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PSYCHOLOGICAL ASPECTS OF (MICRO)INTERVALS OF THE JUST INTONATION SYSTEM

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***Abstract**: This study presents the results of research on the psychological aspects of exactly calculated just intonation intervals, which was performed in the form of a listening test. These micro-interval nuances (śruti) are attributed specific emotions or feelings in ancient Indian music-theoretical texts, just as in the European tradition, various extra-musical qualities have been attributed to different intervals or modes since the Antiquity. The purpose of the research was therefore to try to map the psychological aspects of the selected intervals and to verify whether the respondents agreed on them. In contrast to similar research testing tempered intervals, here we are dealing with precisely tuned concords of characteristic intervals of just intonation systems (5-limit and 7-limit just intonation), realized in the form of sustained drones. The results of this research show that listening to isolated sustained concords can induce a wide range of responses in the listener, which are identical or similar for a significant number of respondents. Moreover, in some cases, the reactions to a given interval/emotion combination coincide or resemble the characteristics given by Indian or European traditions. All the results of the research have been summarized in a table which can serve practical purposes.*

***Keywords:** just intonation, microintervals, drone music, La Monte Young, hindustani raga, shruti*

DOI:

1. GENERAL INTRODUCTION

In the ancient traditions of the high cultures of the West and East, the psychological effect of musical intervals or scales was often taken into account. It is well known that in ancient Greece very specific characteristics were attributed to individual modes, e.g. Plato in his writing The Republic (also "The Constitution", c. 370 BC) recommends the Doric mode for strengthening endurance (e.g. for a person engaged in war or forced trade), while the Phrygian mode was considered suitable for peaceful and conciliatory actions. However, he rejects the Mixolydian modes (considered wailing), Ionian (softening), and Lydian (considered having drinking character) as unsuitable for guardians of state and warriors [1]. Similarly, medieval theorists such as Guido of Arezzo (995–1050), Adam of Fulda (1445-1505) and Gioseffo Zarlino (1517–1590) attributed different characteristics to specific scales, and Baroque affect theory works with the emotional characteristics of particular keys [2, 3]. Similar approaches to modes (or specific maqams) can also be found in Arabic or Persian classical music, whose music theory follows the Greek scholars, including work with microintervals, which have disappeared in European music [4].

As for individual intervals, in the course of European musical history they have acquired a number of associations and connotations, which are mainly related to the degree of their consonance. This has been the subject of a number of studies, for example [5]. In a broad sense, it is a culturally conditioned, i.e. learned, phenomenon, but in this paper, we are primarily concerned with so-called sensory consonance (see below), which is innate and related to the degree of harmonicity of a given interval. The lower in the harmonic series a given interval occurs, the more harmonic and consonant it is (e.g., the perfect fifth and major third, and their inversions, are generally perceived as the most consonant intervals, as this research also confirms). These connotations can be found in the works of a number of authors, such as G. Galilei (1638), G. Tartini (1754), J. J. Rousseau (1782), S. Gervasoni (1800), P. Gianelli (1801), S. Castiglioni (1959), R. Steiner (1975) – see Table 1 below [6].

Far more systematic and detailed in this respect, however, is the theory of North Indian classical music. Unlike in Europe, in India different emotional connotations were also found for subtle micro-interval nuances, the so-called *śruti*, functioning on the principle of just intonation. Unfortunately, however, these principles are falling into oblivion even in India itself, mainly due to the growing popularity of tempered harmonium. The use of specific *śruti* in a given *raga* then helped to achieve its emotional effect on the listener (called *rasa*). For an explanation of the concept of raga, rasa and other principles of Indian classical music see [7, 8, 9]. For example, in the Sunset raga Marwa, associated with the aspect of death, the

interval of the lesser minor second 25/24 plays a crucial role, in contrast to the Sunrise ragas which deal with the greater version of the minor second 16/15, which is 41 cents higher (see Table 1), [10]. This subject has been dealt with in detail by the French musicologist and Indologist Alain Daniélou, who in his writings has provided a detailed overview of the śruti system as presented in the 13th-century Sagīta Ratnākara, including an explanation and derivation of the various microintervals [11, 20]. He also provides a detailed overview of the emotional characteristics of each microinterval (see Table 1).

It is clear that these emotional associations to individual harmonies can be culturally conditioned and subject to the listener's experience. In addition, for practical reasons, we have become accustomed to tempered tuning and its slightly out-of-tune intervals. These the human ear is known to tolerate and it is very practical in typical European music with frequent changes of harmonies and modulations. The subtle interval nuances are therefore usually not distinguished or not even noticed. Even so, musicians playing instruments with the possibility of influencing fine tuning tend to adjust to pure, natural (i.e. not tempered) intervals (e.g. string quartets or a capella singers). Even in blues, a genre that has influenced the entire history of Western popular music, performers work (more or less intuitively) with subtle intonation nuances. The fine shades of thirds and sevenths create here characteristic mood (which, by the way, is a principle very similar to the emotional states rasa in Indian ragas). However, there are musical styles (e.g. drone music) based on the precise tuning of the long-sustained harmonies, taking directly into consideration their psychological and psycho-physiological impacts. The term drone music, drone minimalism or simply drone is commonly used to describe a musical genre based on sustained tones and continuous sound, see for example [12]. In his work, the American composer La Monte Young (the legitimate grandfather of minimal music and drone) purposefully works with specific systems of just intonation, especially the so-called 7-limit just intonation (see below). He explains these principles of concords in terms of pitch perception theory (place and temporal theories of pitch perception, see [13]) as follows:

"The place theory of pitch identification postulates that each time the same frequency is repeated, it is received at the same fixed place on the basilar membrane and transmitted to the same fixed region in the cerebral cortex, presumably by the same fiber or neuron of the auditory nerve. The volley theory of pitch perception assumes that a sequence of electro-chemical impulses is sent travelling along specified neurons of the auditory nerve. (...) Current psychological research and the assumptions of place theory and volley theory suggest that when a specific set of harmonically related frequencies is continuous or repeated, as is often the case in my music, it could more definitively produce (or simulate) a psychological state since the set of harmonically related frequencies will continuously trigger a specific set of the auditory neurons which, in turn, will continuously perform the same operation of transmitting a periodic pattern of impulses to the corresponding set of fixed locations in the cerebral cortex." [14]

According to La Monte Young, a precisely tuned sustained concord can therefore create a very specific psychological response. Indeed, a number of researches and theories from the last decades show that distinguishing the degree of harmonicity of individual intervals is innate to human hearing. So-called "sensory consonance" is the innate ability of the middle and inner ear to distinguish harmonic consonances from non-harmonic ones. *"The universality of sensory consonance may be an emergent property of the nervous system. Indeed, theoretical models based on the phase locking of auditory nerve and midbrain suggest that a neural periodicity detection mechanism may form the basis of consonance and dissonance."* [15] This is a phenomenon independent of culture or musical training, as confirmed by perceptual tests of babies at 2 and 4 months of age, in which the ability to distinguish consonant and dissonant intervals has already been demonstrated (in this case, only fifths and octaves were involved) [16]. In addition, there is an interesting theory that our preference for harmonic tones and their combinations is partly due to their similarity to the spectrum of the human voice. Indeed, intervals that we perceive as consonant are particularly emphasized in the vocal spectrum. *"... our attraction to harmonic tones and tone combinations derives in part from their relative similarity to human vocalization. To the extent that our appreciation of tonal sounds has been shaped by the benefits of responding to conspecific vocalization, it follows that the more voice-like a tone combination is, the more we should "like" it. (...) Intervals we perceive as consonant are specifically emphasized in vocal spectra."* [17] In tempered tuning, on the other hand, there are continuous phase shifts between the wave nodes, and in addition, the so-called combination tones are also out of tune, so that disturbing interferences are created in the harmonics. In the words of La Monte Young: "Because the usual tuning of equal temperament is based on a half-step with a ratio of the 12th root of 2 to 1 (1.059463...:1), its ratios (the octave excepted) are all represented by nonrepeating decimals. Therefore, the amount of time it takes for the periodicity of an equal tempered interval to return to its original phase is theoretically infinite. This means that the ear can never truly measure the exactness of an equal tempered interval. More pertinently, an equal tempered interval does not stimulate a perfectly periodic impulse in the auditory nerve, because the phase relationship of the tones is never the same twice." [18]

From the above, it is obvious that different harmonies can provoke different responses, psychological states in the brain. But to what extent are these feelings individual and to what extent are they common, universally given? For isolated, fine-tuned sustained harmonies (drones), can responses to these intervals be meaningfully mapped in respondents?

