felt valence of harmony is affected by cadence type (major versus minor) and *mean pitch*, and how the felt valence of melodies is affected by *mean pitch*. To ascertain whether any of these features are mediated through universal mechanisms, we conducted an identical experiment in five remote PNG communities (with participants from seven different villages) with limited but differential experience of Western music, and in two Sydney cohorts with considerable, but still differing, levels of experience with Western music. (Our definitions for Western and Western-like music, major and minor, and other musicological terms are provided in ‘[Appendix](#)’.)

The first participant group completing the experiment comprised inhabitants of Towet village, in the Uruwa River Valley, Saruwaged Mountains, Morobe Province, PNG, and were tested during a three-week field trip to the area. After the research team left, local research assistants hiked to the villages of Mup, Mitmit, Kotet, and Yawan, and repeated the experiment on participants from those villages as well as from Bembe and Worin.

The Uruwa River valley is a cloud forest area accessible only by small plane or, for locals, an arduous three-day hike. Between the valley floor and the surrounding mountains, elevation ranges from sea level to peaks of 4,000 m. Villagers are expert farmers and lead self-sufficient lives, without mains electricity or an internal market economy. Mobile phone coverage reached the region in mid-2015, but internet access over the mobile phone network is nearly impossible. A dialect of the Nungon language is spoken in all the villages⁴⁰. Additional information on the area – geography, maps, musical traditions, linguistic, and historical – is provided in ‘[Appendix](#)’.

As summarized below, there are three genres of music present in different, sometimes overlapping, parts of the Uruwa valley: traditional indigenous song; Western-influenced *stringben* (which means ‘string band’ in Tok Pisin, the PNG lingua franca); and Western church hymns.

Across much of the region, traditional indigenous songs are performed at gatherings or specific occasions, such as a successful hunt or the blessing of crops, and are commonly accompanied with a *uwing* drum, which is a wooden hourglass-shaped drum with a single animal-skin head⁴¹, or handmade flutes. Detailed analysis of six local recordings of traditional performances is provided in ‘[Appendix](#)’; in summary, the melodies are monophonic (sung solo or in unison) and rarely exceed a perfect fifth in range. There is typically a ‘focal’ pitch, which is sung more than any other. With the possible exception of a small whole tone (about 1.75 semitones), interval sizes are inconsistent between the songs, and are somewhat inconsistent within each performance. They do not typically conform with Western intervals. Unlike Western music, the aggregated pitch content of each song (e.g., overall pitch range, number of pitches, or mean pitch relative to focal pitch) does not correlate to the emotive content of lyrics or performative contexts, or the village of origin.

Due to missionary involvement, villages in the Uruwa area have adopted either the Lutheran or the Seventh-day Adventist (SDA) church, although the extent of involvement with either varies both within and between the villages. Bembe, Mitmit, Mup, and Worin residents are mostly Lutherans who attend church regularly and hear and perform hymns on Sundays. Based on local people’s reports, and literature describing the Lutheran movement in urban areas of Morobe Province, Lutheran church service hymns are a mixture of traditional and *stringben* sung melodies, often accompanied by guitar or ukulele in the *stringben* style. *Stringben* songs are mostly in a major key with generally major chords^{42,43}. This is confirmed by our analysis of Lutheran hymns recorded in Towet, which shows they comprise 92% major chords and 8% minor (detailed in ‘[Appendix](#)’). Residents of these villages also probably engage in *stringben* and traditional music during the week.

People from Towet are mostly church-going SDA adherents who hear and perform hymns from the *SDA Hymnal*⁴⁴ at services on Friday nights and Saturdays, and in occasional morning and evening services during the week. The hymns are mostly sung in English, and the analysis in ‘[Appendix](#)’ shows that a substantial majority of their keys and chords are major (86% major chords, 12.5% minor, 1% diminished, 0.5% other), and there is no evident association between the valence of the words and the harmony (major/minor). There is very limited partaking in *stringben* or traditional music during

the week (it is frowned on). Kotet and Yawan villages lack their own Lutheran churches (Kotet's was demolished in 2011) and are too far from Worin or Mup to make regular church attendance practicable, but do have SDA churches. This means that *stringben* and traditional music are likely played or heard sporadically only, while SDA followers hear and sing SDA hymns weekly.

The above implies three groups of Uruwa participants with different levels or types of exposure to Western or Western-like music. The *minimal exposure group* comprises non-church-goers, and Lutherans in Kotet/Yawan – they have had only sporadic experience of Western-like music for at least seven years prior to the experiment. The *Lutheran exposure group* comprises all other Lutheran church-goers – they have regular exposure to major harmonies and melodies but less exposure to minor. The *SDA exposure group* comprises all SDA church-goers – they have regular exposure to major harmonies and melodies and, compared with the Lutherans, a slightly wider palette of Western harmonies; they have less regular exposure to indigenous music than the other two groups. Importantly, none of the Uruwa participants have had regular exposure to conventional Western associations between musical features and felt emotion.

In contrast, the Sydney participants are all well-steeped in such associations, and have considerable exposure to Western music. Of the two Sydney groups (non-musicians and musicians, the latter having at least five years training or performance experience), the musicians generally have greater exposure to, and knowledge of, Western music and its cultural associations, and have more refined audition skills (for example pitch discrimination). Therefore, along with the three Uruwa groups, we have a total of five participant groups with differing levels and types of exposure to Western or Western-like music and its cultural embeddings. These five groups serve as the basis of our statistical analysis and its interpretation.

Every participant was presented with 12 different pairs of *cadences* (chord progressions traditionally used in Western music to unambiguously assert a major or minor key) and 30 different pairs of melodies, as detailed in [‘Appendix’](#) (there were other stimuli, which are not analysed here). The first stimulus was preceded by a recording of the Nungon word for ‘one’, the second by ‘two’. Uruwa participants then responded to the question ‘when you hear which tune, are you happy?’ to which the answer is ‘one’ or ‘two’ (this phrasing sounds awkward in English translation, but it follows the standard clause structure used in Nungon). Hence, this question requires the comparison of levels of a basic felt emotion. A forced-choice design, rather than a Likert or continuous scale, was appropriate because the Nungon verb used in the question already entails ‘be very happy’, relative to the equivalent in English, so attempting to modify it with intensifiers would not make much sense. Furthermore, members of these communities are not familiar with scalar or ordinal rating tasks.

Each cadence trial consisted of two successive cadences consisting of two successive chords, each cadence in a distinct key, from the set B major, C major, D $\flat$ major, B minor, C minor, and C $\sharp$ minor. The difference between a major and a minor cadence is in the third of the tonic chord. They were presented in these different keys to disambiguate any effect of mean pitch from any effect of cadence type (major versus minor). Out of all possible ordered pairs from the above set, each participant heard one of two subsets of 12, each of which ensured every key was heard the same number of times. Three melodic subjects were presented in 6 different modes of the diatonic scale (Phrygian, $\text{\AA}$ olian, Dorian, Mixolydian, Ionian, Lydian, listed from lowest to highest mean pitch or, equivalently, from most minor to most major) to test whether mean pitch impacts valence in a melodic context. Every mode had the same tonic, which was asserted with a low C octave sounding simultaneously with the melodies, and every melody ending on that pitch class. Each trial was a sequence of two versions of the same melodic subject, each in one of those modes. All 30 ordered pairs of distinct modes were used.

Between participants, and between the cadence and melody blocks, two sample sets were used: a vocal choir or a string quartet. For the Uruwa participants, bowed strings would likely never have been heard before, so are an unfamiliar timbre. Although not the primary purpose of this study, differing responses to these two timbres might, amongst other things, indicate that timbral familiarity moderates responses.

For the Sydney participants, we expected major cadences to be more likely identified as happy when compared with minor cadences, and for cadences with higher mean pitch to be more likely chosen as the happy one (even after controlling for cadence types; for melodies, we expected results similar to those of Temperley and Tan⁹ – the melodic subject with the higher mean pitch is more likely identified as the happy one, but unfamiliar modes (notably Lydian and Phrygian) are also less likely identified as the happy one. For the Uruwa River Valley participants, we anticipated the similarity of their responses to the Sydney participants would be positively associated with their familiarity with Western music.

Results

The experimental design and analysis were pre-registered at <https://osf.io/qk4f9>. As detailed in the Methods, overall patterns in the data are visualized in Figure 1 with cadences represented on the left and melodies on the right. The figure shows the probability of choosing the second stimulus as the happy one with the colours representing the pitch difference between the first and second stimulus in each trial. In order to test the differing effects of cadence type, mode and mean pitch, we tested four hypotheses (outlined below). Bayesian multilevel logistic regression was used to assess evidence both for and against these hypotheses, and to estimate their expected effect sizes (summarized in Table 1 and Figure 2). These are subsequently detailed in the main text along with any strongly evidenced moderating effects of timbre. As detailed in the Methods, a unit increase in any predictor represents an additive change on the logit scale, which is the logistic-distributed latent scale assumed – in any logistic model – to underlie participants’ binary decisions.

Figure 1: Visualizations of the effects of standard musicological categorizations across the five groups of participants. For each pair of cadences, the effects produced by their cadence sequence and their tonics’ semitone pitch difference; e.g., a C minor cadence followed by a B $\flat$ major cadence has the cadence sequence ‘m:M’ and a tonic pitch change of –2 semitones. For each pair of melodies, the effect of their mode sequence (the Phrygian mode has the lowest mean pitch followed by Æolian, followed by Dorian, and so forth, up to Lydian, which has the highest mean pitch). The bars show the descriptive models’ 95% credibility intervals.

H1 – Cadence type: The effect of Maj to Min compared to Min to Maj, adjusting for mean pitch and timbre. There is very strong evidence for a large positive effect of major cadences on induced happiness in both Sydney groups and the SDA group, and strong evidence in the Lutheran group. For the minimal exposure group, there is no convincing evidence for an effect in either direction; nonetheless, there is only a 23% probability this effect is practically equivalent to zero. Hence, for this group, a convincing claim cannot be made either for or against an effect of cadence type.

H2 – Cadence mean pitch: The effect of a 1-semitone increase in mean pitch, adjusting for cadence type and timbre. There is very strong evidence for a large positive effect of mean pitch on induced happiness in both Sydney groups and strong evidence for a small effect in the Lutheran group. For the SDA group, however, there is evidence (a probability of 0.90) for there being practically no effect, while in the minimal exposure group there is no convincing evidence either for or against an effect. Regarding the moderating effect of timbre, for the Lutheran group, there is a strong evidence ratio (10.70) that the effect of mean pitch difference is greater for string than for vocal timbres.

H3 – Melody mean pitch: The effect of a 1-semitone increase in mean pitch, adjusting for timbre and melodic subject. There is very strong evidence for a large positive effect of mean pitch for both Sydney groups and a medium effect for the Lutheran group. There is weak evidence in favour of a small effect

Figure 2: Visualizations of the models' principal effects across the five groups of participants. For cadences: (a) the effect of their cadence sequence, adjusted for their mean pitch difference and timbre (the difference between the inner two posterior distributions corresponds to H1); (b) the effect of their mean pitch difference (semitones), adjusted for their cadence sequence and timbre (H2). For melodies: (c) the effect of their mean pitch difference (semitones), adjusted for timbre and melodic subject (H3). For cadences and melodies: (d) the effect of their mean pitch difference (semitones), adjusted for timbre (H4). For each cadence sequence plot, the posterior mean and 95% credibility intervals are shown. For each mean pitch difference plot, the posterior mean slope is shown with the thick line, while its uncertainty is visualized with 100 samples from the posterior distribution. The grey dots, which have been spatially jittered, show the observed values.

in the SDA group but, for the minimal exposure group, there is neither evidence for an effect nor for its practical absence.

H4 – Cadence and melody mean pitch: The effect of a 1-semitone increase in mean pitch, adjusting for timbre. Combining the cadences and melodies data allows us to assess the effects of mean pitch from a greater variety and number of musical stimuli (although there is no longer any adjustment for cadence type or melodic subject). There is very strong evidence for a large positive effect of mean pitch for both Sydney groups, as well as smaller effects in the Lutheran and SDA groups. For the minimal exposure group, there is no convincing evidence in favour of an effect in either direction.

Discussion

The results demonstrate that the felt emotional effects of major and minor – operationalized as cadence type and mean pitch – are strongly associated with exposure to Western or Western-like music. That said, for cadence type, we cannot rule out the possibility of a universal effect (resulting from the psychoacoustic properties discussed earlier) because the estimate from the minimal exposure group is insufficiently certain to confirm or deny. For mean pitch difference, the results in the minimal exposure and SDA groups point to only a small or practically non-existent effect. This suggests that the effect of mean pitch on valence – remarkably powerful in the West – is essentially cultural.

Given that none of the Uruwa groups are exposed to conventional (cultural) Western associations between musical features and non-musical emotive events in the Uruwa area, the effects of cadence type in those groups most likely arise from familiarity rather than from associative conditioning. Indeed, a supplementary analysis of twenty Lutheran hymns performed in the *stringben* style⁴³ by musicians from Towet (detailed in 'Appendix') showed that all were in a major key, and minor chords were used for only 8% of the musical beats; all other chords were major. Supplementary analysis of harmony in the *SDA Hymnal* shows more variety than the Lutheran hymns, but it also comprises a preponderance of major chords (86%) over minor (12%) (detailed in 'Appendix'). This provides a ready explanation for

Table 1: Hypothesis tests and summaries of the models’ principal effects across the five groups of participants (the hypotheses are detailed in the main text). ‘Est’, ‘Q5%’, and ‘Q95%’ show the mean and 90% equal-tailed credibility interval for the effect of Min to Maj compared to Maj to Min (H1) or a one-semitone increase in mean pitch (H2–H4). This effect is expressed on the logit (log-odds) scale. ‘Evid.ratio’ is the odds that the effect is in the direction specified by the hypothesis, and ‘Post.p’ is the associated posterior probability of the hypothesis ($Evid.ratio = Post.p / (1 - Post.p)$). We consider evidence ratios > 10 to be strong evidence; > 30 to be very strong. ‘ROPE’ shows the probability that the effect is small enough to be practically equivalent to zero²⁶, which we define as being in the interval $[-0.18, 0.18]$.

