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Emotional responses to Hindustani raga music: the role of musical structure

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Introduction

While music has long been associated with emotions (Miller and Williams, 2008; Patel, 2010), it has also been a subject of interesting debate among philosophers. Consequently, the existence of emotions induced by music has been debated by believers and non-believers referred to as emotivists and cognitivists, respectively. The cognitivists argue that music does not generally evoke emotions in listeners, it merely expresses emotions that are perceived by listeners (Kivy, 1989). In other words, listeners refer to music as happy or sad because the music expresses happiness or sadness, not because the music makes them feel happy or sad. By contrast, emotivists suggest that music actually evokes or induces feelings in listeners (Scherer and Zentner, 2001). Recent studies that have focused on measures other than self reports, namely changes in arousal levels measured by changes in autonomic nervous system activity while listening to music (Krumhansl, 1997; Nyklíček et al., 1997), indicate that music does evoke emotions (for review refer to Sloboda and Juslin, 2010). As a result, many theories have been put forward to explain the mode of induction of emotions by music. Emotional reactions to music have been explained in terms of cognitive appraisals, which claim that emotions are elicited or differentiated on the basis of an individual's subjective evaluation or
appraisal (Scherer, 1999). More recently, Juslin and Västfjäll (2008) have argued that cognitive appraisals are only one of the ways in which emotions are induced, and have proposed six other mechanisms that explain how musical pieces induce emotions: (1) brain stem reflexes (e.g., reactions to dissonance), (2) conditioning (i.e., a particular music is associated with a positive or negative emotion), (3) contagion (i.e., listener perceives the emotional expression of music, and then “mimics” this expression internally), (4) visual imagery (i.e., images evoked by music act as cues to an emotion), (5) episodic memory (i.e., a piece is associated with a particular event, which, in turn, is associated with an emotion), and (6) expectancies that are fulfilled or denied (i.e., emotion is induced in a listener because a specific feature of the music violates, delays, or confirms the listener’s expectations about the continuation of the music).

In the research reported here, we used self-reports by participants as a measure to study the subjectively experienced feeling of emotion while listening to raga of North Indian Classical music (NICM). NICM born out of a cultural synthesis of the Vedic chant tradition and traditional Persian music has been known to induce emotions (Kaufmann, 1965). The central notion in this system of music is that of a raga. The word ‘raga’ originates in Sanskrit and is defined as ‘the act of coloring or dyeing’ (the mind and mood/emotions in this context) and therefore refers Sanskrit and is defined as ‘the act of coloring or dyeing’ (the mind and mood/emotions in this context) and therefore refers to any feeling or passion especially love, affection, mind and mood/emotions in this context) and therefore refers to any feeling or passion especially love, affection, kindness/compassion, tenderness, anger, compassion, disgust, horror, heroism, wonder, peace, and spiritual devotion. From a research perspective, Zentner et al. (2008) have incorporated the type of emotions elicited while listening to music into a scale – the Geneva Emotional Scale (GEMS) which are labeled as wonder, transcendence, tenderness, peacefulness, nostalgia, power, joyful entertainment, tension, and sadness. We used a combination of these two sources in order to arrive at the emotion labels used for this study, namely, happy, romantic, devotional, calm/soothed, angry, longing/yearning, tense/restless, and sad.

The basic set of tones and tone-relationships used in NICM from which raga are derived are the 12-tone octave divisions (Castellano et al., 1984; Bowling et al., 2012). Each interval is a tone defined by the ratio of its fundamental frequency with the tonic, or ‘root’ note and is termed as tonic interval. The “major” intervals are the shuddh swaras or the natural notes namely, second, third, sixth, and seventh while the “minor” intervals are the komal swaras (flat) positions of the same tones. (Tonic interval values used in NICM, frequency ratios, sizes in cents in Just intonation and 12-tone equal temperament (12-TET) tunings and the corresponding interval name in the Western chromatic scale are provided in Table 1). Apart from the 12 tones mentioned in Table 1, there exist a set of 10 more intermittent tones which comprise the 22 sruti system in Indian classical music (Loy, 2011). Sruti refers to subtle intervals produced because of oscillations in pitch. This occurs when a note is subjected to a slow shake or an exaggerated vibrato, either as a decoration or as a functional feature of a raga. However, the prevalence of the 22 srutis in the modern period is a subject of much discussion and debate. A recent analysis of srutis by Serra et al. (2011) has shown that Hindustani classical music has equal-tempered influences as compared to Carnatic music which emphasizes on ornamentation (Koduri et al., 2012) and follows the Just-Intonation system. Consequently, we used the 12-tone classification in Equal temperament scale for evaluating the tonality of ragas.