Do listeners' reactions to individual microinterval shades of the same interval (e.g. lesser or greater versions of minor seconds, minor sixths etc.) differ in any way?

2. OBJECTIVES OF THE RESEARCH

The research entitled *Microintervals in just intonation systems and their psychological aspects* seeks to answer these questions. The research itself is a part of the T. Reindl's project *Microintervals of the Just Intonation System and their Psychological Aspects*, at the Academy of Performing Arts in Prague, 2021-2022. The listening test was prepared and evaluated in cooperation with the Research Centre of Musical Acoustics at the Academy of Performing Arts in Prague (RNDr. Marek Frič, Ph.D. and Mgr. MgA. Viktor Hruška, PhD. et Ph.D.). It builds on a previous online audio test, Ragas and Emotions, in which respondents were asked to rate their emotional responses to samples

of selected North Indian ragas containing characteristic śruti microintervals [19]. In order to isolate the psychological effect of the given intervals, it was necessary to test strictly the concordances themselves (in the form of sustained drones). This led to the development of a new online listening test, the results of which are the subject of this study.

The current research therefore aims to find out,

- whether the respondents agree in their ratings on the characteristics of the intervals tested, and if so, for which intervals/features,
- whether, at least in some cases, the respondents' ratings are close to the properties defined in the Indian tradition of śruti microintervals (eventually with the connotations attributed to individual intervals in the European tradition),
- whether respondents react differently to microinterval nuances of intervals of the same type, i.e. the following pairs:
  - lesser / greater minor second (*lm2* x *gm2*)
  - lesser / greater minor third (*lm3* x *gm3*)
  - lesser / greater minor sixth (*lm6* x *gm6*)
  - lesser / greater minor seventh (*lm7* x *gm7*)
- which of the characteristics the raters were unable to distinguish,
- whether it is possible to cluster respondents into groups with similar responses to the intervals,
- whether or not the ratings of professionals and amateurs differ.

3. TESTED INTERVALS (STIMULI)

A total of 15 intervals were selected for testing, thirteen of which come from the Indian śruti system, which was also the subject of previous research Ragas and emotions, and the remaining two are the basic intervals of the 7-limit system (see below). In other similarly tuned works, unlike our research, intervals of *even*-tempered tuning are usually used, and almost always in the form of repeatedly applied decaying concords (piano etc.), for example [17].

Let us now get familiar with the thirteen "Indian" intervals. These are a selection of the most important intervals of the just intonation system, familiar even in Europe (first defined by Claudius Ptolemy of Alexandria in the 2nd century A.D.). These intervals cover our usual ground of twelve semitones, while the two intervals (minor second and minor sixth) are here in two microtonal variations – the lesser and the greater. A list of these intervals, including their size in cents and the emotive aspects derived from Indian sources (Saṅgīta Ratnākara) is given in Tab. 1. For a complete list of all 22 śruti, including their names and emotional categories, see [20, 21]. In the second column are the names of the notes, with the fundamental note C (of course this is relative, not absolute tuning, i.e. the whole system can be freely shifted) and the traditional Indian solmization syllables (called sargam). A lowering of a given degree by a semitone is marked in the notation by underlining the solmization syllable (e.g. Re, Dha), and a rise by a semitone is marked by an apostrophe (e.g. Ma'). In the last column of the table, we also provide an overview of the most common European connotations of musical intervals, from the Baroque to the 20th century (as presented in the works of the above-mentioned authors), for comparison [6]. Here, however, no micro-interval nuances have traditionally been distinguished, so these features are common to both variants of the same tone. Note the fact that for some intervals the properties are consistent, (e.g. for the perfect fifth), while elsewhere they may even contradict each other, which in practice depends mainly on the context of use of the interval in question. Thus, for example, major second can have both "positive" and "negative" connotations (contradictory properties are marked in italics in Tab. 1).

Interval	Note (in C) / Solm. syllable	Ratio	Size in cents	Character – India	Europe
basic tone	C / Sa	1/1	0	–	–
lesser minor second	Db / Re	25/24	71	sad, pathetic	painful, uptight, afflicted, discouraged, humiliated
***greaterminor* second**	Db / Re	16/15	112	loving, amorous	
major second	D / Re	9/8	204	strong, confident	in suspense, tormented, sad, uptight, *eager, pleasant*
minor third	Eb / Ga	6/5	316	passionate	painful, severe, anguished, melancholic, *sweet, frank, still*
major third (natural)	E / Ga	5/4	386	calm, pleasing	joyous, furious, strong, pleasant, happy, right, pure, quiet, stable, shining
perfect fourth	F / Ma	4/3	498	moonlight, peaceful	lugubrious, active, tense
augmented fourth	F# / Ma'	45/32	590	uncertain, doubtful	hostile, averse, destructive, mysterious
perfect fifth	G / Pa	3/2	702	sunlight, joyful	pleasurable, stimulating, gentle, healthy
lesser minor sixth	Ab / Dha	25/16	773	deep sorrow, sadness	painful, discontented, strained, distressing, unstable *pleasant, active*
greater *minorsixth*	Ab / Dha	8/5	814	loving, enterprising	
major sixth	A / Dha	5/3	884	soft, calm	pleasant, sweet, desirous, bright, *unstable, tense*
minor seventh	Bb / Ni	9/5	1018	desirable, wistful, anxious	sad, painful, melancholic, severe, strained, unsatisfied
major seventh (natural)	Ni	15/8	1088	soft, voluptuous	tense, bitter, disagreeable, gloomy, *optimistic*
octave	Sa	2/1	1200	–	–

Tab.1: A selection of the most important intervals of the śruti system

4. INTERVALS OF 7-LIMIT SYSTEM

In addition to the abovementioned intervals (all of which fall into the most common natural tuning system known as 5-limit), the test also used two essential intervals of the 7-limit just intonation system (so called septimal intervals), which are rather rarely found in Indian ragas but are the basis of the drone music of the aforementioned La Monte Young and his followers. These are the lesser minor seventh 7/4, and the lesser minor third 7/6.

In contrast to the 5-limit system, the 7-limit includes interval ratios derived from the prime number 7. The lesser minor seventh 7/4 (so-called septimal minor seventh, i.e. the seventh note of the overtone series) is the key interval here, which is 31 cents lower than the tempered minor seventh (and thus 49 cents lower than the greater minor seventh 9/5). This interval is rarely used in common musical practice, even though, from accoustical point of view, it is a pure consonance. Other typical septimal intervals here are minor third 7/6 (-29c) and tritone 7/5 (-17c). Tuning systems with a higher prime base,

such as 11-limit, 13-limit, etc., are based on a similar principle [22]. These septimal intervals are found in American blues, an important feature of which are the so-called blue notes, whose characteristic "undertone" intonation, including the characteristic glissandos, creates a typical mood. Another typical example are the American vocal 'barbershop quartets', with their typical dominant seventh chords with a low harmonic seventh (7/4) [23].

In the listening test, the augmented fourth (tritone) was also used in its septimal form, i.e., the 7/5 ratio (-17c, i.e., 7c lower than the tritone listed in the śruti list), which is the purest variant of this interval (we can find the interval in the overtone series between the 5th and 7th harmonics).

In addition, a pure octave recording was used in the test to serve as a sound divider between the stimuli.

Thus, we present the complete set of all fifteen stimuli used in the listening test (including their deviations from equal temperature and the identifiers we use later in the text) in Table 2.

The stimuli for the listening test were recorded as two-minute drones (sustained concords). All intervals refer to a single fundamental tone, which corresponds to the modal nature of Indian music with the omnipresent reference drone Sa, traditionally played on the instrument tampura. In our test, a C3 was chosen as the fundamental tone, gently supported by the lower octave (C4).

The initial sound of the stimuli was created in the virtual instrument Wavetable (within Ableton Live software) from the spectrum of an electric piano. Since these are complex (not sine) tones, to which a subtle reverb is added, it is evident that combinational tones and interference are also produced. However, the resulting sound (as opposed to dry sine waveforms, which sound very sterile) is more pleasant to listen to. In order for the listener to properly immerse himself in the interval, he was asked in the test interface to let each interval affect him for at least one minute. In addition, repeated playback of the stimuli was also possible.