Exposure group by hyp.	Est.	Q5%	Q95%	Evid.ratio	Post.p	ROPE
<i>H1 – Cadence type</i>						
Uruwa: Minimal	−0.14	−1.19	0.91	0.69	0.41	0.23
Uruwa: SDA	1.06	0.59	1.54	6665.67	1.00	0.00
Uruwa: Lutheran	0.90	−0.01	1.84	18.14	0.95	0.07
Sydney: Non-musician	3.47	2.71	4.31	>19999.00	1.00	0.00
Sydney: Musician	8.96	6.08	12.64	>19999.00	1.00	0.00
<i>H2 – Cadences mean pitch</i>						
Uruwa: Minimal	−0.08	−0.40	0.23	0.49	0.33	0.62
Uruwa: SDA	0.08	−0.06	0.21	4.63	0.82	0.90
Uruwa: Lutheran	0.27	0.00	0.53	19.70	0.95	0.29
Sydney: Non-musician	0.91	0.67	1.17	>19999.00	1.00	0.00
Sydney: Musician	1.15	0.70	1.66	3999.00	1.00	0.00
<i>H3 – Melodies mean pitch</i>						
Uruwa: Minimal	0.09	−0.52	0.69	1.46	0.59	0.37
Uruwa: SDA	0.22	−0.08	0.50	8.12	0.89	0.41
Uruwa: Lutheran	0.51	0.13	0.89	65.67	0.98	0.08
Sydney: Non-musician	2.06	1.59	2.52	>19999.00	1.00	0.00
Sydney: Musician	6.31	4.81	7.86	>19999.00	1.00	0.00
<i>H4 – Cadences and melodies mean pitch</i>						
Uruwa: Minimal	−0.05	−0.28	0.18	0.56	0.36	0.78
Uruwa: SDA	0.14	0.03	0.25	54.25	0.98	0.74
Uruwa: Lutheran	0.27	0.09	0.45	120.95	0.99	0.20
Sydney: Non-musician	1.02	0.83	1.22	>19999.00	1.00	0.00
Sydney: Musician	1.56	1.27	1.88	>19999.00	1.00	0.00

the major cadences inducing more happiness than the minor – to participants in the SDA and Lutheran groups, they sounded more familiar.

The SDA hymns analyzed do not, on average, comprise more ascending sequences than descending: each piece almost always starts and ends with the tonic chord in a similar register, which implies the prevalence of upwards and downward motions of mean pitch must be approximately equal. Given the absence of associative conditioning, this could provide a natural explanation for why, in the SDA group, the effects for mean pitch are so small (and smaller than those for cadence type). However, it is not clear why this is not also the case for the Lutheran group, which exhibits a mean pitch effect more comparable to that of cadence type. A possible explanation would be that traditional indigenous music in this group differs from the others, but local knowledge suggests otherwise and our supplementary analysis shows no evidence that pitch difference signifies emotive valence in such music.

Across all of the stimuli, effects are stronger for the Sydney participants than for the Uruwa participants. This may be down to greater familiarity with Western music; it is likely also due to an additional influence of associative conditioning from conventional spatiotemporal associations of major with happy, and minor with sad – something we are sure is absent in Uruwa. The stronger effects for Sydney musicians compared to non-musicians may result from the former’s additional familiarity with musical structure and more firmly embedded associative conditioning, and also from them having better skills at discriminating the stimuli (some of which were quite similar).

In sum, we find no evidence for a universal effect of major harmony or melody inducing greater happiness than minor. That said, our Bayesian approach also allows us to assert a lack of firm evidence against such a universality. We find convincing evidence that the induction of positive affect by major, compared to minor, is enhanced by exposure (familiarity) and by associative conditioning: effects are close to decisive for Sydney musicians and very strong for Sydney non-musicians, both of whom have considerable exposure to conventional pairings of musical features and emotions; they are smaller in

the Lutheran and SDA groups, which have some exposure to Western or Western-like music but not its conventional associations; and smaller still in the group with minimal exposure to Western-like music.

The results reported here show the importance of conducting cross-cultural studies in communities with differing levels of familiarity with Western music, and its cultural context; it is only through such studies that we can uncover the commonalities and varieties at the heart of music cognition.

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Methods

Participants (Uruwa River Valley, Papua New Guinea)

The first participant group consisted of adults (above 18 years old) tested in the Uruwa River Valley, Saruwaged Mountains, Morobe Province, Papua New Guinea. A total of 170 Uruwa participants took part in the experiment and 24,445 observations were collected ($n = 170$, female = 85, mean age = 33.3 years, s.d. = 13.9 years (one participant who did not provide interview data was removed from the model, leading to a total of 169 participants)). Participants were inhabitants of the following villages: Towet, Worin, Bembe, Mitmit, Mup, Kotet, and Yawan. Although some are relatively close to each other, the difficult mountainous terrain means that walking between them takes locals between 30 minutes and many hours (and substantially longer for those unaccustomed to the environment, such as the research team). Due to time constraints and the significant walks required to reach some villages, the experiments in Mup, Mitmit, Kotet, and Yawan were conducted by local research assistants Namush Urung, Ben Waum and Nathalyne Ögate.

Test dates, location (including photographs of the set-up), and participant demographics are detailed in the Supplementary Materials. The sample size was chosen to be as large as possible depending on the availability of adults in the villages. Participants were rewarded with 50 PGK (roughly 20 AUD). The study is in accordance with relevant guidelines and regulations. Written informed consent was obtained from all participants prior to the start of the experiment. The three local research assistants assisted in the researchers’ presence and independently conducted these experiments in the researchers’ absence, translated and verbally explained the participant information sheet, consent form, and the experimental procedure. Financial compensation in local currency for the participants, the research assistants, as well as other community members who were involved in helping to organize the research trip, were financially compensated for their work in local currency was at a rate suitable for the local context at an hourly/daily rate equivalent to those paid by the third author for other research activities (see^{45,46}). We provide more details regarding the ethical considerations of the research in the Supplementary Materials.

Data were removed blockwise by trial type (cadence, melody, intervals, or triads) when a participant always answered ‘one’ or ‘two’ or followed an alternating pattern of ‘one’ and ‘two’ because such a response pattern suggests that task instructions were not followed or that participants applied a specific strategy to answer that was unrelated to their actual perception of happiness (see the Supplementary Materials). Having said that, results changed only slightly compared with models fitted to all the data, and no hypotheses came close to transitioning between strongly and not-strongly evidenced.

Participants (Sydney, Australia)

The second participant group consisted of musicians ($n = 19$, female = 11, mean age = 27.3 years, s.d. = 8.7 years) and non-musicians ($n = 60$, female = 50, mean age = 21.8 years, s.d. = 6.4 years) tested at Western Sydney University in Australia. The non-musicians were undergraduate psychology students recruited through the Western Sydney University’s online research participation system (SONA), whereas the musicians were recruited by adverts and word-of-mouth from the Sydney area. Musicians were defined as having received more than 5 years of formal training in music or music theory. All participants were above 18 years old. After data exclusions resulting from patterned responses or no responses (as detailed in the Supplementary Materials), no participants were removed but one block of cadence trials was removed. Non-musician participants were rewarded with course credit and musicians with 20 AUD, as they were separately recruited. Written informed consent was obtained from all participants prior to the start of the experiment.

Materials

Stimuli were generated in Max 7 (Cycling '74) and presented in PsychoPy v.3.0.2. Stimuli consisted of pairs of intervals, triads, cadences, and melodies and were created in a vocal and an instrumental timbre (only the cadences and melodies are reported here). The vocal timbre was sampled from the voice sample library 'Voices of Rapture' (Soundiron) with the soprano (S) singing 'Oh' and alto (A), tenor (T) and bass (B) singing 'Ah'. The instrumental timbre was sampled from 'Solo Strings Advanced' (Dan Deans) with the S as violin 1, A violin 2, T viola and B cello, which is a standard string quartet. Cadences used SATB (soprano, alto, tenor, bass); melodies A for the melody and T plus B for the octave C drone; intervals were T plus B; triads were A, T and B. The MIDI was generated in Max 7, sent to the above sample sets played in Kontakt 5 (Native Instruments), individually panned left and right as typically found in a commercial recording, and saved as wav files. Stimuli were created in 12 different versions, counterbalancing between the two timbres per stimulus category and with random pitch transpositions for the intervals and triads, enabling us to test as many pairs of intervals, triads, cadences and melodies as possible. These 12 versions were varied between participants. The 144 stimuli were presented over five blocks. Examples of the stimuli can be downloaded from <https://osf.io/c3e9y/files/>.

The order of the blocks was as follows: intervals (30 trials), cadences (12 trials), intervals (30 trials), melodies (30 trials), triads (42 trials). Block order was fixed, but stimulus presentation within blocks was randomized. Participants were asked to decide which stimulus induced happiness (one or two) for cadences and melodies, and which stimulus was 'finished' (one or two) for intervals and triads. The questions for this study were designed to accommodate the cultural and linguistic differences between Western listeners and PNG listeners.

In consultation with community leaders and the research assistants in Towet, language experts at the Summer Institute of Linguistics in Ukarumpa, PNG and based on H.S.S.'s years of research on the Nungon language, we decided to use paired stimuli with binary forced choice using the Nungon word *dongko-ha-rok* ('be.happy-present.tense-you'; 'you are happy') for the happiness question (as detailed in the main text) and *buret-ta-k* ('finish-present.tense-s/he/it'; 'it has finished') for the finished question. The data from the 'finished question' will be reported elsewhere.

Procedure (Uruwa River Valley, Papua New Guinea)

For the first set of participants in PNG, with the experimenters present, the experiment was conducted on the ground floor of a two-storey wooden building in Towet. For the experiments conducted in other villages, the local research assistants were instructed to test in a quiet location. Participants were seated in front of one of the researchers or research assistant and listened to the stimuli through headphones (Audio-Technica M50x or KOSS UR20). As outlined in the main text, every trial followed the same procedure. First, participants heard the word *ingguk* ('one'), followed by stimulus 1, then the word *yoi* ('two'), followed by stimulus 2. After stimulus presentation, participants were asked verbally, in Nungon: 'When you hear which tune, are you happy?'. Answers were recorded in PsychoPy by the experimenters or the local research assistants. Prior to the experiment, participants were presented with four practice trials with both questions to ensure complete understanding of the task. An interview in Nungon was conducted after the experiment to obtain more information about the participants' cultural and musical background (see the Supplementary Materials for the specific interview questions). Questions were asked orally in Nungon by local research assistants and responses were recorded by them or the researchers. The interviewers would interpret the responses as matching a particular choice of those available.

The principal purpose of the questionnaire was to assess musical exposure. However, many of the factors, which were coded from the responses, and all of their interactions, had levels with an insufficient number of participants to make generalization safe. Furthermore, it was apparent that at least some of the responses were inaccurate; for example, participants who were known by other community members to not regularly attend church said they did. Hence, we only included village, church denomination and church attendance in the models, as these were the most reliable answers to define exposure. Estimates are thus at the individual level, based on participant's responses to the questions of church attendance, village and church type, which led to the three groups discussed in the main text.

Procedure (Sydney, Australia)

Participants in Sydney were tested in a soundproof room, seated behind a laptop and listened through headphones (Sennheiser HD 280 Pro, Beyerdynamic DT 770 Pro, or Sennheiser HD 650). The exper-

imental task was explained by a research assistant, but participants indicated their answers themselves by pressing buttons on a keyboard. After the experiment, participants were asked to complete the Goldsmith's Musical Sophistication Index questionnaire, which is designed to elicit information from participants regarding their engagement with music, self-reported listening, singing skills, musical training, and their emotional engagement with music⁴⁷. Some additional questions related to their demographics and musical heritage were asked as well. Even though all participants lived in the metropolitan area of Sydney, many had a multicultural background. A breakdown of participants' countries of origin (they were all residing in Australia) is provided in the Supplementary Materials). The vast majority of participants indicated they listen mostly to Western music genres, such as pop, classical, jazz, R&B, EDM, hard-style, rock, metal, indie, house and drum & bass. Only five participants indicated listening to non-Western music genres, which were Arabic music, classic Chinese music, classical music in other languages (Urdu, Pashto, Punjabi and Kashmiri), and Bollywood music. Of those five participants, only one (the Arabic music listener) did not indicate listening to any Western music genre.

Experiments were conducted in June/July 2019 (Towet village) and July/August/October 2019 (other villages, Western Sydney University). The study was approved by the Towet community leaders, the Papua New Guinea National Research Institute, and the Western Sydney University Human Research Ethics Committee (H13179).

Definition and calculation of musical features

Mean pitch. Mean pitch is calculated as the mean MIDI pitch of all pitches in the stimulus under consideration. For the melodies and cadences, the mean over all pitches in each stimulus in the pair is calculated. The difference in mean pitch – the predictor used in the models – is simply the mean pitch of the second stimulus minus the mean pitch of the first stimulus, and has semitone units.

Cadence type. Here, we refer to the type of cadence, which is either major or minor (see [‘Appendix’](#) for our definition of major and minor). In music theory, this could also be referred to as the cadence's ‘mode’ but, to avoid confusion with the melody modes, we use ‘type’ for the cadences.

Mode. For melodies, ‘mode’ refers to one of the six different scales each melody was played in; here listed in ascending order of average pitch: Phrygian, Æolian, Dorian, Mixolydian, Ionian, and Lydian (Ionian is the common major scale, Æolian is the natural minor scale). To reduce the experiment's duration, the rarely used Locrian mode was omitted (as in Temperley and Tan⁹).