A raga uses a set of five or more notes from the fixed scale of seven notes, to construct a melody. However, it is not enough to define a raga in terms of mode or scale alone, as a number of ragas have the same notes, yet each maintains its own musical identity. For instance, both ragas Miyan ki Malhar and Bahar contain the same notes (Sa, Re, Ga, Ma, Pa, Dha, Ni, Ni) and yet sound quite different because of the way the notes in the scale are approached and combined. As described by Jairazbhoy (1995) when different performances of the same raga are examined we find that allowing for divergence of tradition and the possibility of experimentation, not only are the same notes consistently used, but also particular figurations or patterns of notes occur frequently. The most characteristic patterns of notes in a raga are described as ‘pakar,’ a catch phrase by which the raga can be easily recognized. These patterns of notes for a raga can be described in terms of their melodic movements, ascending (aaroh) and descending (avroh) lines of a raga. Ragas can have different rules of ascent and descent (for example, in raga Desh the ascent is a step by step pentatonic movement (Sa, Re, Ma, Pa, Ni Sa’) while the descent is heptatonic (Sa’ ni Dha Pa, Dha Ma Ga, Re Ga Sa’). Moreover, in a raga, in theory, two notes are given greater importance than the others. These notes are called the vadi – sonant, and the samvadi – consonant. The vadi is the most important note in the characteristic phrase (pakar) of that raga and is superabundant in that raga. On the other hand as compared to the vadi, the samvadi is described as the note that is less frequent but more than the other notes in the raga. The vadi and samvadi could naturally fluctuate, depending on whether the ascending or descending disjunct segments are being emphasized. For instance, in raga Yaman, Ga and Ni would qualify as the two most important notes in the ascent (ni Re Ga and ma Dha Ni) whereas Pa and Re would be the two most important notes in the descent (Sa’ Ni Dha Pa and Pa Ma Ga Re).

A raga composition is typically presented as a specific sequence of events, namely the alaap followed by the gat. Alaap is the note by note delineation of a raga bound by a slow tempo, but not bound by any rhythmic cycle. Gat is the composition rendered at a faster tempo with accompaniment of a percussion instrument that provides a rhythmic cycle. The rhythmic cycle is measured in terms of time units or beats. These rhythmic structures can vary in the degree of pulse clarity. Pulse clarity is the estimate, on a large time scale, of how clearly the underlying pulsation in music is perceivable and is regarded as a measure for the underlying periodicity of the music (Lartillot et al., 2008). Thus, pulse clarity provides a measure of rhythmic regularity. Besides
features such as pulse clarity, tempo is an important factor contributing to the perception of rhythm, which can be estimated as the number of notes presented per second. For the purpose of this study, rhythmic regularity was determined by estimating pulse clarity while tempo was determined in terms of note density of raga excerpts.

A review of the literature indicates that a few studies have investigated the proposal that different raga express emotions that are perceived by the listener’s (Balkwill and Thompson, 1999; Chordia and Rae, 2008; Wieczorkowska et al., 2010). The earliest of these was conducted by Balkwill and Thompson (1999) where they asked 30 Western listeners to judge the expression of 12 Hindustani raga intended to express anger, joy, peace, and sadness. They found that despite being culturally unfamiliar, listeners were sensitive to the intended expression of the raga. A similar study was conducted by Chordia and Rae (2008) in which they studied emotional responses to five raga on a scale of six emotions – happy, peaceful, sad, longing, tense, and romantic. While their results also suggested that raga do consistently elicit specific emotions that are associated with musical properties, they also indicated that the primary predictors of emotion of raga are pitch-class distribution, pitch-class dyad entropy, overall sensory dissonance, and note density. The multiple regression analysis conducted to determine the most important factors and their total predictive value revealed that these features in combination explained between 11% (peaceful) and 33% (happy) of response variance. However, none of the studies have elucidated the role of any specific tonic interval. To summarize, while the studies described above have clearly confirmed that distinct raga elicit distinct emotions, they have used as stimuli the introductory section of raga namely, the alaap. None of them have investigated the emotions experienced during the gat of raga. Consequently, there is little information about the complex interplay of rhythmic regularity and tempo in predicting the emotion experienced for gat of raga.

The current study builds on this past research and extends it to address new questions. The specific objectives of this study were to (1) discriminate the emotion experienced by alaap and gat for various raga (2) investigate the effects of (a) rhythmic regularity, (b) tempo and (c) tonality, on the emotions experienced. Listener responses were sought from a diverse population, for which a website (http://emotion-in-music.nbrc.ac.in/p1/) was developed and the study was conducted online. After analyzing the emotional responses, a label of emotion experienced was assigned to each raga. Three musical features, namely, pulse clarity, tempo, and tonality were estimated for each raga composition. Our specific hypotheses were the following (1) distinct emotional responses would be associated with alaap and gat of a raga; (2) rhythmic regularity and tempo would both modulate emotional response. (3) Since the emotion associated with a raga is believed to be an attribute of the tonic intervals from which it is derived, tonality would influence the emotional response.