No.	Interval	Ratio	Deviation from EDO (cents)	Stimulus identifier
0	octave (the divider)	2/1	0	Oct
1	lesser minor second	25/24	-29	lm2
2	greater minor second	16/15	+12	gm2
3	(greater) major second	9/8	+4	M2
4	lesser (septimal) minor third	7/6	-29	lm3
5	minor third (natural)	6/5	+16	gm3
6	major third (natural)	5/4	-14	M3
7	perfect fourth	4/3	-2	p4
8	augmented fourth (septimal tritone)	7/6	-17	aug4
9	perfect fifth	3/2	+2	p5
10	lesser minor sixth	25/16	-27	lm6
11	greater minor sixth	8/5	+14	gm6
12	majorsixth	5/3	-16	M6
13	lesser (septimal) minor seventh (harmonic)	7/4	-31	lm7
14	greater minor seventh	9/5	+18	gm7
15	major seventh (natural)	15/8	-12	M7

Table 2: List of stimuli used in the audio test

5. RESEARCH METHODS

The basic research tool was therefore an online listening test that was sent to potential respondents. After debugging and testing the Czech version of the test, an English version was finally created. At the beginning of the test, respondents are asked whether they are music professionals or not. The following are technical listening instructions, volume settings. Then comes the evaluation of the individual intervals, the order of which was randomly generated in the test. Each stimulus is given a separate screen with rating scales in the form of sliders. The next stimulus can only be moved to after all scales have been rated, and the respondent is also asked to listen to an octave divider.

The method of bipolar rating scales (so-called semantic differential) was used for the evaluation [6]. We have drawn on a wide range of parameters used in other music psychological research, but we have also taken inspiration from the traditional Indian emotional categories rasa [8]. After selection and trial control evaluation while listening to the stimuli, the following set of seven pairs of polarized emotions was selected:

1. restless – calm
2. sadness – joy
3. darkness – light
4. tightness – openness
5. weight – lightness
6. lowness, smallness – nobility, sacredness
7. masculinity – femininity

The total range of the scales in the test was 100 degrees, i.e., 50 on each side of the center of the scale (i.e., zero in the middle of the scale). Below the rating scales, there was always an "Other Response" box for additional, optional individual responses and comments.

To process the data, standard statistical methods were first used to determine the level of consistency between raters for each interval/emotion combination. This involved calculating the average value of each combination of a given interval and a particular emotion, followed by creating a graphical representation of the ratings in the form of a histogram, in which the average value was plotted as a vertical bold line. The perpendicular horizontal dashed line then indicates the so-called interquartile range (i.e., the difference between the so-called 25^{th} percentile and the 75^{th} percentile), for more details see [24]. The smaller the range, the better the agreement in the ratings of the given parameter. In practice, this means that half of all raters fit within this interval. These quartiles do not necessarily have to be symmetrical around the mean, as can be seen, for example, in the lm2 – restless/calm graph (see Fig. 1). This created a sort of "main stream" of the data that was subsequently analyzed.

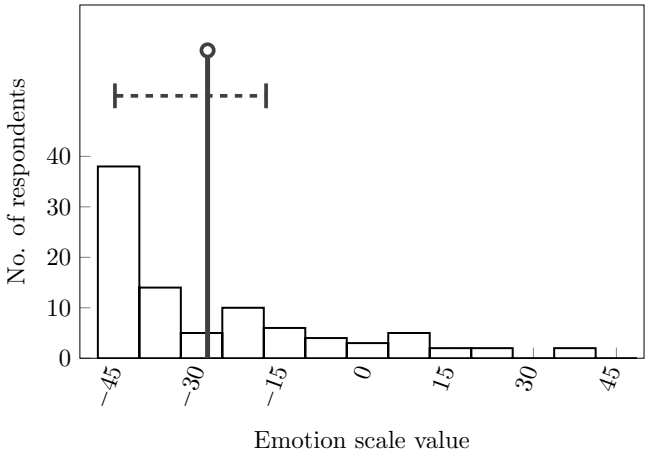


Fig. 1: lm2 – restless/calm

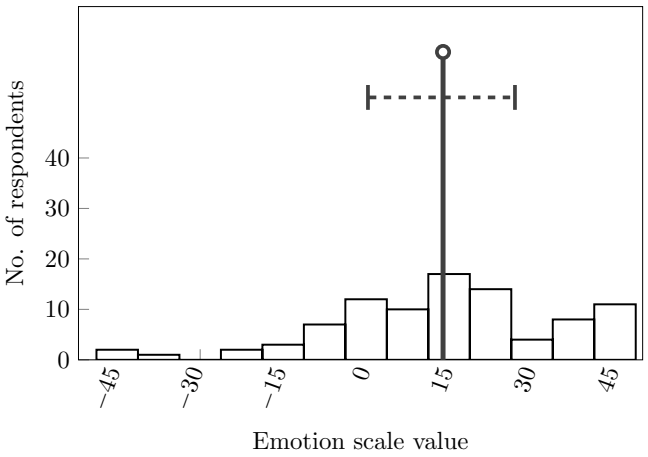


Fig. 2: M6 – darkness/light

In the second wave, the data were analysed in more detail using the DBSCAN (density-based spatial clustering of applications with noise) clustering method [25]. Using this technique, groups with different evaluation tendencies were separated, for which histograms were again generated, showing the mean values with interquartile ranges. The data obtained in this way was then subjected to analysis, which allowed to reveal some additional relationships in the evaluation.

The individual reactions of the listeners, recorded in the form of optional notes at individual intervals, also provided interesting insights. We consider them (in addition to the evaluated data) also very valuable, as they verbally capture the momentary emotional state of the respondents, who wrote these comments out of an urgent need to express other feelings arising while listening to a given interval.

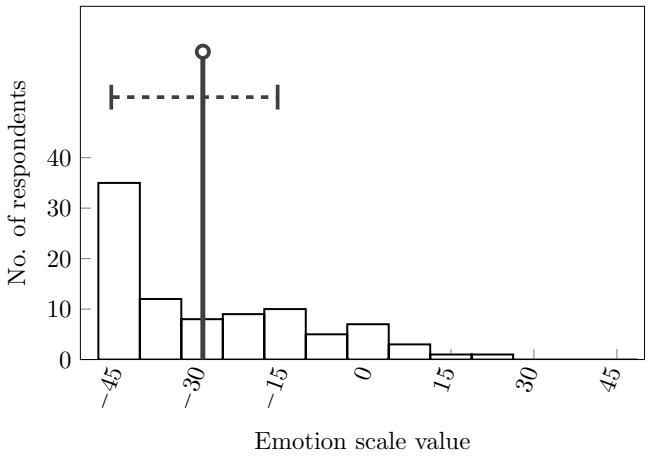


Fig. 3: lm2 – tightness/openness

6. TEST RESULTS

A total of 93 respondents, 35 professionals and 58 non-professionals, took part in the Czech version of the listening test. Out of the total number, only 5 respondents took the English version of the test, so due to the low number, no comparison of the results of the language versions was made.

From the total data, it was first necessary to select a sufficient number of interpretable cases, as too much variance was observed in the responses for some interval characteristics, hence, the statistics of some cases was inconclusive. Therefore, the data were analyzed and according to the graphs, all interval/feature combinations that fit the following criteria were selected:

a) mean value at least 15 away from the scale center – the neutral zero (31 cases in total), e.g. *M6 – darkness/light* (see Fig. 2)

b) from the previous group, the cases with the largest deviation were then selected, where the mean additionally exceeded the value of 25 (7 cases in total), e.g. *lm3 – tightness/openness* (Fig. 3)

c) the smallest interquartile range, i.e. they had the best consistency (19 cases), e.g. *lm7 – masculinity/femininity* (Fig. 4)

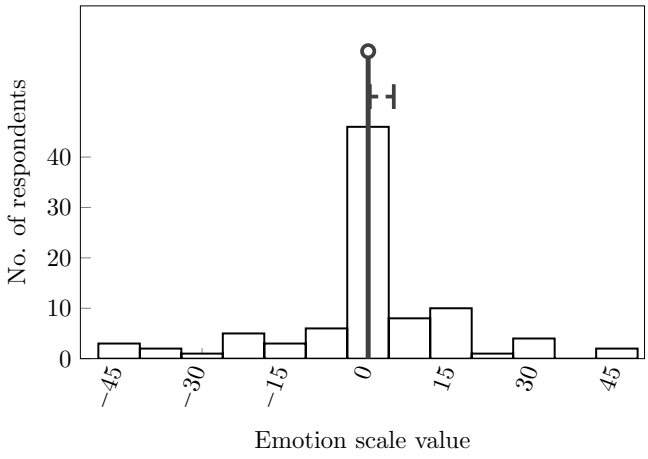


Fig. 4: lm7 – masculinity/femininity

Cases (a) and (b), where the distance of the mean value from zero was at least 15 (or at least 25), indicate that the respondents perceived the characteristic in the interval and agreed on it in sufficient numbers. Cases (c) have the best agreement (lowest variance in ratings) for each characteristic, but their mean value lies closer to the middle of the scale or right in the middle (i.e. zero), indicating that respondents agreed that

they felt the characteristic in the interval to a lesser extent (or not at all).