Timbre. Timbre generally refers to the perceived quality or ‘colour’ of a sound and has been suggested to have an independent and robust effect on listener's perception of emotion in music^{2,16,48,49}, which is not driven by musical expertise⁵⁰. For this experiment, we used two timbres (a vocal and a bowed string timbre). Timbre is used as a moderator of the main predictors in this experiment: *cadence type* and *mean pitch difference*.

Statistical modelling and data analysis

The data were analysed in R⁵¹ using the brms package^{52,53}, which is a front end for the Bayesian inference and Markov chain Monte Carlo (MCMC) sampler Stan⁵⁴. Two types of Bayesian logistic models were run: descriptive models designed to summarize overall patterns in the data (visualized in Figure 1), and hypothesis-driven models designed to assess evidence both for and against the principal hypotheses (H1–H4) related to cadence type (major/minor) and mean pitch difference, as well as their expected effect sizes (reported in Table 1, Figure 2, and the main text).

For all models, every factor was sum-coded (also called deviation-coded), so the reported effect of any predictor is a *main effect*; that is, the mean effect of that predictor over all other factor levels, such as timbre or melodic subject. In the hypothesis-driven models, the mean pitch differences between the two stimuli were in semitone units: $[-2, 2]$ for cadences and $[-5/7, 5/7]$ for melodies, with respective standard deviations of 1.17 and 0.34. The reported effect of a unit increase in any predictor represents an additive change on the logit scale, which is the logistic-distributed latent scale assumed – in any logistic model – to underlie participants' binary decisions.

Descriptive models

In summary, the descriptive models' predictors are basic musicological descriptions of the stimuli: the relationships between the keys and modes of the two stimuli in each trial. In order to present the data in

as ‘raw’ a form as possible (in a Bayesian context), no random effects were included and the priors were approximately uniform on the probability scale.

The data were categorized using standard musicological descriptions with a comprehensible number of levels: cadences were categorized by their sequences (minor to minor, minor to major, major to minor, and major to major) and the change in the tonic pitch from the first to second cadence; melodies were categorized by their sequence of modes. In both models, all other features such as timbre or melodic subject (both of which were balanced by design) were not included and hence averaged over. More formally, in the descriptive models, we have the following predictors:

- $cad_mode1 \in \{\text{Min, Maj}\}$ (type of the first cadence)
- $cad_mode2 \in \{\text{Min, Maj}\}$ (type of the second cadence)
- $tonic_pitch_diff_cat \in \{-2, -1, 0, 1, 2\}$ (semitone pitch difference of the two cadences’ tonics, coded as categories)
- $mel_mode1 \in \{\text{Phrygian, Aeolian, Dorian, Mixolydian, Ionian, Lydian}\}$ (mode of the first melody)
- $mel_mode2 \in \{\text{Phrygian, Aeolian, Dorian, Mixolydian, Ionian, Lydian}\}$ (mode of the second melody)
- $exposure_grp \in \{\text{Minimal, SDA, Lutheran, Non-musician, Musician}\}$

In the descriptive cadence model, there is a 4-way interaction between cad_mode1 , cad_mode2 , $tonic_pitch_diff_cat$, and $exposure_grp$. In the descriptive melody model, there is a 3-way interaction between mel_mode1 , mel_mode2 , and $exposure_grp$. We used a Student’s t -distributed prior with 7.763 degrees of freedom, a mean of 0, and a scale of 1.566 because this distribution on the logit scale approximates a uniform prior on the probability scale⁵⁵.

Hypothesis-driven models

For each of the hypothesis-driven models, we started with the maximal models specified in the pre-registered report (<https://osf.io/qk4f9>) except that instead of using pairs of features from the last two stimuli, their principal components were used; that is, their mean and their difference. The reason for making this linear transformation of the predictors is because it helps to decorrelate them and to make the resulting coefficients easier to interpret (because it is the difference between the last two features that has the greatest relevance).

This led to the following *stimulus-level* predictors in the hypothesis-driven models:

- $cad_mode1 \in \{\text{Min, Maj}\}$ (type of the first cadence)
- $cad_mode2 \in \{\text{Min, Maj}\}$ (type of the second cadence)
- $diff_mean_pitch1_2 \in \mathbb{R}$ (mean pitch difference between the two stimuli, in semitones)
- $timbre \in \{\text{Strings, Voices}\}$
- $melody \in \{1, 2, 3\}$ (the three melodic subjects – as notated in ‘Appendix’ – coded categorically).

In the cadence models, the principal predictors of interest are $diff_mean_pitch1_2$ and the interaction of cad_mode1 and cad_mode2 . The $cad_mode1:cad_mode2$ interaction represents the four different sequences of cadence types: major to major, minor to minor, major to minor, and minor to major. For the effect of cadence type we were, therefore, particularly interested in the contrast between the latter two. Including mean pitch difference in the cadence model means that any modelled effects of cadence type arise from aspects not correlated with mean pitch, such as the previously-mentioned psychoacoustic features of roughness, harmonicity, and spectral entropy. These three predictors interact with $timbre$. In the melody models, there is a 3-way interaction between $diff_mean_pitch1_2$, $timbre$, and $melody$. In the cadence and melodies models, there is just an interaction between $diff_mean_pitch1_2$ and $timbre$.

In every hypothesis-driven model, all within-participant effects were modelled as varying (random) effects across participants. Weakly informative priors were used on all population-level effects: Student’s t -distribution with 3 degrees of freedom, a mean of 0, and a scale of 1. The use of varying effects and weakly informative priors reduces the probability of false positives and overfitting when data are noisy^{56,57}.

A separate hypothesis-driven model was run for each of the five exposure groups rather than using a single model with an exposure group interaction; this allows for partial pooling of information between participants within each group, but not between groups (in an exposure interaction model, each group’s

estimates would be drawn towards the overall mean due the varying effects and shared prior). Ensuring complete separation between groups is appropriate because one of the fundamental research questions is whether some of them (notably the minimal exposure group) may have very different responses to the others. The hypothesis-driven models' formulas and full output summaries are provided in '[Appendix](#)'.

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Author contributions statement

E.A.S. and A.J.M. conceived and designed the experiments with contributions from H.S.S. and R.T.D. E.A.S. and A.J.M. conducted the experiments and analysed the results. H.S.S. planned and supervised the field trip to PNG. E.A.S. and A.J.M. wrote the original draft with input from H.S.S. and R.T.D. All authors reviewed and edited the manuscript.

Supplementary Materials

A. Definitions of musicological terms

Western music. We define this term to mean any music that makes substantial use of a set of structural features commonly found in European music from at least the 17th century (although some of these date substantially further back in the European tradition; some, somewhat later). These include the use of:

- instruments (and human voice) that produce harmonic complex tones and, hence, induce clearly perceptible pitches;
- a set of discrete pitches tuned to a meantone-like system, the most common of which, in contemporary practice, is 12-tone equal temperament where every octave is divided into 12 equal semitones (a meantone system contains intervals (octaves) with a frequency ratio close to $2/1$, and intervals (perfect fifths) with frequency ratios close to, or slightly smaller than, $3/2$, which ensures that 4 perfect fifths minus 2 octaves approximates a frequency ratio of $5/4$);
- frequent use of the diatonic scale (a *well-formed scale*¹ with 5 large steps and 2 small, where the large steps are approximately twice the size of the small)
- frequent use of major and minor chords and, sometimes, diminished and augmented chords, and their extensions (sevenths, ninths, etc.);
- *modulations* between diatonic scales, which are typically smooth because the two scales will share many common pitches and are typically mediated via a pivot chord that is common to both scales;
- common assertion of a tonic pitch class or tonic major or minor chord through the use of cadences, which are well-established chord progressions that typically involve movement from a dominant seventh chord (or major chord) to a major or minor chord a perfect fifth below and, often, this dominant chord is preceded by a chord containing the scale's fourth degree (the subdominant);
- there is an isochronous hierarchical binary or ternary metrical structure, whereby the fastest metrical level (rhythmic pulse) is grouped into either twos or threes to make a slower metrical level, which is itself grouped into twos or threes to make an even slower metrical level, and so on.

This definition of Western music is, therefore, one that allows for Western music or *Western-like music* to be produced in non-Western countries. For example, the Western-like guitar band music in PNG is strongly informed by Western music (through historical musical training provided by missionaries and the use of Western musical instruments²) and comprises almost all of the characteristics of Western music (as defined above), whilst still being quite distinct and recognisable as a genre or style of music that is different from anything actually produced in the West. Of course, this definition of Western music may seem flawed. For example, twentieth century atonal (including most serial) music would not fulfill all of the above criteria and, yet, is clearly a Western phenomenon. However, it is the term 'Western music' that is problematic here, rather than the definition provided above; unfortunately, no other English term is available that can capture all and only the set of features above; furthermore, we feel that in most readers' minds 'Western music' will most readily evoke the characteristics listed above, and this motivates our choice of a practical, though imperfect, term.

Major and minor. Common definitions vary depending on whether they are applied to harmony (individual chords or successions of chords) or to melody (successions of pitches). Here, we omit a few definitional nuances so as to concisely summarize them. Major and minor chords both comprise three distinct *pitch classes* (pitch classes consider any two pitches an octave apart to be the same and are expressed in semitone units). Relative to the chord's *root*, the pitch classes of major and minor chords are, respectively, (0, 4, 7) and (0, 3, 7). Hence the mean pitch of a major chord is higher than that of its analogous minor chord.

For sequences of chords, major and minor typically refer to the tonic chord (the *tonic* is the chord or pitch class that serves as a theoretical 'reference', or musical 'centre' or 'home' of the sequence) or to the preponderance of chords in the sequence. In the experiment, we use cadences comprising mostly major chords ending on a major tonic, and cadences comprising mostly minor chords ending on a minor tonic. In general music theory, cadences often indicate the end of a musical phrase³.

A melody is a sequence of pitches which, like a chord, can be summarized as pitch classes. If the melody has a pitch class 4 semitones above its tonic, it is typically deemed major; if, instead, it has a pitch class 3 semitones above the tonic, it is typically deemed minor. So this definition is analogous to that for chords. However, a more nuanced definition takes into account the intervals between every pitch class in the melody and its tonic. In this experiment, we make use of melodies from 6 (out of a possible 7) *modes* of the *diatonic scale*. The diatonic scale is a well-formed pattern of 5 tones (large steps) and 2 semitones (small steps); each mode of the diatonic scale simply defines which of those scale degrees is considered the tonic. In practice, a piece of music in a given mode will typically start and end on its tonic or otherwise emphasise it; for example, using it as a drone.

The seven different diatonic modes can be ordered by their mean pitch relative to their tonic: Locrian (not traditionally used in Western music, nor in the experiment), Phrygian, Æolian (the ‘natural’ minor scale), Dorian, Mixolydian, Ionian (the major scale), and Lydian. By this ordering, Phrygian can be considered the most minor mode in the experiment; Lydian the most major. The first three modes have a pitch class that is 3 (but not 4) semitones above the tonic; the latter three have a pitch class that is 4 (but not 3) semitones above the tonic.

B. Background information on the Uruwa River valley

General background. The Uruwa River Valley is a remote twelve-village area in the Saruwaged Mountains, Morobe Province, Papua New Guinea. A map of the Uruwa River valley with its villages is presented in Figure 3. Elevation in the area and the surrounding mountains ranges from sea level to peaks of over 4,000 m. As described by Sarvasy⁴, there is hardly any level ground and people live, move and cultivate their crops on steep slopes.

As is common in such remote mountain areas of PNG, there are no roads to the area or nearby mountain regions. The Uruwa River Valley is accessible to outsiders only by small airplane; in the six-village southern, higher-elevation part of the river valley, such airplanes must land on an inclined grassy airstrip at Yawan village that was cleared by villagers, using hand tools, over several years in the 1970s, then extended in the 1990s. Historically, the village communities of the Uruwa River Valley are said to have lived in a state of uneasy truce with each other, punctuated by conflicts⁵. This is reflected in the locations of the villages—each is separated from the others by geographic barriers, such as waterways. Each village community comprises two or more clan groups.

Musical background. There are two main strands of musical traditions in the Uruwa region, as elsewhere in the region⁴¹. Older traditional indigenous genres are accompanied by hourglass-shaped hand-drums (called *uwing* in Nungon) or by flute. Since the 1970s, a style of Western-influenced sung genre, called *stringben* in Tok Pisin (from *string band*), and characterized by guitar or ukulele accompaniment, has co-existed with the older musical styles^{42,43}. Music is primarily heard in weekly church services, on special occasions, or when individuals sing while going about daily activities, or practice for performances. There are no professional musicians, nor people who specialize in musical performance; traditionally, all women sang and danced in communal gatherings, and all men sang, danced, and played *uwing*. Elementary-age children may learn to sing songs in the local language, Nungon, or in Tok Pisin, at school. Few people in the area own radios or other music players, and there is no mains electricity source for charging mobile electronic devices. There is no equipment for viewing movies or videos in the area; nor, for that matter, are any of the Uruwa people who live in distant diaspora areas known to own televisions.

Figure 3: Map of the Uruwa River Valley with villages (bold), rivers (capitals), and language areas (italics). Shadings represent mid-level dialect groupings.