### Materials and Methods

Three minute instrumental renditions of 12 raga were played by a professional musician on sarod (a stringed instrument) and digitally recorded in both alaap and gat. Participants were permitted to provide emotion ratings only after listening to the composition for at least 1 min. This had two advantages: (a) it ruled out random responses, and (b) it gave each participant the flexibility to listen to the composition as per their choice between 1 and 3 min. The list of the raga played and scale used by the artist are given in Table 2. All the pieces in gat were provided similar rhythmic accompaniment on tabla in teen taal, a rhythm symmetrical in structure having sixteen beats in four equal divisions. One-minute sample in both alaap and gat are given as supplementary files (see Supplementary audio clips S1, S2, S3, and S4). A short cartoon film was shown to the participants in an attempt to ensure that all the participants began the survey in a pleasant mood. Participants were instructed to listen to raga excerpts for a minimum of 1 min and rate each raga on all the following emotions on a 0–4 Likert scale (with

### Table 1: Music intervals in Hindustani classical music.

<table>
<thead>
<tr>
<th>Interval name</th>
<th>Abbreviation used</th>
<th>Western scale (Interval name)</th>
<th>Frequency ratio</th>
<th>Just intonation (Cents)</th>
<th>12-TET (Cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shadja</td>
<td>Sa</td>
<td>Perfect unison</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Komal Rhishabha</td>
<td>Re</td>
<td>Minor second</td>
<td>16/15</td>
<td>112</td>
<td>100</td>
</tr>
<tr>
<td>Shuddha Rhishabha</td>
<td>Re</td>
<td>Major second</td>
<td>10/9</td>
<td>183</td>
<td>200</td>
</tr>
<tr>
<td>Komal Gandhara</td>
<td>ga</td>
<td>Minor third</td>
<td>6/5</td>
<td>316</td>
<td>300</td>
</tr>
<tr>
<td>Shuddha Gandhara</td>
<td>Ga</td>
<td>Major third</td>
<td>5/4</td>
<td>396</td>
<td>400</td>
</tr>
<tr>
<td>Madhyama</td>
<td>Ma</td>
<td>Perfect fourth</td>
<td>4/3</td>
<td>498</td>
<td>500</td>
</tr>
<tr>
<td>Tvra Madhyama</td>
<td>ma</td>
<td>Tritone</td>
<td>45/32</td>
<td>590</td>
<td>600</td>
</tr>
<tr>
<td>Panchana</td>
<td>Pa</td>
<td>Perfect fifth</td>
<td>3/2</td>
<td>702</td>
<td>700</td>
</tr>
<tr>
<td>Komal Dhaivata</td>
<td>dha</td>
<td>Minor sixth</td>
<td>8/5</td>
<td>814</td>
<td>800</td>
</tr>
<tr>
<td>Shuddha Dhaivata</td>
<td>Dha</td>
<td>Major sixth</td>
<td>5/3</td>
<td>884</td>
<td>900</td>
</tr>
<tr>
<td>Komal Nishada</td>
<td>ni</td>
<td>Minor seventh</td>
<td>9/5</td>
<td>1018</td>
<td>1000</td>
</tr>
<tr>
<td>Shuddha Nishada</td>
<td>Ni</td>
<td>Major seventh</td>
<td>15/8</td>
<td>1088</td>
<td>1100</td>
</tr>
<tr>
<td>Shadja</td>
<td>Sa’</td>
<td>Perfect octave</td>
<td>2</td>
<td>1200</td>
<td>1200</td>
</tr>
</tbody>
</table>