For the sake of comparison, let us also give an example where the agreement was the smallest, i.e. the largest data variance, e.g. *M2 – restless/calm* (Fig. 5).

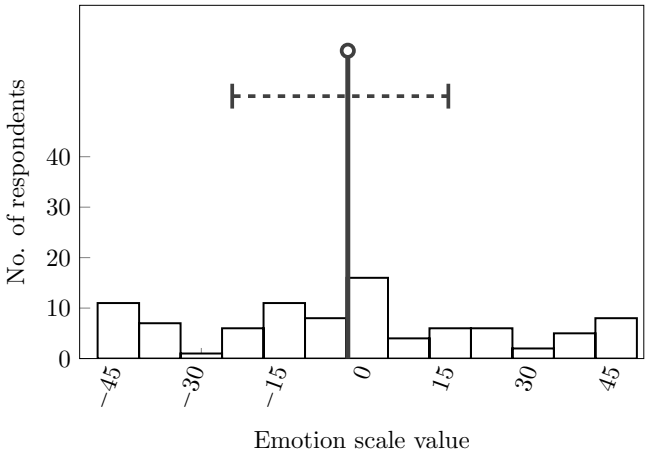


Fig. 5: M2 – restless/calm

Tab. 3 clearly shows all three types of agreement in the evaluation of individual intervals and their properties (where intervals/features with a bias greater than 25 also satisfy the condition of having a bias greater than 15).

No.	Stimulus identifier	restless – calm	sadness – joy	darkness – light	Tightness – openness	weight – lightness	lowness – nobility	masculinity – femininity
1	lm2	>25	>15	>15	>25	>25	>15	>15, A
2	gm2	>25	>15	>15	>25	>25		
3	M2		A	A				
4	lm3		>15					A
5	gm3		>15					A
6	M3	>15	A					A
7	p4		A					A
8	aug4	>15	>15		>15	>15		A
9	p5	>25	A	>15	>15		>15	A
10	lm6	>15	>15		>15	>15		
11	gm6		>15					A
12	M6			>15, A				
13	lm7	>15	A		>15			A
14	gm7		A					A
15	M7	>15						A

Tab. 3: Summary of agreement in interval/feature ratings. A – greatest agreement (lightest shadow), >15 – mean deviation from zero of at least 15 (medium dark shadow), >25 – mean deviation from zero of at least 25 (darkest shadow)

In Tab. 4 we see all intervals/features for which the mean was at least 25 away from zero. The last column then shows the agreement or disagreement of a given rating result with the Indian (or European) connotations listed above in Tab. 1.

Interval	Feature	Value	Correspondence with the traditional concept of interval: I – India, E – Europe (see Table 1)
lm2	restless/calm	significantly left (restless)	I: sadness, despair E (minor second in general): painful, uptight, afflicted, disgusted, humiliated
lm2	tightness/openness	significantly left (tightness)	
lm2	weight/lightness	significantly left (weight)	
gm2	restless/calm	significantly left (restless)	I: erotic, amorous (does not correspond) E (minor second in general): painful, uptight, afflicted, disgusted, humiliated
gm2	tightness/openness	significantly left (tightness)	
gm2	weight/lightness	significantly left (weight)	
p5	restless/calm	significantly to the right (calm)	I: sunlight, joy, activity E: pleasant, stimulating, gentle, healthy

Tab. 4: Deviations in the evaluation >25

In the following Tab. 5 we see all the intervals/features for which the deviation of the mean was smaller (i.e. by at least 15). Here again we see correspondence with both Indian and European traditional conceptions of the interval in question. The table does not repeat cases that also fit the previous 'higher' condition (i.e. >25).

Interval	Featuere	Value	Correspondence with the traditional concept of interval: I – India, E – Europe (see Table 1)
lm2	lowness/nobility	left (low)	I: sadness, despair E: (minor second in general): painful, uptight, afflicted, disgusted, humiliated
lm2	sadness/joy	left (sadness)	
lm2	darkness/light	left (dark)	
gm2	sadness/joy	left (sadness)	I: erotic, amorous (does not correspond) E (minor second in general): painful, uptight, afflicted, disgusted, humiliated
gm2	darkness/light	left (dark)	
lm3	sadness/joy	left (sadness)	I: has no traditional connotations (7-limit interval) An interval typical of the blues genre [26] (the mood of the blues is often defined as a specific kind of sadness).
gm3	sadness/joy	left (sadness)	I: passionate E: painful, heavy, anguished, melancholic, sweet, sincere, calm
M3	restless/calm	right (calm)	I: calm, pleasant E: joyful, strong, cheerful, pleasant, happy, correct, pure, calm, stable, radiant
aug4	restless/calm	left (restless)	I: uncertain, emotional E: hostile, rejecting, destructive, mysterious
aug4	sadness/joy	left (sadness)	
aug4	tightness/openness	left (tightness)	
aug4	weight/lightness	left (weight)	
p5	lowness/nobility	right (nobility)	I: sunlight, joy, activity E: pleasant, stimulating, gentle, healthy
p5	tightness/openness	right (open)	
p5	darkness/light	right (light)	
lm6	restless/calm	left (restless)	I: deep regret, deep sorrow E (lowercase sixth in general): painful, dissatisfied, tense, distressed, unstable, *pleasant, active*
lm6	sadness/joy	left (sadness)	
lm6	tightness/openness	left (tightness)	
lm6	weight/lightness	left (weight)	
gm6	sadness/joy	left (sadness)	I: amorous, pioneering, enterprising E (lowercase sixth in general): painful, dissatisfied, tense, distressed, unstable, *pleasant, active*
M6	darkness/light	right (light)	Ind.: softness, calmness E: pleasant, sweet, wistful, bright, unstable, tense
lm7	restless/calm	left (restless)	I: has no traditional connotations (7-limit interval) E (minor seventh in general): sad, painful, melancholic, heavy, tense, dissatisfied
lm7	tightness/openness	left (tightness)	
M7	restless/calm	left (restless)	I: soft, pleasant (does not correspond) E: tense, bitter, unpleasant, gloomy, *optimistic*

Tab. 5: Deviations in the evaluation >15

Tab. 6 shows the cases of maximum agreement in the ratings that did not fulfill the previous conditions of deviation from zero (deviation less than 15). Often there was a significant maximum of the histogram in the area of the middle of the rating scale (i.e., around the value "0"), which indicates agreement on the neutrality of the given characteristic. Here, however, one should also take into account the fact that a slider located in the middle of the scale may also indicate the respondent's inability to recognize any emotion in the interval (see Fig. 4).