Linguistic background. Linguistically, each village had its own language variety, with distinctive pronunciation and vocabulary. One historical dialect, that of Mitmit and Bembe, is nearly obsolete today, due to mass deaths, then intermarriage, several decades ago⁴. Although the term *Nungon* is used nowadays to describe the entire dialect continuum of the six-village, southern Uruwa River Valley communities, this term simply means ‘what’, such that ‘I speak Nungon’ can be understood to mean ‘I say *nungon* for ‘what’’, as opposed to the people of the northern Uruwa villages, who say *yao* or *yano*. As seen in the shading in Figure 3, the term for ‘what’ is actually *nuon* in the dialects of two villages of the southern six (Mup and Mitmit), but structurally these dialects are more similar to those of the four other villages (Worin, Towet, Yawan, and Kotet) than to the northern Uruwa varieties, so these are considered part of the major grouping labeled Nungon. Judging by historical records from 20th-century linguistic surveys of the region⁶, it is more traditional, and even today, more precise, to refer to the speech varieties by the village name: so the Towet dialect, Worin dialect, and so forth. The languages of the Uruwa area are classified as belonging to the Finisterre branch of the Finisterre-Huon family of Papuan languages, which straddles the Huon Peninsula and runs into the Finisterre Range, along the border of Madang and Morobe Provinces.

Figure 4: A map of the Huon Peninsula.

Historical background. The first European visitor to the region, the Swiss missionary Saueracker, passed through the Uruwa area in 1928 from the region to the east of the Uruwa area, where the distantly related Nukna language is spoken. But most early missionary activity in the Uruwa River Valley was done by Papua New Guinean missionaries who lived in the region for many years, and also introduced coffee farming, cabbage, pumpkin, peanuts, and some other crops. By the 1960s, most people in the area had been baptized as Lutheran Christians. The Lutheran church used another Papuan language, Kâte, as a lingua franca in much of northeast New Guinea, and some older Nungon speakers attended a Kâte school and became literate in Kâte. Songs in the Kâte language are still known by Nungon speakers, and performed occasionally in the Lutheran churches in Worin and Mup. The Lutheran church was known for welcoming local musical traditions and encouraging the use of *uwing* drums and local languages in services. With the advent of the *stringben* style, that also became incorporated into Lutheran services. In contrast, the later-arriving Seventh-Day Adventist church, which made inroads in the Uruwa area from the late 1970s on, strictly prohibited use of any PNG music styles in church services: hymns must be drawn from the official *SDA Hymnal*, and sung to traditional North American and European melodies. People baptized into the SDA church had to renounce playing the *uwing* drum, in addition to the major lifestyle shifts required of SDA adherents: abstention from consuming pork (traditionally, central to feasts and gatherings in much of PNG), tobacco and betelnut. Today, Towet village is the only Uruwa

village in which the majority of people adhere to the SDA church. In all other villages, SDA followers are either in the minority or non-existent. Lutheran churches today are found in Worin and Mup villages, and SDA churches are found in Towet, Yawan, Kotet, and Worin villages. There used to be a Lutheran church in Kotet, which was demolished at the end of 2011.

Economically, the Uruwa area was traditionally linked to other parts of the Huon Peninsula (north-east PNG) by the Vitiaz Strait trade circuits and other trade circuits, whereby Uruwa forest products were traded for coastal products such as clay vessels (see Figure 4). This tradition continued through the 1990s and many Uruwa families maintain “trade-friend” relationships with families at centers along the traditional trade circuits, and have working understanding of the languages spoken in their regions.

A major cultural shift began in 1995 in the southern Uruwa villages, when Towet man Dono Ögate and his wife Eni, who had married into the area from the Nukna region to the east, returned to the region from the port city of Lae and began a concerted effort to ‘develop’ their community. Eni trained as the founding teacher of the first elementary school in Yawan village, established in 1998, and together the couple began distributing non-traditional clothing, such as T-shirts and shorts, to their community, and teaching them to speak and read the English-based creole Tok Pisin. In 2019, Dono Ögate was recognized for this work by the Digicel Foundation: he received the national 2019 Overall Man of Honour award.

In 2009, the YUS Conservation Area (encompassing much of the Uruwa villagers’ highest-elevation landholdings and extending into the neighbouring Som and Yupna regions) was established, through the efforts of local people and an organization, the Tree Kangaroo Conservation Program (TKCP), linked to Seattle’s Woodland Park Zoo. Since then, TKCP has been the major instigator of small-scale development and aid initiatives in the region, and employs a handful of people throughout the YUS Conservation Area, who travel regularly between the TKCP office in Lae and their home villages. The YUS Conservation Area also attracted other academic researchers to the area, including teams from James Cook University (JCU), Conservation International (CI), and the New Guinea Binatang Research Centre (BRC). Most of this research was biology-focused, with the exception of some engagement with villagers around livelihoods (JCU), and the long-term linguistic research by H.S.S.

The majority of this research brought only short-term employment opportunities for a handful of local people, spanning either the length of the foreigners’ field trip, or at most 1–2 years (in the case of BRC). In perhaps the longest-running contractual scheme, H.S.S. has paid several local people, including the three organizers of the 2019 Towet “research fair” to which these experiments belonged, to record and transcribe child speech in Nungon since 2015, as part of a long-term longitudinal study of child language development in the region.

Whether the events described in this subsection significantly impacted participants’ musical experiences over time is uncertain (indeed, models with participants’ age as a smooth spline effect, which ‘interacted’ with our principal effects, did not give consistent or decisive results) but they provide a perspective on changes happening in the area. A more thorough description of the history of the Uruwa River valley can be found in Sarvasy⁴.

C. Analysis of traditional music recordings from Kotet, Yawan, Towet, and Worin

In order to gain some insight into the traditional music across the area, we analysed six songs from a larger set of audio recordings made by H.S.S. in Kotet, Yawan, Towet, and Worin in 2011–13. The songs were (with a short description):

- **Ex. 1** Joyous song for decorating a young initiand. Performed by Manggirai, a man in his 60s. From Kotet.
- **Ex. 2** Melancholic song sung to the singer by her deceased daughter in a dream. Performed by Inewe, a woman in her 60s. From Kotet.
- **Ex. 3** Melancholic traditional song associated with a legend. When out on a hunting trip with her sister and brother-in-law, a woman enters a cave and has her head chopped off by a demon. Her sister finds her, returns her head to her neck with sticky sap, and hangs the handle of a heavy string bag of game from her forehead, to hold her head in place. Then, as they make their way down the mountain to meet the brother-in-law, the sister sings a mournful song bemoaning her sister's accident. Performed by Fooyu, a woman in her 50s. From Yawan.
- **Ex. 4** Traditional song associated with preparing to slaughter a pig for a feast: joyous. Performed by Nongi, a man in his 70s. From Towet.
- **Ex. 5** Song composed by the late husband of the singer, as he gazed out over their landholdings and prepared to die. Performed by Irising, a woman in her 60s. From Towet.
- **Ex. 6** Exemplar of the songs that young men sing from a ridge above the village on returning from a successful hunt, alerting their relatives below to start cooking vegetables to accompany the meat. Performed by Yamosi, a boy in his late teens. From Worin.

In all but one recording, there is just one singer. In Ex. 3, a second singer follows – with a small lag – the main singer's pitch in unison (approximately the same pitch). As shown through the notes above, we selected one song with positive valence and one with sad valence from each village, where available. For Yawan, we chose one sad song because no happy songs were recorded (other recorded songs are in a 'spirit language' and are not obviously interpretable as positively or negatively valenced); for Worin, we chose one happy song because no sad songs were recorded.

The pitch intervals in the songs are frequently noticeably microtonal (by which we mean they do not necessarily correspond to the intervals of Western music); furthermore, the pitches are often rather inconsistent. For these reasons, it would be inappropriate for the analysis to rely on a Western notational system of pitches; instead, we use computational pitch detection with fine resolution across both pitch and time. The pitch detection was performed with MATLAB's Audio Toolbox using the normalized correlation function^{7,8} in 52 ms windows with 42 ms overlaps. For each window, the harmonic ratio (periodicity) of the audio was also calculated in order to select only those portions of the detected pitches that correspond to clearly pitched sounds (such as sung vowels). For each song, the threshold at which the harmonic ratio was deemed high enough to include that portion of the detected pitch, and the pitch range over which the detection algorithm searched, were adjusted by hand to produce a comprehensive but clean pitch envelope.

In Figure 5, for each of the six songs, we graph: (1) on the left, the vocal pitch envelope over the song's duration and its mean pitch (dotted line); (2) in the middle, a smoothed density plot of pitches over the song's entire duration (this is a nonperiodic absolute monad expectation vector); (3) on the right, a smoothed density plot of all pitch intervals in the song (this is a nonperiodic relative dyad expectation vector, which is similar to an autocorrelation of the pitch density but, crucially, each individual pitch does not contribute any density at an interval of zero size)⁹. The graphs for (2) and (3) were calculated using the `expectationTensor` function from the Music Perception Toolbox (<https://github.com/andymilne/Music-Perception-Toolbox>); the MATLAB script calling this function, and the pitch detection functions, is available at <https://osf.io/qk4f9>.

Figure 5: For six songs: pitch envelope (left) in seconds; pitch density (middle); interval density (right).

Informed both by listening and the computations summarized in Figure 5, the pitch content of each piece is now briefly outlined (cents are 100th of standard semitone hence 1200th of a standard octave):

Ex. 1 (Kotet, male, happy) comprises more than 6 distinct pitches and is the most complex song to analyse, in part due to a gradual downward shift of the *focal* (most common) pitch, which gradually drops by about one third of a semitone over the first half of the song. The next most frequent pitch is approximately 350 cents higher than the focal pitch, often connected to it by one or more intermediate pitches which are rather variable in tuning. There are also occasional lower pitches, which decorate the focal pitch; these are also variable in tuning. Strikingly, two substantially higher pitches occur midway through the song, which are approximately 7 and 8.5 semitones higher than the focal pitch.

Ex. 2 (Kotet, female, sad) comprises 3, or possibly 4, distinct pitches. There is a focal pitch midway between B3 and C4 and two higher pitches, which are approximately 2 and 3 semitones higher. The final two ‘reiterations’ of the focal pitch, however, are sung about 40 cents higher than before creating, for my (A.J.M.) ears, the possibility of a distinct new pitch.

- Ex. 3 (Yawan, female, sad)** comprises a repeated descending sequence of 4 distinct pitches, which loosely approximates a narrowed version of the familiar pentatonic pitch class subset (0,3,5,7) (the outer interval is actually more like 6.5 semitones). This song does not exhibit a unique focal pitch that is emphasised substantially more than any other.
- Ex. 4 (Towet, male, happy)** has 4 distinct pitches: the song alternates between principal pitches approximating D3 and E3 (of which the first is focal), which are decorated with pitches approximating C3 and F3.
- Ex. 5 (Towet, female, sad)** has, perhaps, 3 distinct pitches. There is a distinct lower focal pitch at Ab3. There is another higher pitch, which is rather flexible in tuning and often performed with pitch swoops centred approximately a major third higher than the focal pitch. Near the end there is a brief instance of a distinctly higher pitch about 8 semitones higher than the focal pitch; hence the three pitches loosely approximate those of an augmented triad.
- Ex. 6 (Worin, male, happy)** has 5 distinct pitches approximating C3, D3, F3, G3, A3 and has a distinctly anhemitonic pentatonic flavour with pitch intervals closely approximating those found in Western music. The focal pitch is F3.

We can pick out some interesting generalities across these songs. The mean pitch sung by male and female singers is similar: respectively, 315 and 498 cents below middle C, which are approximately A3 and G3, respectively. The females, therefore, are singing in what would be considered, in Western practice, to be a fairly low register (although close to the typical fundamental frequency of female speech). The pitch range covered by the principal pitches rarely exceeds a perfect fifth (although small in comparison to Western art music, ranges such as this are common in European folk songs). The number of distinct pitches is relatively small (although, given their variability, it is not always clear which pitches are distinct). There is often a focal pitch (or small range of pitches) that is sung substantially more than any other pitch; the only clear exception is Ex. 3, where no pitch seems clearly favoured. The pitches are often sung with noticeable variation – this can be seen in the central column of plots where the peaks are relatively wide.

In terms of intervals between pitches, as shown in the right column of plots (note that these are intervals across the entire song and so include intervals between pitches widely separated in time), we see a clear preponderance of very small intervals. These result from approximate continuations of, or close repetitions of, some pitches (i.e., the broad peaks in the pitch density plots). Beyond that, there is common use of an interval that is a ‘small’ whole tone (180–200 cents), as well as a variety of larger intervals that are often inconsistent within, and certainly between, performances. These larger intervals range up to a maximum of about 850 cents but, as mentioned above, are uncommon greater than about 700 cents. It is worth noting that – beyond the unison interval of 0 cents – there is little correspondence to melodic intervals common in Western music: peaks in the right column of plots typically fall between the semitone grid lines. An exception is Ex. 6, where there are peaks close to all semitone intervals between 200 and 700 cents.

In terms of tonal structure, it is plausible that the focal pitch in a song acts as something loosely analogous to a tonic: a point of frequent return against which the other pitches are intended to be mentally compared. It is worth noting that, of the examples with a distinct focal pitch (1, 2, 4, 5, and 6), the focal pitch is the lowest of the principal pitches in every example except the sixth. Every song’s mean pitch minus its highest density pitch is, in order of example number, 158, 113, 352, 48, 83, and 30 cents.

With regard to whether the songs have happy (Ex. 1, 4, and 6) or sad (Ex. 2, 3, 5) words or performative contexts, there is no obvious association with the just described mean–focal pitch values; there is also no evident association with the number of distinct pitches, the inconsistency (spread) of pitches, or the overall range of pitches used. This accords with the way that Uruwa community members tend to talk about music; in ten years of association with the village, H.S.S. has never heard people describe the melodies of songs as evoking emotions alone; rather, the spare lyrics are the main conduit for emotion. Further, song lyrics themselves can involve the juxtaposition of imagery representing death, for instance, and new life. It is possible that more mournful songs that were not accompanied by dancing (such as Ex. 2, 3, 5) are traditionally sung with slower tempi than more joyous songs. There is also no obvious difference between the songs by village; an observation supported by Dono Ögate who stated that, for old music in Kotet, Yawan, Towet, Worin, Bembe, and Mup, ‘individual songs are different across the communities, but the style is the same’ (translated from Nungon by H.S.S.).