Each interval is a tone defined by the ratio of its fundamental frequency to the tonic (Sa). Interval names, abbreviations used, frequency ratios and sizes in cents in Just intonation and 12-TET tunings are given in table. The corresponding interval name in the Western chromatic scale is also given. In the notation used the seven Shuddha swaras are denoted by capital letters (Sa, Re, Ga, Ma, Pa, Dha, Ni), four komal swaras, and one tvra swara are denoted by small letters (re, ga, ma, dha, ni).
Table 2 | The table lists the ragas used in the study and the scale used by the artist to play the raga.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Raga</th>
<th>Scale used by Artist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tilak kamod</td>
<td>Sa Re Ga Ma Pa Dha N</td>
</tr>
<tr>
<td>2</td>
<td>Hansadhwani</td>
<td>Sa Re Ga Ma Pa Dha N</td>
</tr>
<tr>
<td>3</td>
<td>Desh</td>
<td>Sa Re Ga Ma Pa Dha N</td>
</tr>
<tr>
<td>4</td>
<td>Yaman</td>
<td>Sa Re Ga Ma Pa Dha N</td>
</tr>
<tr>
<td>5</td>
<td>Rageshreee</td>
<td>Sa Re Ga Ma Pa Dha N</td>
</tr>
<tr>
<td>6</td>
<td>Jog</td>
<td>Sa ga/Ga Ma Pa Dha N</td>
</tr>
<tr>
<td>7</td>
<td>Marwa</td>
<td>Sa re Ga ma Dha N</td>
</tr>
<tr>
<td>8</td>
<td>Lalit</td>
<td>Sa re Ga Ma/ma dha N</td>
</tr>
<tr>
<td>9</td>
<td>Malkauns</td>
<td>Sa Ga Ma dha N</td>
</tr>
<tr>
<td>10</td>
<td>Shree</td>
<td>Sa re Ga ma Pa dha N</td>
</tr>
<tr>
<td>11</td>
<td>Basant Mukhari</td>
<td>Sa re Ga Ma Pa dha N</td>
</tr>
<tr>
<td>12</td>
<td>Miyan ki todi</td>
<td>Sa re Ga Ma/ma Pa dha N</td>
</tr>
</tbody>
</table>

0 being ‘not at all felt’ to 4 being ‘felt the most’). The emotion labels were; happy, romantic, devotional, calm/soothed, angry, longing/yearning, tensed/restless, and sad. The emotion labels in the response form were also presented in Hindi and transliterated to Hindi (for example, Happy – ‘खुश’, khush). The ragas were presented in alternating alaap and gat blocks. The experiment consisted of four such blocks with each block consisting of six ragas. The presentation of alaap or gat as the first block was counterbalanced across subjects. The order of presentation of ragas within each block was randomized across participants. The participants were given an option to opt out of the survey after rating at least two blocks (i.e., 12 ragas – six alaap and six gat). The survey was presented in English.

Participant Details
Participants were recruited through word of mouth and social media platforms. Since the study was conducted online participants from across the world participated in the study. In view of the primary objectives of the study as described earlier, the analysis presented in this study focuses only on data from Indian participants who completed at least half the survey [i.e., rated at least six alaap excerpts (out of 12) and six gat excerpts (out of 12)]. Thus, ratings from 122 participants (F = 66, M = 56) were considered for analysis presented herein. Their ages were distributed as follows – below 20 years (12%), 20–40 years (59%), 40–60 years (26%), and above 60 years (2%). Participants also rated their familiarity with NICM on a scale of 0–4 (0 not at all, 1 a little, 2 somewhat, 3 very, and 4 expert). Analysis of demographic details showed that 42% of the participants reported themselves as not at all or a little familiar with NICM and 56% of participants considered themselves as somewhat, very familiar or expert in NICM. Two participants (2%) did not give their familiarity details. The Institutional Human Ethics Committee of the National Brain Research Centre, India, approved the study.

Data Analysis
Analysis was conducted at three levels (1) behavioral analysis of emotional response, (2) extraction of musical features of ragas and (3) correlation and regression analysis to investigate the relationship between musical features and emotional response.

The results of the survey were analyzed using SPSS v.20 as described below.

Behavioral Analysis
Median ratings for each emotion were computed to assign an emotion label to a raga. The emotion with the highest median rating for a given raga was assigned as the typical emotion elicited by that raga.

Assessment of Musical Structure
Tempo, Rhythmic Regularity and Tonality
As per the objectives of this study, the effect of three musical structures namely tempo, rhythm and tonality on emotional response were assessed.

Tempo was estimated in terms of number of notes presented per second and was measured in terms of note density. Rhythmic regularity was measured in terms of time units or beats and was calculated in terms of pulse clarity. Matlab-based toolbox (MIR v.1.5) developed by Lartillot et al. (2008) was used to estimate both note density and pulse clarity. To estimate the note density, the mireventdensity function was used which estimates the average frequency of events (note onsets per second) for an excerpt. Similarly, pulse clarity was estimated by using mirpulseclarity function in terms of the Shannon entropy of the fluctuationspectrum of a particular musical composition (Pampalk et al., 2002). Music with easily perceived beats has a distinct and regular fluctuation spectrum and consequently has a low fluctuation entropy and high pulse clarity.