Interval	Feature	Value	Correspondence with the traditional concept of interval: I – India, E – Europe (see Table 1)
lm2	masculinity/femininity	slightly left (masculinity)	I: sadness, despair E: (minor second in general): painful, uptight, afflicted, disgusted, humiliated
M2	sadness/joy	centre	I: sadness, despair E: tense, distressed, sad, uptight, *eager, pleasant*
M2	darkness/light	centre	
lm3	masculinity/femininity	slightly left (masculinity)	Interval typical of the blues genre
gm3	masculinity/femininity	centre	I: passionate E: painful, heavy, anguished, melancholic, *sweet, sincere, calm*
M3	masculinity/femininity	centre	I: calm, pleasant E: joyful, strong, cheerful, pleasant, happy, correct, pure, calm, stable, radiant
M3	sadness/joy	slightly right (joy)	
p4	masculinity/femininity	centre	I: moonlight, stillness, passivity E: sad, active, tense
p4	sadness/joy	slightly right (joy)	
zv4	masculinity/femininity	slightly left (masculinity)	I: uncertain, emotional E: hostile, rejecting, destructive, mysterious
p5	masculinity/femininity	slightly right (femininity)	I: sunlight, joy, activity E: pleasant, stimulating, gentle, healthy
p5	sadness/joy	slightly right (joy)	
gm6	masculinity/femininity	Centre	I: amorous, enterprising E: painful, dissatisfied, tense, distressed, volatile, *pleasant, active*
M6	masculinity/femininity	slightly right (femininity)	I: softness, calmness E: pleasant, sweet, wistful, bright, volatile, tense
lm7	masculinity/femininity	Centre	I: has no traditional connotations E (minor seventh in general): sad, painful, melancholic, heavy, tense, dissatisfied
lm7	sadness/joy	slightly left (sadness)	
gm7	masculinity/femininity	Centre	I: desire, eroticism, anxiety E (minor seventh in general): sad, painful, melancholic, heavy, tense, dissatisfied
gm7	sadness/joy	slightly left (sadness)	
M7	masculinity/femininity	Centre	I: soft, pleasant E: tense, bitter, unpleasant, gloomy, *optimistic*

Tab. 6: Best matches in the evaluation (regardless of bias)

In contrast, the lowest consistency (i.e., the greatest variance of rating data) was achieved primarily for the following intervals/features: *M2 – restless/calm*, *lm3 – lowness/nobility, M6 – restless/calm*, *M6 – tightness/openness*. In the graph of *M2 – restless/calm* (Fig. 5), it can be seen how the data in the histogram is distributed almost evenly across the entire rating scale, there is no significant maximum.

7. SEPARATION OF GROUPS OF RESPONDENTS WITH SIMILAR TENDENCIES BY THE CLUSTERING METHOD

When the graphs were evaluated, it became apparent that in cases where the distribution of respondents' answers has more than one distinct peak, the arithmetic mean does not have a good descriptive value for the feature. In such cases, the DBSCAN cluster separation method mentioned above proved useful, detecting three groups (clusters) with different rating tendencies (i.e. similar responses to the intervals). Thus, we were able to capture a significant fraction of the minor histogram peaks into one of the auxiliary clusters. Essentially, there is one main stream of raters and two smaller clusters with different tendencies. A total of 65 % of the respondents fall into these three clusters, while the remaining 35 % have a larger, harder-to-capture variance and thus represent a kind of "noise". The different interval/emotion combinations were again displayed as a histogram with three distinct vertical lines indicating the mean values:

1. Group 1 (hereafter G1, mean value in black): 49 respondents (54%)
2. Group 2 (G2, mean value in dark grey): 5 respondents (5.5%)
3. Group 3 (G3, mean value in light grey): 5 respondents (5.5%)

The principle can be clearly seen in the graph *M3 – restless/calm* (Fig. 6), where the histogram has 2 peaks, with the mean value (vertical line) indicating the overall average. However, its peak is at the point where, paradoxically, there are not many ratings in the histogram. But the remaining two marked mean values for groups G2 and G3 correspond correctly to the histogram peaks, with G2 having the smallest interquartile range, so there is the greatest agreement. Thus, the graph shows that for group G2 the interval is very quiet, while for G3 it is neutral. Adjectives associated with the qualities being evaluated are italicized in the text (*e.g. calm, low, masculine* etc.).

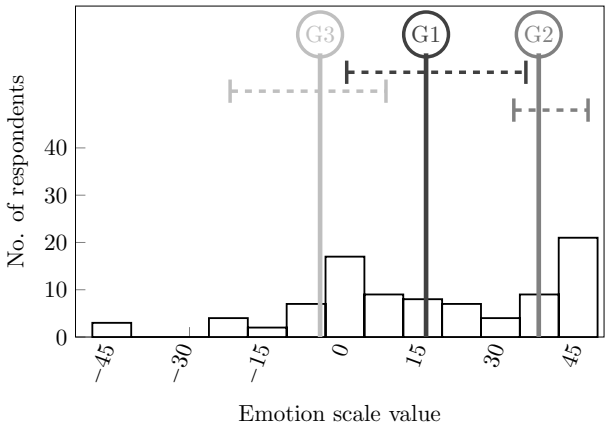


Fig 6: M3 – restless/calm (DBSCAN)

Groups G2 and G3 are often distinct from the mainstream G1 raters, and the values of these groups are often polarized, i.e., they use the extremes of the rating scale. Regarding the ratio of professionals to non-professionals, the G2 group contained 2 professionals and 3 non-professionals, while the G3 group contained only one professional and 4 non-professionals.

Let us now give some of the most striking examples of the different ratings of these groups.

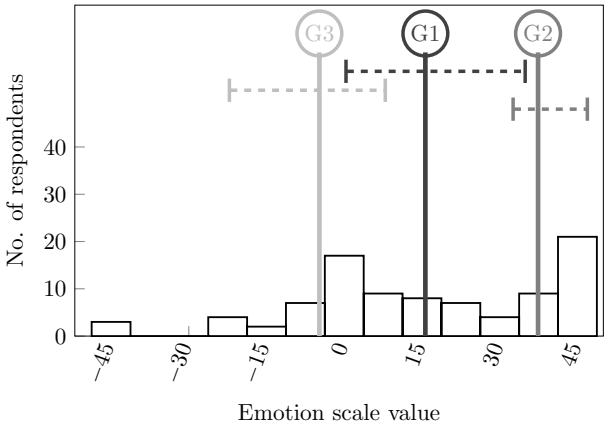
The interval feature *restless/calm:*

- The p5 interval is rated by the G2 group as maximally *calm*, while for G3 this feature is *neutral*, G1 lies in the middle, between these groups,
- *lm3* is a very *restless* interval for G2, while it is slightly *restless* for G3 and *neutra*l for G1.

Lowness/nobility:

The p4 and p5 are perceived by the G2 group as strongly noble intervals, while the other groups rate them only as slightly noble (see Fig. 7), the graph also shows that the G2 group has

a very narrow interquartile range, i.e. a very good agreement between the raters.



Masculinity/femininity:

The intervals that G2 and G3 raters jointly marked slightly towards the male pole are mainly *M2* (most significantly), *gm2, M7, lm2, and very slightly lm3*. Then

- gm3, lm6 – were perceived by the G3 group as slightly *masculine* (for the others they are *neutral*),
- lm7 – was slightly *masculine* for G2 (*neutral* for others),
- M6 – one of the few cases where the interval is perceived as (slightly) *feminine*, and that only for group G2.

However, it is interesting to observe how the perception of microinterval nuances varies between groups. Let us then compare the ratings for pairs of microinterval variants of the same interval (selecting only those features for which the groups differ in their ratings):

Minor seconds lm2 and gm2*:*

All the features are rated more or less the same for both intervals, with only a small difference for *lowness/nobility* and *darkness/light*:

- *Lowness/nobility* – for *lm2* there is more consistency, all groups perceive *lowness* in the interval, while for *gm2* only group G2 perceives *lowness* significantly, while G3 is closer to zero,
- *darkness/light – lm2* is very *dark* for both G2 and G3, while *gm2* is very *dark* only for G2, and only slightly *dark* for G3 (Fig. 8).

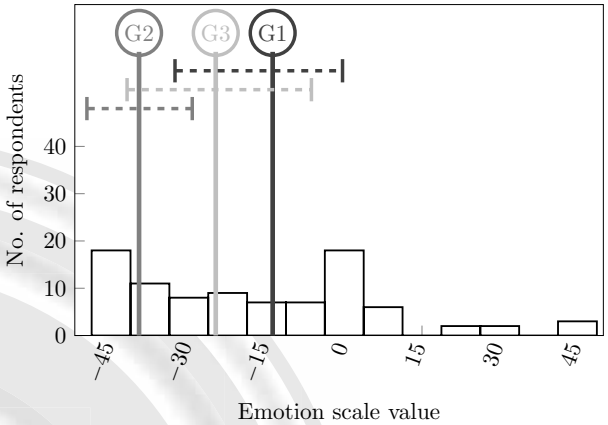


Fig. 8: gm2 – darkness/light (DBSCAN)

Minor thirds– differences:

- *Restless/calm: lm3* is the *restless* interval for G2 (most) and G3, while *gm3* is *neutral* for all groups,
- *lowness/nobility*: for *lm3*, G2 (strongly) and G3 (slightly) perceive lowness, for *gm3* only *G2* perceives *lowness* moderately, while G1 and G3 are slightly off the centre towards *nobility*,
- *sadness/joy*: G2 perceives more polarized *sadness* in *lm3* than others,
- *tightness/openness: lm3* shows more *tightness* for G2.