Of course, it may be that emotion is signified via the temporal ordering of pitches, such as might be captured by their contour, the tempo, and the vocal delivery and timbre. We do not focus on these temporal and performative aspects in this subsection because the principal features investigated in the main experiment (cadence type and mean pitch difference) are aggregated over time. As demonstrated in that experiment, in Western music, aggregated pitch features such as these are strongly related to emotive valence.

In summary, across the set of traditional songs analysed here, melodies are monophonic (sung solo or in unison) and rarely exceed a perfect fifth in range. There is typically a ‘focal’ pitch, which is sung more than any other. With the possible exception of a small whole tone of about 1.75 Western semitones, interval sizes are not consistent between songs and singers, and are somewhat inconsistent within each performance. They do not typically conform with Western intervals. Unlike in Western music, there is no evidence that the aggregated pitch content of each song (e.g., overall pitch range, number of pitches, or mean pitch relative to focal pitch) is associated with whether it has words or performative contexts that are either happy or sad; nor is it associated with the village of origin.

D. Analysis of *stringben* Lutheran hymn recordings from Towet

Thirty hymns were performed by a group of Towet musicians in two separate sessions: 1 male ukulele player and singer, 1 or 2 (depending on the session) male acoustic guitar players and singers, 1 boy *uwing* drum player, 2 or 5 (depending on the session) female singers also clapping. These were recorded by our research assistants in Worin in May 2020. Twenty of these were randomly selected and their chords analysed by ear. Every piece was in the key of E major (every piece started and ended with an E major chord and used standard cadences); for this reason, the table below shows the proportion of chords with Roman numerals relative to the tonic E major. Only four different chords were used across the twenty songs: the tonic (I) E major was the most common (it was played on 57% of beats); the dominant triad (V) B major was the next most common (21% of beats); the subdominant triad (IV) A major was the third most common (13% of beats); the least common chord was the submediant (VI) C# minor (8%). The E major chord was typically decorated with a thirteenth (C#) (also known as an added sixth) at the start and end of each song (but not elsewhere), and the E major chord was typically decorated with a seventh (D) – making this a dominant seventh (V7) chord – only when it was the penultimate chord leading to the final tonic E.

Table 2: Chords used in twenty hymns performed by Towet musicians in the guitar band style. BPM gives the tempo of the song (the number of beats per minute), No. beats is the total number of beats in each song, the remaining columns give the numbers of beats occupied for the four chords played (I, IV, V, and VI) ignoring extensions (thirteenth and sevenths). The final row gives the median BPM and No. beats, and the percentages for each chord across all twenty hymns. Note that I, IV, and V are major chords, while VI is minor; hence 92% of chords are major and 8% are minor.

BPM	Key	No. beats	No. I beats	No. IV beats	No. V beats	No. VI beats
110	E maj	299	194	0	37	68
106	E maj	281	204	0	49	28
111	E maj	365	252	80	33	0
107	E maj	345	144	20	157	24
110	E maj	265	168	24	41	32
108	E maj	327	146	28	105	48
108	E maj	249	136	52	21	40
104	E maj	317	160	64	61	32
115	E maj	439	288	48	99	4
114	E maj	357	209	76	40	32
107	E maj	357	133	56	144	24
90	E maj	262	134	40	64	24
108	E maj	385	237	64	48	0
111	E maj	485	225	60	176	24
111	E maj	389	233	22	40	94
113	E maj	245	185	18	42	0
115	E maj	313	201	44	36	32
118	E maj	365	189	32	108	36
112	E maj	441	263	134	44	0
110		345	57%	13%	21%	8%

E. Analysis of SDA hymns

Thirty-one hymns were randomly selected from the *SDA Hymnal*, which is the source book for all hymns sung at all SDA services in the Uruwa area. They are presented in four-part harmony and were analysed to determine the proportion of chord types (major, minor, diminished, augmented, and suspended) in each hymn and across all hymns. Dominant 7ths and other extensions of major chords are categorized as ‘major’; half-diminished and diminished 7ths as ‘diminished’, extensions of augmented chords are categorized as ‘augmented’; suspended chords are categorized as ‘suspended’ only when they are not obviously passing to a major or minor chord (in which case they are categorized as major or minor, respectively; but these are exceedingly rare, anyway). The results are summarised in Table 3. In summary, there is more variety than found in the Worin recordings but there is still a substantial majority (86%) of major chords. The words for the two minor-key hymns are not intrinsically sad in nature; like most of the hymns, they are focused on praise and worship and have, if anything, a positive emotional valence.

Table 3: Proportions of chord-types over 31 hymns randomly selected from the *SDA Hymnal*. For each hymn, the proportions are the number of beats (quavers or crotchets; whichever is appropriate for the song) each chord type is played divided by the total number of beats with any chord in that hymn. Of the 31 hymns, only two are in a minor key. Averaging these proportions across all hymns, 86% of chords are major, 12% are minor, 1% are diminished; less than 0.5% are augmented or suspended.

Hymn name	Hymn No.	Key	Maj	Min	Dim	Aug	Sus4
There Is a Fountain	336	Bb maj	100%	0%	0%	0%	0%
Lord, Speak to Me	541	G maj	88%	9%	0%	3%	0%
Christ for the World	370	F maj	96%	4%	0%	0%	0%
Near, Still Nearer	301	Db maj	93%	7%	0%	0%	0%
Jesus Is All the World to Me	185	G maj	86%	14%	0%	0%	0%
Power in the Blood	294	F maj	100%	0%	0%	0%	0%
What a Friend We Have in Jesus	499	F maj	99%	0%	1%	0%	0%
When I Survey the Wondrous Cross	154	F maj	83%	17%	0%	0%	0%
Now Thank We All Our God	559	Eb maj	77%	20%	3%	0%	0%
Where Cross the Crowded Ways of Life	355	Ab maj	75%	19%	6%	0%	0%
Abide With Me	50	Eb maj	77%	22%	2%	0%	0%
My Maker and My King	15	C maj	94%	6%	0%	0%	0%
Glorious Things of Thee Are Spoken	423	Eb maj	89%	8%	3%	0%	0%
This Is My Father’s World	92	D maj	92%	8%	0%	0%	0%
He Leadeth Me	537	C maj	91%	9%	0%	0%	0%
O Sing a New Song to the Lord	19	G maj	81%	19%	0%	0%	0%
Lead On, O King Eternal	619	C maj	85%	15%	0%	0%	0%
Ye Servants of God	256	G maj	85%	15%	0%	0%	0%
Just as I Am	314	D maj	100%	0%	0%	0%	0%
O Zion, Haste	365	Ab maj	88%	10%	0%	2%	0%
Now Let Us From This Table Rise	404	C maj	67%	29%	4%	0%	0%
Praise God, From Whom All Blessings	695	C maj	76%	24%	0%	0%	0%
I Surrender All	309	D maj	100%	0%	0%	0%	0%
Dear Lord and Father	481	C maj	86%	5%	5%	0%	4%
Shall We Gather at the River	432	Db maj	100%	0%	0%	0%	0%
God Has Spoken by His Prophets	413	F min	44%	48%	5%	0%	3%
O Love That Wilt Not Let Me Go	76	G maj	90%	10%	0%	0%	0%
Bless Thou the Gifts	686	G maj	88%	9%	0%	3%	0%
The God of Abraham Praise	11	E min	68%	30%	2%	0%	0%
I Will Follow Thee	623	Ab maj	99%	0%	1%	0%	0%
Give of Your Best to the Master	572	Eb maj	66%	28%	6%	0%	0%
			86%	12%	1%	0%	0%

F. Stimuli

Cadences

Figure 6: Cadence example C major – C# minor. Each cadence consisted of either mostly major chords or mostly minor chords in order to make any effect of mode as clear as possible, and all chords in a given cadence were from a single diatonic scale in order to avoid any additional effects resulting from scale structure. All cadences had a tonic pitch of B, C or C# in order to decorrelate average pitch height from mode (hence allowing their separate effects to be disambiguated). Given there are 6 different keys (i.e., 2 modes $\times$ 3 tonic pitches), this would lead to a total of 30 ordered pairs (without repetition) to test, however for the sake of experiment time, it was decided to reduce this to a smaller number of pairs. The precise pairs of cadence keys were chosen to ensure that, for each participant, each cadence (characterized by its tonic and its mode) was heard an equal number of times (4 times out of 12 trials), that there was an equal split of major and minor cadences (6 each), and that the average pitch change across the 12 was zero. This led to two slightly different sets of 12 cadences which were allotted evenly between participants. Each cadence followed – as much as feasible within the above constraints – standard musical rules (e.g., voice-leading rules and chord choices). The only traditional compositional rule broken was the use of a minor dominant chord for the minor cadences in order to fulfil the first two constraints stated above.

Melodies

Figure 7: The three melodic subjects used in the experiments. Each subject was played in 6 different modes, obtained by changing the notated key signature: 1 sharp for Lydian, no accidentals for Ionian, 1 flat for Mixolydian, 2 flats for Dorian, 3 flats for Æolian, and 4 flats for Phrygian. All melodies were accompanied by a quiet note on C2 and C3. All notes were played legato except for the notes at the end of each slur, which were slightly shortened to help separate the musical phrases. Ignoring these subtle phrase-motivated variations in durations, within each melodic subject, the notes whose pitches changed between any two modes (D, E, F, A, and B) had the same overall duration; for example, in the first subject, every such pitch sounds for a combined duration of 3 quavers (e.g., three quavers or one crotchet and one quaver).

G. Participant demographics and data exclusions

Table 4: Test locations and participant numbers

Dates	Test location	Participants' origin	No. Participants	Experimenters
27 June–7 July 2019	Towet	Towet	87	E. A. Smit, A. J. Milne
27 June–7 July 2019	Towet	Worin	1	E. A. Smit, A. J. Milne
14–25 July 2019	Mup	Mup	18	B. Waum, N. Urung
14–25 July 2019	Mup	NA (missing interview)	1	B. Waum, N. Urung
30 July–4 August 2019	Mitmit	Mitmit	1	B. Waum, N. Urung, N. Ögate
30 July–4 August 2019	Mitmit	Bembe	19	B. Waum, N. Urung, N. Ögate
30 July–4 August 2019	Mitmit	Worin	3	B. Waum, N. Urung, N. Ögate
6–8 August 2019	Kotet	Kotet	15	B. Waum, N. Urung, N. Ögate
1–3 October 2019	Kotet	Kotet	16	B. Waum, N. Urung, N. Ögate
3–8 October 2019	Yawan	Yawan	9	B. Waum, N. Urung, N. Ögate

Table 5: Overview of numbers of blocks before and after exclusions due to patterned responses.

Group	Block	No. blocks	
		Before Exclusions	After Exclusions
Uruwa: all	Cadences	169	111
	Melodies	169	122
Uruwa: minimal	Cadences	29	17
	Melodies	29	19
Uruwa: Lutheran	Cadences	44	35
	Melodies	44	36
Uruwa: SDA	Cadences	96	59
	Melodies	96	67
Sydney: all	Cadences	79	78
	Melodies	79	79
Sydney: non-musician	Cadences	60	59
	Melodies	60	60
Sydney: musician	Cadences	19	19
	Melodies	19	19

Table 6: Nationalities of the Sydney participant group

Nationality	No. participants
Australian	41
Bangladeshi	1
Chinese	7
Egyptian	1
Greek	4
Indonesian	3
Iraqi	4
Lebanese	6
Middle Eastern (other)	1
New Zealand	1
Pakistani	1
Persian	1
Russian	1
Spanish	2
Sudanese	1
Tibetan	1
Vietnamese	1
Not provided	2

H. Ethics and risk management considerations

Ethics We acknowledge that conducting research cross-culturally is sensitive and requires extensive work to ensure a fruitful collaboration for all parties involved¹⁰. We appreciate the many challenges involved in cross-cultural research and we aim to be transparent about the processes involved in the current study. Here, we outline the steps that were undertaken to ensure that the presence of researchers would not adversely impact the communities²⁵. The study was approved by the Towet community leaders, the Papua New Guinea National Research Institute, and the Western Sydney University Human Research Ethics Committee (H13179).

Risk management Dr. Hannah Sarvasy has been adopted as a clan member of the specific community, and has been working with the community since 2011, is fluent in the Nungon language. She has previously conducted language experiments in the community and has established very good relationships with the community. Her extensive knowledge of the community and cultural customs helped to ensure that local cultural values are respected in the design and conduct of the research. The other researchers received advance education by Dr. Sarvasy about local taboos to minimize the risk of participants being offended by the words or actions of a researcher.

Prior to travelling, all decisions regarding the research and the benefits and risks associated with the project were discussed and consulted by phone with local community leaders. No decisions were made without their approval and payment of local research assistants, participants and community members involved in any way with the research was in accordance with the local community leaders.

The experiment was designed to ensure minimum discomfort and a practice part was included in order for participants to familiarise themselves with the equipment. Participants could withdraw from the study at any time without affecting the relationship with the researcher. Participants were able to place the headphones on their heads themselves and adjust the volume accordingly, therefore ensuring the sound levels are comfortable to them. We ensured that, even at the maximum loudness setting, the acoustic levels were still moderate. Participants could stop the experiment and leave at any point without loss of remuneration.

Participation in the research was voluntary for community members and they were remunerated in local currency for their time, earning more than would be possible for a day's labor doing anything else in the region. However, their participation in the research does mean time away from their usual work activities doing farming, childcare, domestic activities, and house construction. Thus, care was taken to ensure that participants' time in the study was minimized as much as possible.

Prior to the fieldwork, management of personal safety risks involved comprehensive briefings by Dr. Hannah Sarvasy of all personnel to minimize the risk of researchers' inadvertently violating local codes of conduct (hence inciting anger). Precautions throughout the trip included continually checking with local community members and leaders to monitor any unanticipated safety risks and to ensure that the community was pleased with how the researchers were conducting themselves.