The third musical structure, namely tonality, is a central organizing principle in many different kinds of music and pitches are heard in relation to a tonic pitch (Chordia and Rae, 2008). It was calculated by estimating the mean frequency of occurrence of different tonic intervals as described by Bowling et al. (2012). Tonic interval is the difference in cents between the fundamental frequencies of the note being compared with the tonic. The pitch was extracted using Melodia- Melody extraction toolbox for every 30 ms window for all ragas (Salamon and Gómez, 2012) and converted into cents using the following formula (refer
to equation no. 1, \( f_1 \) is the frequency of the note in Hz and \( f_0 \) is the frequency of the tonic in Hz.

\[
\text{Equation 1. Pitch (cents) } = 1200 * \left[ \log_2 \left( \frac{f_1}{f_0} \right) \right]
\]

An important point for consideration here was bin size. As pointed out in the introduction, apart from the 12 tones mentioned in Table 1, there exist a set of 10 intermittent tones which comprise the 22 sruti system in Indian classical music (Loy, 2011). Consequently, a smaller bin size would be considered more suitable to faithfully capture all the tonic intervals. However, recent work by (Koduri et al., 2012) has shown that Hindustani music uses the equi-tempered scale as compared to Carnatic music and has primarily equal-tempered influences. It is therefore sufficient to use the 12-tone classification in Equal temperament scale for evaluating the tonality of ragas. As seen from Table 1, a bin size of 100 cents would be sufficient. Accordingly, to estimate tonality, the corresponding interval size data was collated in 100 cent bins spanning three octaves (labeled from -1200 to 2400 cents). The mean frequency of occurrence of tonic intervals was calculated for each bin. Three octaves were then folded into one by adding the mean frequency of occurrence of the notes in each of the corresponding bins across the three octaves. For instance, the mean frequency of occurrence of komal re would be the additive mean frequency of occurrence in -1100, 100, and 1100 cent bins [refer to Supplementary Figure S1 (Image1)].

**Relationship Between Musical Structure and Emotional Response**

To assess whether there were statistically significant differences in rhythmic regularity (pulse clarity) and tempo (note density) among the ragas with different experienced emotions one-way ANOVAs were conducted. The values of pulse clarity and note density for both alaap and gat of ragas were taken as dependent variables and the emotions experienced were taken as the independent variable.

To study the effect of tonality on emotional response, correlation analysis was conducted. Correlations were calculated between the average rating of an emotion and the mean frequency of occurrence of tonic intervals across the 12 ragas played in gat. To characterize which of these tonic intervals were the best predictors of the emotional response stepwise linear regression analysis was conducted. In the regression analysis, the vector containing average ratings for an emotion across the 12 ragas was taken as the dependent variable and the mean frequency of occurrence of the 12 tonic intervals was taken as the independent variable.

**Results**

**Behavior**

In order to assign an emotion label to a raga median ratings for each emotion were computed. Shapiro–Wilk normality test were conducted to assess the normality of the data. The normality tests conducted on the ratings of each emotion for all the ragas were significant (\( p < 0.001 \)) indicating non-normal distributions of ratings. Consequently, non-parametric statistical tests were used to compare the median ratings of emotions for each raga. To evaluate differences in the medians of ratings of the eight emotions for each raga, Friedman one-way ANOVA by rank tests were conducted (refer to Supplementary Tables S1 and S2). The results of Friedman ANOVA were significant at \( p < 0.001 \). To further assess the highest experienced emotion post hoc Wilcoxon tests were conducted. For each raga, seven post-hoc Wilcoxon tests were conducted, wherein the median of the highest rated emotion was compared with other seven emotions. In the post hoc test, emotions whose median rating did not differ significantly from each other [marked with an asterisk (*) in Supplementary Tables S1 and S2] were considered as the highest experienced emotions by the participants for that particular raga. On this basis, the highest experienced emotion was determined and emotion label was assigned to each raga. The highest experienced emotions were, ‘calm’ and ‘sad’ for the arrhythmic phase (alaap) of ragas and ‘happy’, ‘tensed,’ and ‘longing’ for the rhythmic phase (gat) of ragas. The ragas with emotion labels of calm/happy were Hansdhwani, Tilak Kamod, Desh, Yaman, Ragesree, Jog while ragas with emotion labels of sad/longing/tensed were Malkauns, Shree, Marwa, Miyan ki Todi, Basant Mukhari, Lalit.

Response matrices representing the median ratings of experienced emotions by the participants were plotted for alaap and gat (refer to Figure 1). The median ratings of emotion are color coded where the intensity of color represents the strength of the emotional response. The highest median rating for ragas rated as ‘calm/smoothing’ during ‘alaap’ shifted to ‘happy’ when played in gat. On the other hand, the highest median rating for ragas rated as ‘sad’ shifted to ‘longing/yearning’ or ‘tensed/restless’ during gat. ‘Angry’ remained the lowest rated emotion for both categories of ragas.