Minor sixths:

- *Restless/calm:* for lm6 there is (compared to gm6) a greater consensus of all groups towards *restless*,
- *lowness/nobility:* G2 perceives more *lowness* in lm6, while G3 perceives *lowness* in gm6,
- *tightness/openness:* for G3, lm6 is *tighter* than gm6,
- *weight/lightness:* for G2, gm6 is *heavier* than lm6 (the opposite of what we would expect), but the mainstream perceives G1 as *heavier* than lm6.

Minor sevenths:

- *Masculinity/femininity:* for G2, lm7 is slightly more *masculine* than *gm7*,
- *restless/calm:* for G2 and G3, lm7 is more *restless* than *gm7* (see Fig. 9a and 9b),
- *lowness/nobility:* the G3 group perceives intense *lowness* in *lm7* compared to *gm7*, the G2 group, on the other hand, perceives moderate *nobility* in *gm7*,
- *sadness/joy:* G3 perceives more *sadness* in *lm7*, G2 perceives moderate *joy* in *gm7*,
- *tightness/openness:* G3 perceives strong *tightness* in *lm7*, G2 perceives *openness* in *gm7* (see Figures 10a and 10b),
- *weight/lightness:* the G3 perceives more *weight* in the lm7,
- *darkness/light:* G2 perceives slight *darkness* in *lm7*, while in *gm7 light*.

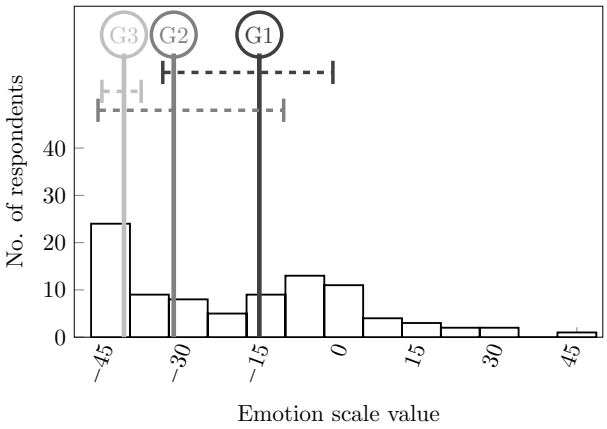


Fig. 9a: lm7 – restless/calm (DBSCAN)

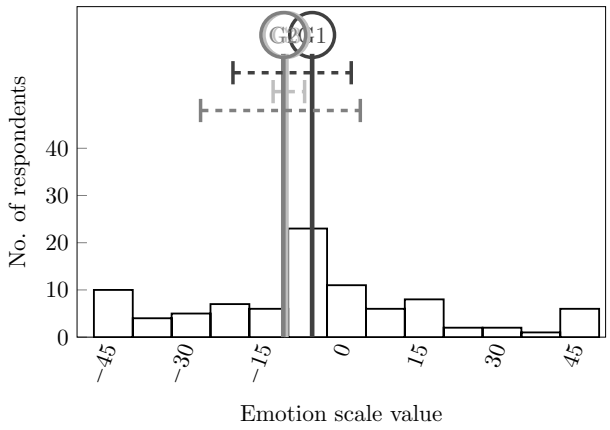


Fig. 9b: gm7 – restless/calm (DBSCAN)

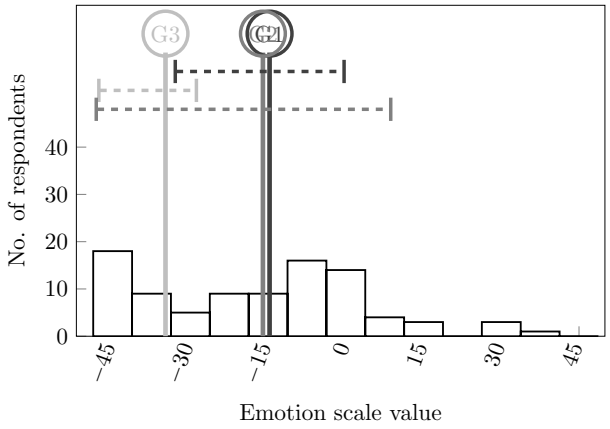


Fig. 10a: lm7 – tightness/openness (DBSCAN)

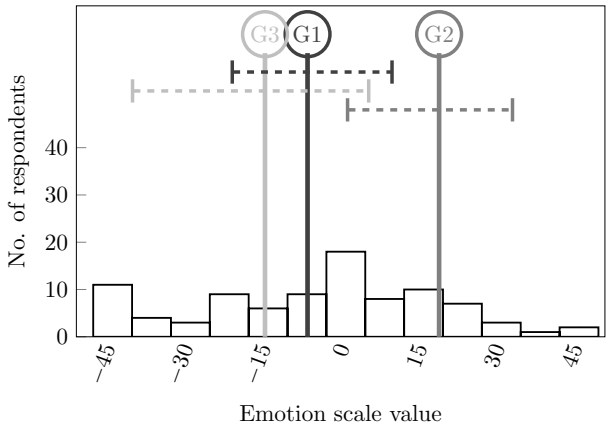


Fig. 10b: gm7 – tightness /openness (DBSCAN)

8. DATA INTERPRETATION

A summary of all relevant results of the evaluation of the emotional aspects of the intervals is shown in Tab. 7:

1. General (common) "rough" assessment corresponding to Tab. 3. For each feature, there is only one indication, either an arrow or a zero (see below),
2. separate evaluation of individual groups – cases where the cluster analysis has led to differentiation of individual groups (marked by the letter G with the group number and arrows). Thus, we can see different reactions for a single feature. These data are especially interesting in the case of microinterval nuances.

No.	*Stimulus identifier*	*restless – calm*	*sadness – joy*	*darkness – light*	*tightness – openness*	*weight – lightness*	*lowness – nobility*	*masculinity – femininity*
1	lm2	<<<	<< **G2: <<**	<< **G3: <<**	<<<	<<<	<< **G3: <<**	<
2	gm2	<<<	<< **G2: <**	<< **G3: <**	<<<	<<<	<< **G3: <**	<
3	M2	G1: < G2: << G3: <<	G1,2: 0 G3: <	G1,2: 0 G3: <	G1,2: 0 G3: <<	G1: 0 G2: < G3: <<	G1,2: 0 G3: <	G1: < G2: << G3: <<
4	lm3	G1: 0 **G2: << G3: <**	G1,3: < **G2: <<<**	**G1: <** **G2: <<<** G3: <<	G1: < **G2: <<<** G3: <<	G1: < **G2: <<<** G3: <<	**G1: 0** **G2: <<<** **G3: <<**	G1: 0 G2,3: <
5	gm3	**G1,2,3: 0**	G1,3: < **G2: <<**	**G1: 0** **G2: <<** G3: <<	G1: < **G2: <<** G3: <<	G1: < **G2: <<** G3: <<	**G1,3: >** **G2: <**	G1: 0 G2,3: <
6	M3	G1: >> G2: >>> G3: 0	G1,2: > G3: 0	>>	G1,2: >> G3: <	G1: > G2: 0 G3: <	G1,3: > G2: >>	G1: 0 G2,3: <
7	p4	G3: 0 G1,2: >	G1: > G2,3: 0	G1,G2: > G3: 0	G1: > G2: >> G3: 0	G1,2: > G3: <	G1,2: > G2: >>	0
8	aug4	G1: < G2: <<< G3: <<	G1: < G2: <<< G3: <<	G1: < G2: << G3: <	G1: << G2: <<< G3: <<	G1: < G2: <<< G3: <<	G1: 0 G2: << G3: <<	0
		restless – calm	*sadness – joy*	*darkness – light*	*tightness – openness*	*weight – lightness*	*lowness – nobility*	*masculinity – femininity*
No.	*Stimulus identifier*	*restless – calm*	*sadness – joy*	*darkness – light*	*tightness – openness*	*weight – lightness*	*lowness – nobility*	*masculinity – femininity*
9	p5	G1: >> G2: >>> G3: >	>	G1,2: >> G3: >	G1,2: >> G3: 0	G1,2: >> G3: 0	G1: >> G2: >>> G3: >>	>
10	lm6	**G1: <** G2: << **G3: <<**	<< **G2,3: <<**	G1: 0 **G2,3: <**	**G1: <** G2: << **G3: <<**	**G1: <** G2: << **G3: <<**	G1: < **G2: <<** G3: <<	0
11	gm6	**G1: 0** G2: << **G3: <**	<< **G2: <<<** G3: <<	G1: 0 **G2: <<** G3: <	**G1: 0** G2: << **G3: <**	**G1: 0** G2: << **G3: <**	**G2: 0** G3: <<	0
12	M6	G1: 0 G2: >> G3: >	G1,3: > G2: >>	>>	G1: 0 G2: >> G3: >	G1: > G2,3: >>	G1,3: > G2: >>	>
13	lm7	**G1: <** **G2: <<** **G3: <<<**	G1,2: 0 **G3: <**	G1: > **G2: <** G3: 0	<< G1,2: < **G3: <<**	G1,2: 0 **G3: <<**	G1,2: 0 G3: <<	**G1,3: >** G2: <
14	gm7	**G1: 0** **G2,3: <**	G1,3: 0 **G2: >**	G1: > **G2: >>** G3: 0	G1,3: < **G2: >>**	G1,3: 0 **G2: >**	G1: 0 G2: > G3: <	**G1: 0** **G2,3: <**
15	M7	G1,2: < G3: <<<	G1: 0 G2,3: <<	G1: > G2: 0 G3: <	<<	G1: 0 G2,3: <	G1: 0 G2,3: <	G1: 0 G2,3: <<
		restless – calm	*sadness – joy*	*darkness – light*	*tightness – openness*	*weight – lightness*	*lowness – nobility*	*masculinity – femininity*