I. Uruwa interview

The interview with participants from the Uruwa River Valley consisted of the following questions with possible answers provided in brackets:

1. What is your age?
2. Which village are you from?
3. Male/female?
4. Do you go to church? (Yes; no; sometimes)
5. Which do you go to? (SDA; Lutheran; I do not go to church)
6. When you go to church, do you sing songs or do you just listen? (I sing; I just listen)
7. Are you a song leader? (Yes; no)
8. Do you sing hymns outside of church? (Yes; no; sometimes)
9. When they sing songs, do you understand the words you sing?(Yes; no; sometimes)
10. Are you always happy or always sad when you hear all church songs, or are you happy when you hear some church songs and sad when you hear other songs? (Always happy; always sad; sometimes happy sometimes sad)
11. Why? Is the meaning of the words grabbing you that you feel sad or the sound? (Meaning of the words; the sound; meaning of the words and the sound)
12. Did you used to try different songs? (Yes; no)
13. What types of music did you used to play or sing? (*Biru* (a local flute); *uwing* (an hour glass shaped drum); guitar)
14. If a song seized you on the insides, how did it make you feel? (Happy; sad; sometimes happy sometimes sad)
15. When you used to sing a song in other peoples' language, would you understand? (Yes; no)
16. When you were small, how did the older people used to do songs or music? (*Biru*; *uwing*; guitar)
17. These days on your phone or radio, what songs do you find beautiful? (Open question, only answered if people have a phone or radio)
18. These days, do you listen to songs from other places or not? (Yes; no)
19. From where?

J. Full summaries of hypothesis-driven models

All models outputs show the following regression coefficients of the group-level and population-level effects:

- *Estimate*: mean coefficient of the posterior distribution.
- *Estimate error*: standard deviation of the posterior distribution.
- *l-95% CI* and *u-95% CI*: lower and upper 95% credibility intervals.
- *Rhat*: provides information on the convergence of the algorithm.
- *Bulk ESS* and *Tail ESS*: effective sample size measures.

Cadences

Uruwa: Minimal Exposure

```
Family: bernoulli
Links: mu = logit
Formula: bin_response ~ (cad_model1 * cad_mode2 + diff_mean_pitch1_2) * timbre + (cad_model1 * cad_mode2 + diff_mean_pitch1_2 | participant)
Data: data_cut_min_cad (Number of observations: 204)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000
```

Group-Level Effects:
~participant (Number of levels: 17)

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.49	0.45	0.79	2.54	1.00	7129	11841
sd(cad_model1Min)	0.37	0.26	0.01	0.99	1.00	7010	8490
sd(cad_mode2Min)	0.73	0.38	0.08	1.58	1.00	4897	5296
sd(diff_mean_pitch1_2)	0.38	0.26	0.02	1.00	1.00	7656	9302
sd(cad_model1Min:cad_mode2Min)	0.89	0.39	0.17	1.72	1.00	5619	4377
cor(Intercept,cad_model1Min)	0.17	0.39	-0.65	0.82	1.00	22749	14094
cor(Intercept,cad_mode2Min)	0.10	0.35	-0.59	0.72	1.00	16658	14769
cor(cad_model1Min,cad_mode2Min)	0.16	0.40	-0.66	0.82	1.00	7750	11981
cor(Intercept,diff_mean_pitch1_2)	-0.13	0.38	-0.79	0.63	1.00	21919	14806
cor(cad_model1Min,diff_mean_pitch1_2)	-0.15	0.41	-0.83	0.67	1.00	11844	14214
cor(cad_mode2Min,diff_mean_pitch1_2)	-0.20	0.39	-0.83	0.61	1.00	15756	15359
cor(Intercept,cad_model1Min:cad_mode2Min)	-0.11	0.33	-0.70	0.55	1.00	15792	13309
cor(cad_model1Min,cad_mode2Min:cad_mode2Min)	-0.12	0.40	-0.80	0.67	1.00	6453	10324
cor(cad_mode2Min,cad_model1Min:cad_mode2Min)	-0.17	0.36	-0.79	0.56	1.00	10349	13604
cor(diff_mean_pitch1_2,cad_model1Min:cad_mode2Min)	0.13	0.39	-0.64	0.80	1.00	8607	13887

Population-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-0.34	0.39	-1.12	0.43	1.00	8106	12061
cad_model1Min	-0.03	0.21	-0.44	0.39	1.00	21751	13844
cad_mode2Min	0.04	0.26	-0.48	0.55	1.00	14817	14192
diff_mean_pitch1_2	-0.08	0.19	-0.47	0.30	1.00	18120	14937
timbreStrings	-0.26	0.38	-1.05	0.47	1.00	8273	11123
cad_model1Min:cad_mode2Min	-0.08	0.28	-0.65	0.48	1.00	16278	14503
cad_model1Min:timbreStrings	-0.11	0.21	-0.53	0.31	1.00	20181	14765
cad_mode2Min:timbreStrings	0.04	0.26	-0.48	0.58	1.00	15199	13781
diff_mean_pitch1_2:timbreStrings	0.11	0.19	-0.27	0.50	1.00	19703	14212
cad_model1Min:cad_mode2Min:timbreStrings	-0.16	0.28	-0.74	0.40	1.00	15128	13988

Uruwa: SDA

```
Family: bernoulli
Links: mu = logit
Formula: bin_response ~ (cad_model1 * cad_mode2 + diff_mean_pitch1_2) * timbre + (cad_model1 * cad_mode2 + diff_mean_pitch1_2 | participant)
Data: data_cut_SDA_cad (Number of observations: 708)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000
```

Group-Level Effects:
~participant (Number of levels: 59)

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.74	0.15	0.48	1.05	1.00	8100	13573
sd(cad_model1Min)	0.36	0.15	0.04	0.66	1.00	5565	5432
sd(cad_mode2Min)	0.29	0.16	0.02	0.62	1.00	5062	8285
sd(diff_mean_pitch1_2)	0.22	0.14	0.01	0.51	1.00	5180	8528
sd(cad_model1Min:cad_mode2Min)	0.18	0.13	0.01	0.47	1.00	7194	10976
cor(Intercept,cad_model1Min)	-0.51	0.28	-0.91	0.20	1.00	13013	12363
cor(Intercept,cad_mode2Min)	0.12	0.34	-0.58	0.73	1.00	20254	14025
cor(cad_model1Min,cad_mode2Min)	-0.08	0.37	-0.75	0.64	1.00	13181	14937
cor(Intercept,diff_mean_pitch1_2)	-0.19	0.35	-0.79	0.57	1.00	19896	13956
cor(cad_model1Min,diff_mean_pitch1_2)	-0.03	0.38	-0.73	0.70	1.00	15828	15268
cor(cad_mode2Min,diff_mean_pitch1_2)	0.04	0.39	-0.71	0.75	1.00	14152	15720
cor(Intercept,cad_model1Min:cad_mode2Min)	0.11	0.38	-0.65	0.77	1.00	26118	14856
cor(cad_model1Min,cad_mode2Min:cad_mode2Min)	-0.01	0.39	-0.74	0.73	1.00	20068	16054
cor(cad_mode2Min,cad_model1Min:cad_mode2Min)	0.17	0.40	-0.66	0.83	1.00	14735	16272
cor(diff_mean_pitch1_2,cad_model1Min:cad_mode2Min)	0.02	0.40	-0.74	0.76	1.00	17813	17206

Population-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	0.30	0.13	0.05	0.56	1.00	14574	15576
cad_model1Min	0.19	0.10	-0.01	0.39	1.00	25081	14367
cad_mode2Min	-0.34	0.10	-0.53	-0.15	1.00	28136	15841
diff_mean_pitch1_2	0.08	0.08	-0.09	0.24	1.00	28267	15639
timbreStrings	0.07	0.13	-0.18	0.32	1.00	13875	14882
cad_model1Min:cad_mode2Min	0.05	0.09	-0.12	0.23	1.00	36536	13526
cad_model1Min:timbreStrings	-0.15	0.10	-0.34	0.05	1.00	22630	15174
cad_mode2Min:timbreStrings	0.03	0.10	-0.16	0.21	1.00	26998	15568
diff_mean_pitch1_2:timbreStrings	0.01	0.08	-0.15	0.17	1.00	31574	16344
cad_model1Min:cad_mode2Min:timbreStrings	-0.07	0.09	-0.25	0.11	1.00	33116	15225

Uruwa: Lutheran

```
Family: bernoulli
Links: mu = logit
Formula: bin_response ~ (cad_model1 * cad_mode2 + diff_mean_pitch1_2) * timbre + (cad_model1 * cad_mode2 + diff_mean_pitch1_2 | participant)
Data: data_cut_Lut_cad (Number of observations: 420)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000
```

Group-Level Effects:


```

~participant (Number of levels: 35)

Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.07 0.26 0.62 1.64 1.00 6944 10791
sd(cad_modelMin) 0.62 0.24 0.16 1.12 1.00 6023 5327
sd(cad_mode2Min) 1.01 0.26 0.57 1.57 1.00 8514 12922
sd(diff_mean_pitch1_2) 0.64 0.22 0.22 1.10 1.00 6981 6938
sd(cad_modelMin:cad_mode2Min) 0.48 0.26 0.03 1.02 1.00 5001 7199
cor(Intercept,cad_modelMin) -0.17 0.31 -0.72 0.46 1.00 14494 14483
cor(Intercept,cad_mode2Min) 0.22 0.26 -0.31 0.68 1.00 9538 13266
cor(cad_modelMin,cad_mode2Min) -0.22 0.31 -0.77 0.40 1.00 5369 9313
cor(Intercept,diff_mean_pitch1_2) -0.16 0.29 -0.68 0.42 1.00 13568 13820
cor(cad_modelMin,diff_mean_pitch1_2) 0.46 0.29 -0.20 0.89 1.00 7342 8780
cor(cad_mode2Min,diff_mean_pitch1_2) -0.29 0.28 -0.78 0.30 1.00 14228 15383
cor(Intercept,cad_modelMin:cad_mode2Min) 0.13 0.34 -0.57 0.74 1.00 17821 15368
cor(cad_modelMin,cad_modelMin:cad_mode2Min) 0.12 0.36 -0.61 0.77 1.00 11938 15330
cor(cad_mode2Min,cad_modelMin:cad_mode2Min) -0.18 0.34 -0.77 0.54 1.00 16161 16001
cor(diff_mean_pitch1_2,cad_modelMin:cad_mode2Min) 0.05 0.35 -0.64 0.71 1.00 15338 16551

```

```

Population-Level Effects:

Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept 0.24 0.22 -0.18 0.67 1.00 11705 12501
cad_modelMin 0.20 0.17 -0.13 0.54 1.00 17204 14438
cad_mode2Min -0.25 0.21 -0.66 0.17 1.00 14581 14940
diff_mean_pitch1_2 0.27 0.16 -0.05 0.59 1.00 16322 14184
timbreStrings 0.18 0.22 -0.25 0.62 1.00 13767 14072
cad_modelMin:cad_mode2Min 0.05 0.16 -0.25 0.36 1.00 18261 13069
cad_modelMin:timbreStrings -0.15 0.17 -0.49 0.18 1.00 17125 14386
cad_mode2Min:timbreStrings 0.14 0.21 -0.27 0.57 1.00 15459 14019
diff_mean_pitch1_2:timbreStrings 0.21 0.16 -0.10 0.53 1.00 18068 14865
cad_modelMin:cad_mode2Min:timbreStrings 0.06 0.15 -0.25 0.36 1.00 20420 14119

```

Sydney: Non-musician

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ (cad_model1 * cad_mode2 + diff_mean_pitch1_2) * timbre + (cad_model1 * cad_mode2 + diff_mean_pitch1_2 | participant)
Data: data_cut_nonmus_cad (Number of observations: 707)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000

```

```

Group-Level Effects:
~participant (Number of levels: 59)

Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.67 0.19 0.31 1.05 1.00 6254 5529
sd(cad_modelMin) 0.43 0.20 0.05 0.84 1.00 5372 6328
sd(cad_mode2Min) 0.83 0.19 0.48 1.23 1.00 7922 11725
sd(diff_mean_pitch1_2) 0.74 0.18 0.42 1.12 1.00 8792 12294
sd(cad_modelMin:cad_mode2Min) 0.18 0.13 0.01 0.50 1.00 9692 11326
cor(Intercept,cad_modelMin) 0.16 0.33 -0.52 0.76 1.00 13262 12660
cor(Intercept,cad_mode2Min) -0.07 0.27 -0.59 0.46 1.00 7144 10142
cor(cad_modelMin,cad_mode2Min) -0.34 0.31 -0.84 0.36 1.00 4492 5743
cor(Intercept,diff_mean_pitch1_2) 0.34 0.25 -0.19 0.78 1.00 7041 10791
cor(cad_modelMin,diff_mean_pitch1_2) 0.36 0.31 -0.33 0.85 1.00 4582 6721
cor(cad_mode2Min,diff_mean_pitch1_2) -0.39 0.23 -0.79 0.09 1.00 9530 13450
cor(Intercept,cad_modelMin:cad_mode2Min) 0.10 0.39 -0.67 0.79 1.00 29254 16449
cor(cad_modelMin,cad_modelMin:cad_mode2Min) 0.03 0.41 -0.74 0.77 1.00 24195 15481
cor(cad_mode2Min,cad_modelMin:cad_mode2Min) -0.05 0.39 -0.76 0.71 1.00 28930 17015
cor(diff_mean_pitch1_2,cad_modelMin:cad_mode2Min) 0.09 0.39 -0.68 0.78 1.00 26206 17501

```

```

Population-Level Effects:

Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept -0.19 0.14 -0.49 0.08 1.00 18176 15136
cad_modelMin 0.57 0.14 0.31 0.85 1.00 14951 14771
cad_mode2Min -1.17 0.17 -1.51 -0.86 1.00 15093 13774
diff_mean_pitch1_2 0.91 0.15 0.63 1.22 1.00 16336 14524
timbreStrings -0.11 0.14 -0.38 0.16 1.00 22369 16575
cad_modelMin:cad_mode2Min -0.04 0.12 -0.26 0.19 1.00 30954 15905
cad_modelMin:timbreStrings -0.09 0.13 -0.34 0.16 1.00 27487 16023
cad_mode2Min:timbreStrings -0.29 0.16 -0.60 0.02 1.00 21137 15313
diff_mean_pitch1_2:timbreStrings -0.13 0.14 -0.42 0.14 1.00 19687 15516
cad_modelMin:cad_mode2Min:timbreStrings 0.05 0.11 -0.17 0.26 1.00 38298 15090

```

Sydney: Musician

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ (cad_model1 * cad_mode2 + diff_mean_pitch1_2) * timbre + (cad_model1 * cad_mode2 + diff_mean_pitch1_2 | participant)
Data: data_cut_mus_cad (Number of observations: 228)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000

```

```

Group-Level Effects:
~participant (Number of levels: 19)

Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.92 0.54 0.07 2.11 1.00 5469 7257
sd(cad_modelMin) 0.49 0.39 0.02 1.44 1.00 11137 10555
sd(cad_mode2Min) 1.50 0.62 0.42 2.90 1.00 5736 5340
sd(diff_mean_pitch1_2) 0.56 0.39 0.03 1.47 1.00 7421 9634
sd(cad_modelMin:cad_mode2Min) 0.87 0.53 0.05 2.05 1.00 5195 8069
cor(Intercept,cad_modelMin) -0.02 0.40 -0.76 0.74 1.00 26271 14540
cor(Intercept,cad_mode2Min) 0.06 0.36 -0.66 0.72 1.00 7864 10894
cor(cad_modelMin,cad_mode2Min) -0.11 0.41 -0.81 0.69 1.00 5776 10557
cor(Intercept,diff_mean_pitch1_2) 0.11 0.39 -0.66 0.79 1.00 16706 15032
cor(cad_modelMin,diff_mean_pitch1_2) -0.00 0.41 -0.75 0.75 1.00 12355 14873
cor(cad_mode2Min,diff_mean_pitch1_2) 0.15 0.38 -0.63 0.80 1.00 19486 16275
cor(Intercept,cad_modelMin:cad_mode2Min) -0.15 0.39 -0.80 0.65 1.00 12968 13736
cor(cad_modelMin,cad_modelMin:cad_mode2Min) 0.00 0.40 -0.74 0.74 1.00 12897 14352
cor(cad_mode2Min,cad_modelMin:cad_mode2Min) 0.07 0.37 -0.65 0.74 1.00 18117 16826
cor(diff_mean_pitch1_2,cad_modelMin:cad_mode2Min) -0.14 0.39 -0.81 0.66 1.00 12673 15804

```

```

Population-Level Effects:

Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept 0.15 0.41 -0.65 0.97 1.00 15437 13678
cad_modelMin 1.74 0.49 0.93 2.86 1.00 10619 8887
cad_mode2Min -2.74 0.65 -4.20 -1.63 1.00 9584 9720
diff_mean_pitch1_2 1.15 0.30 0.61 1.78 1.00 18811 12885
timbreStrings -0.26 0.39 -1.05 0.49 1.00 16315 13681
cad_modelMin:cad_mode2Min -0.48 0.41 -1.31 0.28 1.00 15478 12879
cad_modelMin:timbreStrings -0.35 0.37 -1.11 0.35 1.00 15757 12856
cad_mode2Min:timbreStrings -0.12 0.47 -1.05 0.82 1.00 15050 13138
diff_mean_pitch1_2:timbreStrings -0.13 0.27 -0.68 0.40 1.00 22119 14451
cad_modelMin:cad_mode2Min:timbreStrings 0.27 0.39 -0.50 1.04 1.00 16592 13544

```

Melodies

Uruwa: Minimal Exposure

```
Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre * melody + (diff_mean_pitch1_2 * melody | participant)
Data: data_cut_min_mel (Number of observations: 569)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
        total post-warmup samples = 20000
```

Group-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.67	0.36	1.09	2.50	1.00	8811	13064
sd(diff_mean_pitch1_2)	0.79	0.51	0.04	1.94	1.00	7225	10484
sd(melody1)	0.37	0.22	0.02	0.86	1.00	7735	10293
sd(melody2)	0.19	0.15	0.01	0.56	1.00	12594	12283
sd(diff_mean_pitch1_2:melody1)	0.74	0.55	0.03	2.04	1.00	10327	12235
sd(diff_mean_pitch1_2:melody2)	0.67	0.53	0.02	1.98	1.00	11540	10538
cor(Intercept,diff_mean_pitch1_2)	-0.02	0.35	-0.68	0.64	1.00	32339	13839
cor(Intercept,melody1)	0.02	0.35	-0.65	0.66	1.00	33150	15275
cor(diff_mean_pitch1_2,melody1)	-0.20	0.37	-0.81	0.57	1.00	13825	15086
cor(Intercept,melody2)	-0.08	0.38	-0.76	0.66	1.00	39201	14848
cor(diff_mean_pitch1_2,melody2)	-0.04	0.38	-0.73	0.68	1.00	22316	16353
cor(melody1,melody2)	-0.05	0.38	-0.73	0.68	1.00	22604	17223
cor(Intercept,diff_mean_pitch1_2:melody1)	-0.17	0.37	-0.78	0.60	1.00	30002	15765
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody1)	-0.04	0.38	-0.73	0.68	1.00	21651	15847
cor(melody1,diff_mean_pitch1_2:melody1)	0.07	0.37	-0.66	0.74	1.00	19536	15958
cor(melody2,diff_mean_pitch1_2:melody1)	0.02	0.38	-0.69	0.72	1.00	15356	17038
cor(Intercept,diff_mean_pitch1_2:melody2)	-0.03	0.37	-0.71	0.68	1.00	39020	13507
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody2)	0.01	0.37	-0.70	0.70	1.00	25178	16121
cor(melody1,diff_mean_pitch1_2:melody2)	-0.03	0.38	-0.72	0.69	1.00	22007	16648
cor(melody2,diff_mean_pitch1_2:melody2)	0.02	0.38	-0.70	0.73	1.00	15502	16308
cor(diff_mean_pitch1_2:melody1,diff_mean_pitch1_2:melody2)	-0.09	0.38	-0.77	0.65	1.00	14994	17365

Population-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-0.27	0.38	-1.01	0.47	1.00	6732	9703
diff_mean_pitch1_2	0.09	0.37	-0.65	0.80	1.00	27148	16002
timbreStrings	-0.09	0.37	-0.83	0.63	1.00	6765	10553
melody1	-0.27	0.19	-0.64	0.10	1.00	23084	16458
melody2	0.12	0.17	-0.21	0.44	1.00	25292	16387
diff_mean_pitch1_2:timbreStrings	-0.13	0.37	-0.87	0.61	1.00	25233	14017
diff_mean_pitch1_2:melody1	-0.20	0.46	-1.09	0.69	1.00	27389	16492
diff_mean_pitch1_2:melody2	-0.30	0.50	-1.30	0.68	1.00	29897	16196
timbreStrings:melody1	-0.09	0.19	-0.46	0.28	1.00	22431	15332
timbreStrings:melody2	0.03	0.17	-0.29	0.36	1.00	25365	16099
diff_mean_pitch1_2:timbreStrings:melody1	-0.50	0.47	-1.42	0.43	1.00	27184	15644
diff_mean_pitch1_2:timbreStrings:melody2	0.52	0.50	-0.44	1.53	1.00	29156	16242

Uruwa: SDA

```
Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre * melody + (diff_mean_pitch1_2 * melody | participant)
Data: data_cut_SDA_mel (Number of observations: 2009)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
        total post-warmup samples = 20000
```

Group-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.20	0.14	0.95	1.50	1.00	6012	10377
sd(diff_mean_pitch1_2)	0.52	0.29	0.03	1.11	1.00	4403	6569
sd(melody1)	0.21	0.13	0.01	0.48	1.00	4559	8054
sd(melody2)	0.36	0.14	0.06	0.62	1.00	3540	3742
sd(diff_mean_pitch1_2:melody1)	0.36	0.26	0.02	0.97	1.00	8049	9868
sd(diff_mean_pitch1_2:melody2)	0.70	0.42	0.04	1.56	1.00	4882	8044
cor(Intercept,diff_mean_pitch1_2)	0.04	0.31	-0.57	0.62	1.00	24169	13599
cor(Intercept,melody1)	-0.07	0.33	-0.68	0.60	1.00	24743	13400
cor(diff_mean_pitch1_2,melody1)	0.03	0.36	-0.67	0.71	1.00	11575	13787
cor(Intercept,melody2)	-0.01	0.27	-0.52	0.51	1.00	20636	14545
cor(diff_mean_pitch1_2,melody2)	-0.28	0.34	-0.82	0.50	1.00	4326	7337
cor(melody1,melody2)	-0.31	0.37	-0.85	0.53	1.00	5145	9286
cor(Intercept,diff_mean_pitch1_2:melody1)	0.11	0.37	-0.63	0.76	1.00	28149	15060
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody1)	0.07	0.37	-0.66	0.74	1.00	17326	14954
cor(melody1,diff_mean_pitch1_2:melody1)	0.10	0.38	-0.65	0.77	1.00	15905	15754
cor(melody2,diff_mean_pitch1_2:melody1)	-0.13	0.37	-0.77	0.61	1.00	17644	17557
cor(Intercept,diff_mean_pitch1_2:melody2)	-0.09	0.32	-0.67	0.55	1.00	25475	14602
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody2)	-0.12	0.36	-0.75	0.60	1.00	10018	13266
cor(melody1,diff_mean_pitch1_2:melody2)	0.08	0.37	-0.65	0.74	1.00	10153	13600
cor(melody2,diff_mean_pitch1_2:melody2)	0.15	0.35	-0.59	0.76	1.00	12336	14695
cor(diff_mean_pitch1_2:melody1,diff_mean_pitch1_2:melody2)	-0.08	0.38	-0.75	0.66	1.00	11633	15987

Population-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	0.24	0.15	-0.06	0.54	1.00	4293	7743
diff_mean_pitch1_2	0.22	0.18	-0.13	0.57	1.00	24789	15624
timbreStrings	-0.10	0.16	-0.40	0.21	1.00	4006	7307
melody1	0.02	0.08	-0.14	0.17	1.00	21601	15094
melody2	-0.19	0.09	-0.36	-0.01	1.00	19692	15467
diff_mean_pitch1_2:timbreStrings	0.07	0.18	-0.28	0.42	1.00	25564	15477
diff_mean_pitch1_2:melody1	-0.09	0.24	-0.55	0.37	1.00	20337	16116
diff_mean_pitch1_2:melody2	0.00	0.27	-0.53	0.54	1.00	21054	16008
timbreStrings:melody1	-0.11	0.08	-0.27	0.05	1.00	22395	16628
timbreStrings:melody2	-0.14	0.09	-0.32	0.03	1.00	19617	15558
diff_mean_pitch1_2:timbreStrings:melody1	0.11	0.23	-0.35	0.56	1.00	20646	16899
diff_mean_pitch1_2:timbreStrings:melody2	-0.32	0.27	-0.85	0.22	1.00	19932	15770

Uruwa: Lutheran

```
Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre * melody + (diff_mean_pitch1_2 * melody | participant)
Data: data_cut_Lut_mel (Number of observations: 1080)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
        total post-warmup samples = 20000
```

Group-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.81	0.15	0.56	1.13	1.00	7982	12860
sd(diff_mean_pitch1_2)	0.49	0.33	0.02	1.22	1.00	6619	10245
sd(melody1)	0.22	0.14	0.01	0.53	1.00	6798	9587
sd(melody2)	0.29	0.16	0.02	0.62	1.00	5913	8387

```

sd(diff_mean_pitch1_2:melody1) 0.52 0.37 0.02 1.38 1.00 7408 10666
sd(diff_mean_pitch1_2:melody2) 0.50 0.37 0.02 1.36 1.00 9283 9796
cor(Intercept,diff_mean_pitch1_2) -0.09 0.34 -0.71 0.61 1.00 28227 14979
cor(Intercept,melody1) 0.01 0.34 -0.64 0.66 1.00 24659 13637
cor(diff_mean_pitch1_2,melody1) -0.03 0.37 -0.72 0.68 1.00 14226 15370
cor(Intercept,melody2) 0.06 0.32 -0.57 0.65 1.00 24593 14887
cor(diff_mean_pitch1_2,melody2) 0.05 0.37 -0.66 0.72 1.00 12166 14730
cor(melody1,melody2) -0.04 0.37 -0.72 0.68 1.00 12493 14971
cor(Intercept,diff_mean_pitch1_2:melody1) 0.05 0.35 -0.63 0.70 1.00 28845 15031
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody1) -0.07 0.38 -0.74 0.67 1.00 18179 15459
cor(melody1,diff_mean_pitch1_2:melody1) -0.01 0.37 -0.70 0.69 1.00 17556 16739
cor(melody2,diff_mean_pitch1_2:melody1) -0.00 0.37 -0.70 0.70 1.00 17872 16387
cor(Intercept,diff_mean_pitch1_2:melody2) 0.08 0.37 -0.65 0.74 1.00 32708 15606
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody2) -0.00 0.38 -0.71 0.71 1.00 19467 16079
cor(melody1,diff_mean_pitch1_2:melody2) 0.08 0.38 -0.66 0.76 1.00 18991 16815
cor(melody2,diff_mean_pitch1_2:melody2) 0.08 0.37 -0.66 0.75 1.00 16895 16863
cor(diff_mean_pitch1_2:melody1,diff_mean_pitch1_2:melody2) -0.09 0.38 -0.76 0.65 1.00 12048 16786