**Musical Structure**

**Rhythmic Regularity and Tempo**

The average note density was higher in gat than in alaap of ragas (refer to Figure 2A). A paired sample t-test was conducted to compare the note density in alaap and gat of ragas. There was a significant difference in note density across alaap (\( M = 0.76, \ SD = 0.06 \)) and gat (\( M = 1.23, \ SD = 0.13 \)); \( t(11) = -13.98, \ p < 0.001 \). The pulse clarity was also significantly higher in gat as compared to alaap (refer to Figure 2B). A paired sample t-test conducted to compare the pulse clarity across alaap (\( M = 0.04, \ SD = 0.01 \)) and gat (\( M = 0.43, \ SD = 0.04 \)) was significant; \( t(11) = -34.76, \ p < 0.001 \).

Thus tempo (measured in terms of note density) and rhythmic regularity (measured in terms of pulse clarity) were both significantly higher for gat as compared to alaap of a raga.

**Tonality**

The percent mean frequency of occurrence of tonic intervals were averaged across alaap of ragas for which emotional response was ‘calm’ and ‘sad’ (Figure 3). The analysis of tonic intervals revealed that ragas that were rated for ‘calm’ were characterized primarily by major intervals (shuddh swaras) while those rated for ‘sad’ were characterized by minor intervals (komal swaras).
Two-tailed Mann–Whitney U-test was conducted to assess the statistical significance of the differences in the mean frequency of occurrence of major and minor intervals. The results revealed that (a) the mean frequency of occurrence of the major second \([\text{shuddh Re} (z = -1.92, p \leq 0.05)]\) and major third \([\text{shuddh Ga} (z = -2.24, p < 0.05)]\) was significantly higher in ragas with 'calm' emotional response. (b) The mean frequency of occurrence of minor second \([\text{komal re} (z = -2.88, p < 0.05)]\) and minor sixth \([\text{komal dha} (z = -2.88, p < 0.05)]\) was significantly higher for ragas with 'sad' emotional response (for complete statistics of the texts refer to Supplementary Table S3). The results remained consistent for gat of ragas [see Supplementary Figure S2 (Image2)].

**Relationship Between Musical Structure and Emotional Response**

**Effect of Rhythmic Regularity and Tempo**

The next analysis focused on investigating the relationship between emotional response and musical structure. Two separate ANOVAs were conducted. In the first ANOVA, pulse clarity was taken as the dependent variable while the emotions experienced across ragas (calm, happy, sad, and tensed) were treated as the independent variable. In the second ANOVA, note density was the dependent variable, while the emotions experienced across ragas (calm, happy, sad, and tensed) were treated as the independent variable. The results of the two ANOVAs are summarized in Table 3.

There were no outliers and the data for note density and pulse clarity was normally distributed for each group, as assessed by boxplot and Shapiro–Wilk test \((p < 0.05)\), respectively. Since, homogeneity of variances, as assessed by Levene’s Test of Homogeneity of Variance was violated for both note density \((p = 0.003)\) and pulse clarity \((p = 0.02)\), the results of
Welch ANOVA and post hoc Games-Howell test for multiple comparisons are reported. The results of one-way ANOVA indicate that there were statistically significant differences in note densities, depending on the experienced emotion [Welch’s $F(3,8.78) = 59.11, p < 0.0005$]. The note density was higher for gat of raga rated as happy ($M = 1.28$, $SD = 0.13$) as compared to calm ($M = 0.78$, $SD = 0.08$) and for tensed ($M = 1.18$, $SD = 0.11$) as compared to sad ($M = 0.73$, $SD = 0.02$). Games-Howell post hoc analysis revealed that the mean increase in note density from alaap of raga rated as ‘calm’ to gat of raga rated as ‘happy’ [0.50, 95% CI (0.31,0.70)] was statistically significant ($p < 0.005$). Similarly, the increase from alaap of raga rated as ‘sad’ to gat of raga rated as ‘tensed’ [0.45, 95% CI (0.28,0.62), $p = 0.001$] was statistically significant ($p < 0.005$).

The results of one-way ANOVA for pulse clarity showed similar results, [Welch’s $F(3,9.89) = 486.68, p < 0.0005$]. The pulse clarity for gat of raga rated as happy ($M = 0.42$, $SD = 0.05$) or tensed ($M = 0.44$, $SD = 0.03$) was higher as compared to alaap of raga rated as calm ($M = 0.04$, $SD = 0.01$) or sad ($M = 0.04$, $SD = 0.01$). Games-Howell post hoc analysis revealed that the mean increase of pulse clarity from alaap of raga rated as ‘calm’ to gat of raga rated as ‘happy’ [0.38, 95% CI (0.31,0.45)] was statistically significant ($p < 0.005$). Similarly, the increase from alaap of raga rated as ‘sad’ to gat of raga rated as ‘tensed’ [0.40, 95% CI (0.31,0.45)] was statistically significant, ($p < 0.005$).