Tab. 7: Resulting summary evaluation of the emotional aspects of the intervals

Markings in the table:

- arrows to the left "<<<" indicate a negative value of the scalar pair (e.g. *restless*), arrows to the right ">>>" indicate a positive value (e.g. *calmness*):
  a) one arrow – the feature was perceived slightly,
  b) two arrows – the feature was perceived to a medium degree,
  c) three arrows – the feature was perceived to the maximum extent,
  d) 0 – feature not perceived,
- individual groups are marked G1, G2, G3, followed by an arrow (e.g. "G1: <" indicates a slightly negative value perceived by group G1, "G3: >>>" indicates a strong positive value perceived by group G3),
- cases where the perception of micro-interval nuances by the separated groups was different are marked in bold,
- for comparison with the matches and deviations in Tab. 3 of the general assessment (>15, >25, A), the shading of the cells is maintained in the table. Thus, white boxes generally represent properties with larger data variance, i.e. with less precision.

Here is an example of how to interpret the interval features from the table:

For example, the perfect fifth *p5* was perceived as *calm* (in medium degree for G1, maximal for G2, slightly for G3), slightly *joyful* (for all raters), *light* (medium for G1 and G2, slightly for G3), medium *open* (but neutral for G3), medium *light* (neutral for G3), considerably *noble* (medium for G1 and G3, maximal for G2), and slightly *feminine* for all raters.

9. DISCUSSION OVER THE RESULTS

Let us now look at each interval in turn and compare the features found with the traditional Indian and European conception of these intervals.

In the general evaluation, the **minor second** interval received the highest number of agreements. Respondents strongly coincide in their general evaluation of this interval as evoking *restless*, *tightness*, *weight*, *sadness* and *darkness*, which corresponds to the traditional Indian characterisation of the lesser minor second interval (*sad, pathetic*). This is apparently also due to the fact that in Europe the minor second has long been considered the most dissonant interval.

In the case of **the major second**, there was good agreement for the features *sadness* and *darkness*, both emotions were felt slightly in the negative direction or at zero. Furthermore, there are tendencies towards *restless, tightness, weight, lowness* and *masculine* aspect in G2, G3. This corresponds more with the European tendency to perceive this interval as dissonance.

For the **minor third**, only *sadness* had a more significant value in the overall assessment, and it was the same for both its nuances. However, cluster analysis revealed more detailed responses for both variants of this interval (see below).

The **major third** is confirmed to be perceived as a *calm* and *joyful* interval, which corresponds to both Indian and European traditions. Some evaluators then also perceived *openness*, *lightness* and *nobility* here.

Perfect fourth – here, more interesting results emerged after cluster separation (in the general evaluation, respondents did not agree on any emotional features). Separated groups here perceived *calmness, joy, lightness* to a small extent. More strongly, *openness* and *nobility.* However, the G3 group (in contrast to others) *fel*t a *slight weight*. (Indian connotations of the interval are: *moonlight, peaceful*)

The tritone (augmented fourth) was confirmed as a truly dramatic interval, and from the beginning there was a good general agreement in the perception of restless, *sadness*, *tightness* and *weight*.

There is also a great deal of unambiguity in the **perfect fifth** in the *assessment of calm*, *light*, *openness* and *nobility*, which corresponds to the conception of the fifth as the most consonant (indeed, in the Middle Ages, *sacred*) interval. There is also a slight perception of *joy*, and this is one of the few intervals where the *feminine* aspect is present to a small extent.

The minor sixth (like the minor second) was rated as *restless*, *sad*, *tight* and *heavy*, but only in its lower lm6 variant. The greater minor sixth *gm6* was rated only as *sad*, which, although not consistent with Indian tradition, confirms the different (and more intense) emotional impact of the lesser variant (*śruti*) of this interval. Sensitivity to these nuances became much more pronounced after selection of groups with different rating tendencies (see below).

Major sixth – here, in the mainstream evaluation, respondents only significantly agreed on the *feeling of light*, and only to a moderate degree. The separated groups here, however, also felt additionally *calm*, *joy*, *openness*, *lightness*, *nobility* and *masculinity*, some in mild, others in medium degrees (see Tab. 7), which corresponds to the Indian conception as well as to the positive part of the European aspects.

In the case of the **minor sevenths**, there was a high agreement in the general assessment on the features of *restless* and *tightness* (*at lm7*), and there was also good consensus on *sadness* (slightly left) and *masculinity* (neutral), see Tab. 6. Interesting results then emerged after the groups were separated (see below).

The interval of the **major seventh**, was generally manifested as mainly *restless*. In addition, *sadness*, *tightness*, *masculinity*, and to a lesser extent weight and lowness were significantly perceived. Indians traditionally perceive this interval as *soft* and *voluptuous*, so our results correspond more with the European tradition, where this interval is considered *tense*, *bitter*, *disagreeable* and *gloomy*.

10. COMPARISON OF RESPONSES TO MICRO-INTERVAL NUANCES

The ability to distinguish micro-interval nuances became more pronounced only after separating groups with different rating tendencies using the DBSCAN clustering method. The ten respondents (i.e., groups G2 and G3) proved to be far more receptive to these subtle tuning variations than the mainstream G1.

Interesting differences in the perception of microintervals emerged especially when evaluating microinterval pairs of minor third, minor sixth and **minor seventh**. Respondents are less sensitive to the nuances of the minor second, and they rate its lesser and greater versions generally similarly for the parameters *restless*, *tightness*, *weight*, and *masculinity*. This is probably mainly due to the fact that the minor second as such is perceived as the most dissonant interval across Eu-

ropean music history, making it very difficult to distinguish between its lesser and greater versions. Even so, there were different perceptions for the parameters of *sadness*, *darkness* and *lowness*. Groups G2 and G3 perceived both of these parameters more strongly for the lesser version (*lm2*).

Definitely more interesting in this respect is the **minor sixth**. In its lesser variant *lm6*, the following qualities (compared to the greater *śruti gm6*) were more intensely manifested: *restless, sadness, tightness, weight* and *lowness*, especially for group G3. Only the perception of the *dark/bright* scale does not correspond with the assumptions here, because group G2 perceives the greater version of the interval as *darker*.