```

Population-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	0.25	0.15	-0.05	0.54	1.00	8699	11706
diff_mean_pitch1_2	0.51	0.23	0.06	0.97	1.00	24208	15333
timbreStrings	0.13	0.15	-0.17	0.42	1.00	8380	11781
melody1	-0.26	0.11	-0.48	-0.06	1.00	26314	15988
melody2	0.02	0.11	-0.20	0.24	1.00	23842	15780
diff_mean_pitch1_2:timbreStrings	0.02	0.23	-0.43	0.48	1.00	25956	14827
diff_mean_pitch1_2:melody1	-0.54	0.31	-1.14	0.06	1.00	23098	16038
diff_mean_pitch1_2:melody2	0.16	0.33	-0.48	0.82	1.00	25423	16501
timbreStrings:melody1	-0.06	0.11	-0.27	0.15	1.00	25285	15635
timbreStrings:melody2	0.20	0.11	-0.02	0.42	1.00	22430	15401
diff_mean_pitch1_2:timbreStrings:melody1	-0.12	0.30	-0.72	0.46	1.00	24029	16096
diff_mean_pitch1_2:timbreStrings:melody2	-0.18	0.33	-0.83	0.49	1.00	26203	16956

Sydney: Non-musician

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre * melody + (diff_mean_pitch1_2 * melody | participant)
Data: data_cut_nonmus_mel (Number of observations: 1800)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000

```

Group-Level Effects:

~participant (Number of levels: 60)

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.46	0.09	0.29	0.64	1.00	8977	11732
sd(diff_mean_pitch1_2)	1.65	0.29	1.12	2.26	1.00	9595	13038
sd(melody1)	0.18	0.12	0.01	0.44	1.00	5970	8673
sd(melody2)	0.25	0.13	0.02	0.51	1.00	4570	8272
sd(diff_mean_pitch1_2:melody1)	0.44	0.32	0.02	1.17	1.00	6448	10234
sd(diff_mean_pitch1_2:melody2)	0.52	0.35	0.02	1.31	1.00	7901	10363
cor(Intercept,diff_mean_pitch1_2)	0.17	0.21	-0.25	0.57	1.00	5856	10303
cor(Intercept,melody1)	-0.10	0.34	-0.72	0.58	1.00	21051	14784
cor(diff_mean_pitch1_2,melody1)	-0.22	0.34	-0.78	0.53	1.00	18700	15612
cor(Intercept,melody2)	0.19	0.32	-0.50	0.74	1.00	16551	14388
cor(diff_mean_pitch1_2,melody2)	-0.06	0.31	-0.64	0.56	1.00	18373	13705
cor(melody1,melody2)	-0.00	0.36	-0.68	0.69	1.00	10329	12628
cor(Intercept,diff_mean_pitch1_2:melody1)	0.11	0.35	-0.60	0.73	1.00	23496	14586
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody1)	-0.07	0.35	-0.71	0.63	1.00	23130	16080
cor(melody1,diff_mean_pitch1_2:melody1)	0.01	0.37	-0.70	0.70	1.00	18074	16103
cor(melody2,diff_mean_pitch1_2:melody1)	0.01	0.37	-0.69	0.70	1.00	17710	15792
cor(Intercept,diff_mean_pitch1_2:melody2)	-0.12	0.35	-0.73	0.59	1.00	22909	14890
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody2)	0.26	0.35	-0.51	0.82	1.00	19079	14422
cor(melody1,diff_mean_pitch1_2:melody2)	-0.08	0.37	-0.74	0.65	1.00	17159	16251
cor(melody2,diff_mean_pitch1_2:melody2)	0.04	0.36	-0.66	0.71	1.00	17447	16557
cor(diff_mean_pitch1_2:melody1,diff_mean_pitch1_2:melody2)	-0.11	0.38	-0.77	0.64	1.00	14939	17161

Population-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-0.23	0.08	-0.39	-0.08	1.00	14598	15469
diff_mean_pitch1_2	2.06	0.28	1.51	2.61	1.00	13490	14078
timbreStrings	-0.08	0.08	-0.24	0.08	1.00	14099	15091
melody1	-0.34	0.09	-0.51	-0.17	1.00	22460	16708
melody2	0.02	0.09	-0.15	0.19	1.00	23138	16458
diff_mean_pitch1_2:timbreStrings	-0.09	0.27	-0.62	0.43	1.00	14715	14848
diff_mean_pitch1_2:melody1	-0.12	0.25	-0.60	0.37	1.00	24032	16693
diff_mean_pitch1_2:melody2	-0.21	0.27	-0.74	0.33	1.00	23833	15288
timbreStrings:melody1	0.09	0.09	-0.08	0.26	1.00	23357	15873
timbreStrings:melody2	-0.05	0.09	-0.22	0.12	1.00	23000	16195
diff_mean_pitch1_2:timbreStrings:melody1	-0.15	0.24	-0.62	0.32	1.00	23844	17008
diff_mean_pitch1_2:timbreStrings:melody2	0.27	0.27	-0.27	0.81	1.00	23715	16325

Sydney: Musician

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre * melody + (diff_mean_pitch1_2 * melody | participant)
Data: data_cut_mus_mel (Number of observations: 570)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000

```

Group-Level Effects:

~participant (Number of levels: 19)

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.23	0.16	0.01	0.61	1.00	8600	10549
sd(diff_mean_pitch1_2)	2.94	0.82	1.59	4.79	1.00	10695	14273
sd(melody1)	0.21	0.16	0.01	0.60	1.00	13539	11518
sd(melody2)	0.29	0.21	0.01	0.78	1.00	8710	10115
sd(diff_mean_pitch1_2:melody1)	0.84	0.66	0.03	2.46	1.00	10510	10277
sd(diff_mean_pitch1_2:melody2)	0.96	0.74	0.04	2.75	1.00	10280	11004
cor(Intercept,diff_mean_pitch1_2)	-0.12	0.35	-0.75	0.59	1.00	5262	9588
cor(Intercept,melody1)	0.05	0.38	-0.67	0.74	1.00	27396	15398
cor(diff_mean_pitch1_2,melody1)	-0.11	0.37	-0.76	0.62	1.00	26576	15391
cor(Intercept,melody2)	0.09	0.38	-0.66	0.75	1.00	20834	15220
cor(diff_mean_pitch1_2,melody2)	-0.03	0.35	-0.69	0.65	1.00	25071	15867
cor(melody1,melody2)	-0.06	0.39	-0.75	0.69	1.00	15977	15248
cor(Intercept,diff_mean_pitch1_2:melody1)	0.02	0.38	-0.70	0.72	1.00	23941	14843
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody1)	-0.08	0.36	-0.73	0.63	1.00	25761	14801
cor(melody1,diff_mean_pitch1_2:melody1)	0.01	0.38	-0.71	0.71	1.00	17802	14954
cor(melody2,diff_mean_pitch1_2:melody1)	0.03	0.37	-0.69	0.72	1.00	17536	16425
cor(Intercept,diff_mean_pitch1_2:melody2)	0.00	0.38	-0.69	0.70	1.00	24590	15259
cor(diff_mean_pitch1_2,diff_mean_pitch1_2:melody2)	0.05	0.36	-0.65	0.72	1.00	27809	16041
cor(melody1,diff_mean_pitch1_2:melody2)	-0.05	0.38	-0.74	0.67	1.00	18886	16738
cor(melody2,diff_mean_pitch1_2:melody2)	0.00	0.37	-0.69	0.70	1.00	17361	16714
cor(diff_mean_pitch1_2:melody1,diff_mean_pitch1_2:melody2)	-0.04	0.38	-0.73	0.70	1.00	15226	17486

Population-Level Effects:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-0.23	0.14	-0.52	0.04	1.00	22856	14799
diff_mean_pitch1_2	6.31	0.94	4.49	8.20	1.00	12806	13675
timbreStrings	-0.04	0.14	-0.31	0.24	1.00	22827	16207
melody1	-0.41	0.20	-0.80	-0.03	1.00	23866	15756
melody2	0.33	0.20	-0.05	0.72	1.00	21919	14392
diff_mean_pitch1_2:timbreStrings	0.33	0.67	-0.97	1.71	1.00	18556	14751
diff_mean_pitch1_2:melody1	-0.64	0.60	-1.85	0.51	1.00	24799	16350
diff_mean_pitch1_2:melody2	0.03	0.61	-1.15	1.28	1.00	24922	14663
timbreStrings:melody1	0.28	0.19	-0.09	0.66	1.00	21906	15283
timbreStrings:melody2	0.08	0.19	-0.29	0.46	1.00	21736	16405
diff_mean_pitch1_2:timbreStrings:melody1	-0.42	0.59	-1.61	0.70	1.00	25977	15640
diff_mean_pitch1_2:timbreStrings:melody2	0.15	0.59	-1.01	1.33	1.00	26532	15948

Cadences and melodies

Uruwa: Minimal

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre + (diff_mean_pitch1_2 | participant)
Data: data_cut_min_cad_mel (Number of observations: 773)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
        total post-warmup samples = 20000

Group-Level Effects:
~participant (Number of levels: 19)

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)      1.34    0.28    0.89    1.98 1.00    4922    9299
sd(diff_mean_pitch1_2) 0.21    0.16    0.01    0.59 1.00    7930    7598
cor(Intercept,diff_mean_pitch1_2) -0.19    0.54   -0.97    0.89 1.00   15485   11230

Population-Level Effects:

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept      -0.25    0.31   -0.87    0.35 1.00    3427    6853
diff_mean_pitch1_2 -0.05    0.14   -0.33    0.23 1.00   17970   13600
timbreStrings     -0.11    0.31   -0.73    0.50 1.00    3960    7098
diff_mean_pitch1_2:timbreStrings  0.04    0.14   -0.23    0.32 1.00   18456   13748

```

Uruwa: SDA

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre + (diff_mean_pitch1_2 | participant)
Data: data_cut_SDA_cad_mel (Number of observations: 2717)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
        total post-warmup samples = 20000

Group-Level Effects:
~participant (Number of levels: 69)

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)      1.04    0.12    0.82    1.30 1.00    4468    7632
sd(diff_mean_pitch1_2) 0.13    0.10    0.01    0.36 1.00    5351    6895
cor(Intercept,diff_mean_pitch1_2)  0.04    0.52   -0.91    0.92 1.00   17215   12110

Population-Level Effects:

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept      0.24    0.13   -0.02    0.50 1.00    2647    5101
diff_mean_pitch1_2 0.14    0.07    0.01    0.27 1.00   19705   14658
timbreStrings     -0.01    0.13   -0.26    0.26 1.00    2456    5022
diff_mean_pitch1_2:timbreStrings  0.01    0.07   -0.12    0.14 1.00   22652   14540

```

Uruwa: Lutheran

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre + (diff_mean_pitch1_2 | participant)
Data: data_cut_Lut_cad_mel (Number of observations: 1500)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
        total post-warmup samples = 20000

Group-Level Effects:
~participant (Number of levels: 38)

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)      0.77    0.13    0.54    1.05 1.00    5797   10015
sd(diff_mean_pitch1_2) 0.38    0.16    0.05    0.71 1.00    4077    4731
cor(Intercept,diff_mean_pitch1_2) -0.22    0.36   -0.86    0.53 1.00   10202    7566

Population-Level Effects:

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept      0.23    0.14   -0.04    0.50 1.00    4575    7672
diff_mean_pitch1_2 0.27    0.11    0.05    0.49 1.00   14036   13570
timbreStrings     0.16    0.14   -0.10    0.44 1.00    4551    7589
diff_mean_pitch1_2:timbreStrings  0.11    0.11   -0.11    0.32 1.00   13592   13205

```

Sydney: Non-musician

```

Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre + (diff_mean_pitch1_2 | participant)
Data: data_cut_nonmus_cad_mel (Number of observations: 2507)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
        total post-warmup samples = 20000

Group-Level Effects:
~participant (Number of levels: 60)

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)      0.33    0.07    0.21    0.47 1.00    9127   12083
sd(diff_mean_pitch1_2) 0.67    0.12    0.45    0.92 1.00   8994   12190
cor(Intercept,diff_mean_pitch1_2)  0.67    0.19    0.24    0.97 1.00   3589    5142

Population-Level Effects:

      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept     -0.19    0.06   -0.31   -0.07 1.00   11123   13796
diff_mean_pitch1_2  1.02    0.12    0.80    1.26 1.00   11613   13458
timbreStrings     -0.07    0.06   -0.19    0.05 1.00   11969   14330
diff_mean_pitch1_2:timbreStrings -0.12    0.11   -0.35    0.10 1.00   11343   13630

```

Sydney: Musician

```
Family: bernoulli
Links: mu = logit
Formula: bin_response ~ diff_mean_pitch1_2 * timbre + (diff_mean_pitch1_2 | participant)
Data: data_cut_mus_cad_mel (Number of observations: 798)
Samples: 4 chains, each with iter = 6000; warmup = 1000; thin = 1;
         total post-warmup samples = 20000

Group-Level Effects:
~participant (Number of levels: 19)

```

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.10	0.08	0.00	0.30	1.00	10343	9553
sd(diff_mean_pitch1_2)	0.35	0.23	0.02	0.87	1.00	6167	7725
cor(Intercept,diff_mean_pitch1_2)	0.03	0.57	-0.94	0.95	1.00	7252	11086

```
Population-Level Effects:

```

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-0.10	0.09	-0.27	0.07	1.00	20481	14232
diff_mean_pitch1_2	1.56	0.19	1.21	1.95	1.00	12505	11703
timbreStrings	-0.03	0.09	-0.20	0.14	1.00	18748	13842
diff_mean_pitch1_2:timbreStrings	-0.10	0.18	-0.47	0.25	1.00	12472	12864

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