In summary, both tempo and rhythmic regularity of a raga modulate emotional response and high arousal emotions (happy and tensed) are associated with faster rhythm.

**Effect of Tonality**

To study the effect of tonality on emotional response, correlation and stepwise linear regression analysis was conducted. Since, listeners of gat of raga experienced high arousal emotions; analysis was conducted only for gat.

To assess the influence of minor and major intervals on happy and tensed ratings, the ratio of mean frequency of occurrence of minor to major intervals was estimated and correlated with average ratings of ‘happy’ and ‘tensed’ emotion. The correlation plot of average ‘happy’ and ‘tensed’ ratings with the ratio of mean frequency of occurrence of minor to major tonic intervals is shown in Figure 4. The plot indicates that minor/major tonic interval frequency ratio is negatively correlated with happy ratings ($r = -0.59, p < 0.05$) and positively correlated with tensed ratings ($r = 0.65, p < 0.05$). This indicates that an increase in mean frequency of occurrence of minor intervals is associated with tense emotion, whereas an increase in mean frequency of occurrence of major intervals is associated with happy emotion.

Further, correlations were calculated between the average rating of an emotion and mean frequency of occurrence of each of the tonic intervals across the twelve raga (refer to Table 4).
The results of the correlation analysis indicate that the mean frequency of occurrence komal re, shuddh Re, and komal dha have significant correlations. To characterize which of these tonic intervals are the best subset for predicting the emotional response stepwise linear regression analysis was conducted. In the regression analysis, the vector containing average ratings for an emotion across the 12 ragas was taken as the dependent variable and the mean frequency of occurrence of the 12 tonic intervals were taken as the independent variables. The assumptions of linearity, independence of errors, homoscedasticity and normality of residuals were met. The results of regression analysis are reported in Table 5. The percent mean frequency of occurrence of the minor second (komal re, re) explained 58% of the variance for ratings of ‘happy’ emotion \( R^2 = 0.58, F(1,10) = 16.48, p < 0.05 \) and 89% of the variance for ratings of ‘tensed’ emotion \( R^2 = 0.89, F(1,10) = 44.46, p < 0.001 \). The mean frequency of occurrence of komal re was significantly negatively correlated with ‘happy’ \( \beta = -0.79, p < 0.05 \) and positively correlated with ‘tensed’ \( \beta = 0.91, p < 0.001 \) emotion ratings.

**Discussion and Conclusion**

This study reports for the first time emotional responses of North Indian Classical ragas when rendered in two distinct presentation modes, namely, alaap and gat. Specifically, we found that (1) distinct emotional responses are associated with alaap and gat of a raga. (2) Pulse clarity and tempo significantly influenced the emotion experienced in terms of arousal. (3) Major intervals (shuddh swaras) are predictive of reported positive valence while minor intervals (komal swaras) are predictive of reported negative valence. (4) The minor second is a significant predictor of negative valenced emotional response. We discuss below the implications of these results.

**Ragas and Emotional Response**

The key finding of our study was the experimental verification of the hypothesis that distinct emotional responses would be associated with alaap and gat of a raga. During the arrhythmic phase (alaap), an artist introduces the notes of the raga and the exposition is focused on setting the scale and the key structure of the melody. The rhythmic phase (gat) on the other hand, is faster and rhythmic and a percussionist accompanies the artist. As a consequence, the alaap of raga is believed to set the mood of raga, while gat enhances perception of emotion for that raga (Chib, 2004; Juslin and Sloboda, 2011).

Our results indicate that ragas evoke a gamut of responses that range from ‘happy’ and ‘calm’ to ‘tensed’ and ‘sad’ (as shown by results in Figure 1, Supplementary Tables S1 and S2). In particular, the emotional response to ragas (like Desh and Tilak Kamod) shifts from ‘calm/soothing’ in the slower arrhythmic alaap to ‘happy’ in the faster rhythmic gat. In parallel, the emotional response of ‘sad’ in the slower arrhythmic phase shifts to ‘tensed’ in the faster rhythmic phase (e.g., Shree and Miyan ki Todi; Figures 1A,B). An interesting feature was the fact that all ragas universally generated a calming effect and anger remained the lowest rated emotion category. This is in consensus with research on Western music which shows that negative emotions like anger which are regularly experienced in everyday life are only rarely experienced in response to music (Juslin and Laukka, 2004; Laukka, 2006). However, anger relates to irritation, which is most likely to arise when people are exposed to music they fail to understand, dislike, or even abhor (Zentner et al., 2008), or when the music is unwanted/too loud and thus considered annoying, i.e., noise.