The specific **septimal intervals** *lm3* and *lm7* do not have traditional connotations in India or Europe, but significant differences have been noted for these intervals compared to greater variants of these intervals. For the lesser variant of the minor thirth *lm3*, more intense perceptions of negative aspects of all features were observed among the separated groups than for its greater version *gm3* (except for *masculinity*, see Tab. 7). Also, for the **minor seventh**, there was a tendency to perceive the greater microinterval more towards the positive values of a given scale for almost all parameters. Thus, *gm7* is perceived by G1 and G3 groups as more *joyful*, *sacred*, *open, light* and *bright* than *lm7*. The only exception here is the *masculinity/femininity* scale, as G1 and G3 perceive *lm7* as a slightly *feminine* interval.

11. INDIVIDUAL REACTIONS OF RESPONDENTS

A total of 27 respondents, including 12 music professionals and 15 non-professionals, took the opportunity to express their further feelings and observations in the form of verbal comments. The vast majority of these responses indicate a certain positive engagement and immersion in the evaluation process. Only one respondent (a professional musician) is openly sceptical about the test in his very first remark: *"It's pointless – the sustained concord can't express anything other than calmness."* In the notes, listeners report a wide range of responses and associations, from one-word phrases (e.g. *"nervousness"*) to entire sentences. The experience with the listening test was clearly beneficial for them and they really liked some of the harmonies (some of them even requested them for meditative listening at home afterwards).

In some cases, the notes may reveal influences of musical training, various "learned" associations or symbolism that prevent the respondent from evaluating the interval spontaneously. For example, for the interval aug4 one listener states, *"Triton, the devil interval – a common cliché in applied music to express tension."*

Often, however, it is clear from the note that the interval in question has indeed evoked a strong emotional reaction! E.g. *"The lonely despair of the old woman, resignation combined with sadness. "*

It is also clear from the comments that feelings evolve when listening to concords. The listener gets used to the initially unpleasant interval, sometimes he even gradually finds a delight in it. E.g. *"at the beginning restless, gradually to calm and after one minute back to restless"*, or *"at the beginning more negative feelings, after about 30 – 40 seconds everything calmed down"*.

The respondent of the English version of the test also analysed the effect of combination tones. For *lm6* he stated: *"this interval produces very strong wavering difference tones above the two fundamental pitches. The waving effect it creates is very calming. I find that the longer the notes are sustained the more peaceful it becomes."*

In some cases, the comments correspond to the assumed properties of the intervals and to the evaluation of the emotional scales. For example, the interval of perfect fifth *p5* was evaluated with the following words (the quoted comments of individual respondents are separated by semicolons): *meditation ; feeling empty ; solid support ; well-being ; finding*. In a case of major third *M3* we have found notes: *beauty ; cleanliness ; organ ; church ; I feel things are arranged as they should be*.

Quite varied are the impressions of the major seventh *M7: like someone looking forward to something but also worried ; irritability ; anxiety ; tension ; relaxing ; uncertainty in anticipation ; nervousness ; feeling at ease with the state of affairs ; not everything is according to my expectations, but that's okay.*

Individual response to microinterval nuances

Let us now concentrate on the comments made for significant microinterval nuances (i.e. intervals significantly deviated from their tempered versions).

Minor second:

For the lesser minor second *lm2*, a significant *śruti* of the *rāga Marwa* (associated with *the bhayanaka rasa* – fear), we noted the following verbal reactions: *nervousness* (indicated twice by different respondents) ; *fear, blood pounding in the temples, buzzing of bees ; restlessness ; uncertainty in the cosmic space ; as if someone is standing behind me, feeling of danger ; I feel a precursor of complete equanimity when the higher tone goes M2 lower ; a cave in*

For the greater version of this interval, i.e. *gm2*, the following notes are: *almost in the middle ; tension (2x) ; dark, funereal feeling ; overlapping ; the difference tones that this interval produces are very satisfying to listen to*.

Minor sixth:

Another significant "low śruti" which is often associated with sunset in India is the lesser minor sixth *lm6*. Respondents wrote for it: disgust ; *misfortune is already rolling in, tragedy cannot be stopped – ancient drama ; danger ; inner trembling, nervousness ; obscurity. In one case: promise, lifting*.

For the greater version (*gm6*), the only comments were: feeling like a prison, like a cage ; *heaviness in the upper part of the legs ; this one was so hard to grip.*

Minor thirds:

Respondents reacted to the specific "blues" microinterval of the 7-limit system in the following words:

lm3: resignation ; I didn't listen, it didn't do me any good physically – it made my ears hurt ; it seems serious, or a truly poetic comment: the dissolving fog opens up a view of a damp, dense forest.

In a case of greater version of minor third *gm3* they have stated: *devotion ; lonely despair of the old woman, reconciliation combined with sadness ; ambiguity, discord, industry.*

Minor seventh:

Quite a large number of comments are for the lesser minor seventh *lm7: trance ; urgency (perhaps like the urgency of a siren) ; freezer or fridge ; tightness ; nervousness ; unpleasant vibrations ; tension ; unpleasantness, irritation, probably mainly caused by the fact that I could feel the second note a tiny bit higher than it was ; heaviness with the promise of better, unpleasant tension, expectation of improvement.*

Greater version of minor seventh *gm7* was rated by listeners with the words: *getting closer ; depression ; dawn ; distinct restlessness, tightness ; this harmony is rather unpleasant – for a headache.*

Partial conclusion of individual reactions

Certain tendencies in the perception of individual intervals can be observed in the spontaneous comments recorded by the listeners, which often coincide with their expected characteristics. Even in microtonal variants (*śruti*) of the same interval, differences in their perception are noticeable in a number of cases. This is particularly evident in the greater and lesser versions of the minor sixth, where the urgency and number of notes in the lesser version of the *lm6* interval suggest that its emotional potential is stronger.

Two respondents then provided interesting notes for the lesser and greater versions of the minor seventh, which clearly indicate different feelings when listening to these intervals (it should be remarked here that the individual stimuli were played randomly in the test.):

1. *lm7: difficulty with promise of better, unpleasant tension, expectation of improvement / gm7: getting closer*
2. *lm7: tension / gm7: sunrise*

However, other reactions differ in their perception of this interval, as can be seen for example in the case of the major seventh *M7*. Interestingly, however, this is an interval where the estimated effect differs considerably between the Indian and European approaches (see Tab. 1).

12. CONCLUSION

The results of our research show that listening to isolated sustained harmonies can induce a wide range of psychological responses in the listener, with a significant number of cases being identical or similar. Moreover, in some instances, the responses to a particular interval/emotion combination match or resemble characteristics given by Indian or European traditions. There was also a relatively large number of interesting individual verbal reactions, which (among other things) indicate a certain positive engagement of the respondents and immersion in the evaluation process.

Undoubtedly, the richest and most interesting results came from the DBSCAN clustering analytical method, which was able to separate groups with different evaluation tendencies. Thus, further interesting data were obtained, which, above all, showed that a part of the audience (10 respondents in total) was able to distinguish even micro-interval variations of the intervals. All the results were compiled in a summary table (Tab. 7), which is thus the main output of this research and which can also serve practical purposes The most significant differences in ratings were observed for the variants of the m7 interval, for which the more perceptive respondents of the G2 and G3 groups appeared to be able to clearly distinguish its microinterval nuances. This was similar for some of the features of the minor sixth, minor third and minor second. Responses to the lesser versions of these intervals almost always tended toward the negative poles of the rating scales, whereas responses to the greater versions were (here only in some cases) biased slightly in the positive direction. The ability to perceive these nuances differently was also evident in some of the verbal evaluations. Of course, it can be argued that the scales are correlated, i.e., if an interval is perceived as sad, for example, it is usually also rated as *dark, tight, heavy*, etc., which is obviously related to its perceived degree of consonance. Even so, in some cases the ratings of the individual features differ (e.g. for intervals *gm3, lm7* or *M7*).

The obtained results correspond strongly with the theory of Indian classical music, where the lesser versions of the *śruti* microintervals are always perceived as *sadder, heavier, more tight, darker*. For example, the microinterval shades of minor seconds and minor sixth are purposefully worked with in Indian music in the ragas associated with sunrise/sunset, to achieve the required *rasa* atmosphere [21].

This confirms the meaningfulness of the Indian traditional *śruti* system, which is unfortunately falling into oblivion in India itself, replaced by rough tempered tuning. However, these principles can (and do) find application by Western composers, who, thanks to the contemporary possibilities of musical technology (electronic instruments, software applications), can work very precisely with the micro-interval nuances of just intonation.

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