**Role of Musical Structure in Emotion Experienced**

The results revealed that pulse clarity (estimate of rhythmic regularity) and note density (estimate of tempo) differ among ragas with different experienced emotions, where high arousal emotions (happy/tensed) are associated with a faster rhythm. In addition, tonality significantly influenced the emotion experienced as the increase in mean frequency of occurrence of
minor intervals was associated with 'tensed' emotion whereas increase in mean frequency of occurrence of major intervals was associated with 'happy' emotion (refer to Figure 4). Thus, our results indicated that the tonal distribution patterns determine the underlying mood (raga) of a raga and the presence of rhythm changes the level of arousal of emotions experienced.

These results appear to be universal across musical genres. For instance, in a study conducted by Husain et al. (2002), participants were asked to listen to four versions of Mozart sonata (fast-major, fast-minor, slow-major, and slow-minor) and rate their affective state on adjectives on a 7-point Likert scale. The results showed that slow-tempo versions caused increases in listeners’ levels of arousal, whereas the fast-tempo versions caused decreases in arousal. By contrast, the slow-tempo versions were accompanied by increases in listeners’ levels of arousal, whereas the slow-tempo versions caused decreases in arousal. By contrast, the slow-tempo versions were accompanied by increases in listeners’ levels of arousal, whereas the slow-tempo versions caused decreases in arousal.

The first of these is with regard to the concept of sruti and further studies should attempt to investigate its role in detail.

At the same time, the present study is characterized by certain limitations which restrict the generalizability of these findings. The first of these is with regard to the concept of sruti in NICM. The 12-tone semitone system of western music is clearly at odds with the 22 sruti system since some semitones are composed of one sruti while others of two or more. However, the sruti system still cannot account for the minute deviations from the norm, many of which are unconsciously presented by the artist. Thus for the purposes of this study, we were obliged to use the twelve semitone system, while making allowances for minor variations which is a limitation of this study. Secondly, to arrive at an emotion label for a raga, we should ideally have multiple excerpts of the same raga, played on different instruments by different performers (in alaat or gat) and then rated by listeners. When responses across different performers and different instruments all emerge with the same label, we would then have truly assigned an emotion label to a raga. Hopefully, further studies conducted on a large scale can address this question. Finally, we used self-reports to assess participants emotional responses. It can therefore not be ruled out that at least some of

<table>
<thead>
<tr>
<th>Happy</th>
<th>Romantic</th>
<th>Calm</th>
<th>Longing</th>
<th>Tensed</th>
<th>Sad</th>
</tr>
</thead>
<tbody>
<tr>
<td>β = -0.79*</td>
<td>β = -0.83**</td>
<td>β = -0.88**</td>
<td>β = 0.89**</td>
<td>β = 0.91**</td>
<td>β = 0.80*</td>
</tr>
<tr>
<td>R^2 = 0.58</td>
<td>R^2 = 0.66</td>
<td>R^2 = 0.75</td>
<td>R^2 = 0.78</td>
<td>R^2 = 0.89</td>
<td>R^2 = 0.60</td>
</tr>
<tr>
<td>F(1,10) = 16.48,</td>
<td>F(1,10) = 22.19,</td>
<td>F(1,10) = 330.61,</td>
<td>F(1,10) = 39.22,</td>
<td>F(1,10) = 44.46,</td>
<td>F(1,10) = 17.23,</td>
</tr>
<tr>
<td>p &lt; 0.05</td>
<td>p &lt; 0.001</td>
<td>p &lt; 0.001</td>
<td>p &lt; 0.001</td>
<td>p &lt; 0.001</td>
<td>p &lt; 0.05</td>
</tr>
</tbody>
</table>

The results of the first predictive model with values of adjusted R^2, standardized coefficient (&beta;) and F ratio of ANOVA results are reported in the table. The correlation coefficients (&beta;) marked with a single (*) and a double asterisk (**) are significant correlations at p < 0.05 and p < 0.001 respectively.
the participants rated expressed emotion instead of experienced emotion.

Nevertheless, our study provides new evidence that ragas evoke distinct emotional responses across distinct presentation modes (alaap and gat). This opens up the possibility of using different ragas as robust mood-inducing stimuli, which is relevant for studies on emotion. We also found that rhythmic regularity and tempo influence emotion experienced. Finally, one of the most interesting findings of our study was the association of the minor second with 'tensed' emotion. This is distinct from past work in Western classical music that has shown an association for the minor third with sadness in Western music (Curtis and Bharucha, 2010). Future work will attempt to extend these findings to larger population in order to delineate influences of culture, familiarity and musical training on emotion experienced.

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Supplementary Material

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2015.00513/abstract

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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