

PERCEPTION OF MODULATIONS IN SOUTH INDIAN CLASSICAL (CARNĀTIC) MUSIC BY STUDENT AND TEACHER MUSICIANS: A CROSS-CULTURAL STUDY

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MODULATION, A SHIFT IN MODE (RĀGAM), IS important in South Indian classical (Carnātic) music. Here we investigate the sensitivity of Carnātic and Western listeners to such shifts. Carnātic music has two kinds of shifts: rāgamālikā (retaining tonal center, resembling a shift from C major to C minor in Western music) and grahabēdham (shifting tonal center, resembling a shift from C major to A minor). Listeners heard modulating pieces of music and indicated the point of modulation, and were measured for accuracy and latency. Indians were more accurate than Westerners with both types of modulation but Westerners were faster with grahabēdhams. Cues could explain performance differences between nationalities: Indians were more familiar with rāgamālikā-type modulations whereas Westerners' culture made them more familiar with grahabēdham-type modulations. Increased caution toward the less familiar grahabēdhams for Indians could explain their slower response time compared to rāgamālikās. With grahabēdhams, hit rates for both groups were comparably high, but Westerners' lower level of accuracy was due to higher false-alarm rates to lures that were superficially similar to actual modulations. This indicated their dependence on surface-level cues in the absence of familiarity and culture-specific information. Music training helped teachers in both groups make fewer errors when compared to students. Older listeners' performance was comparable to that of younger listeners.

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ONE PARTICULAR AREA OF INTEREST IN MUSIC perception is how and when we perceive and process shifts in tonality. Modulations in music are shifts of key (of tonal scale) that are primarily done to change the mood of the song, for example, from

happy and bright to serious and dark. Modulations are not unique to Western music. Indian, Arabic, and Japanese music also employ modulations, and great composers all over the world have exploited this device for centuries. The present behavioral study investigates the perception of tonal modulations in South Indian classical (Carnātic) music.

Modulations in Western music sometimes introduce chords and tones in a new key that are unexpected in the original key, and may even subsequently violate the expected musical structure. Studies that directly investigate listeners' perception of modulation are sparse (e.g., Koelsch, Gunter, Schröger, & Friederici, 2003; Krumhansl & Kessler, 1982; Toiviainen & Krumhansl, 2003). However numerous studies indirectly examine perception of shifts of tonality by studying listeners' sensitivity to violation of musical expectancies. Such studies have primarily been conducted with Western stimuli, specifically constructed for the study. These stimuli usually consisted of five-chord sequences with one chord (e.g., the third or the last) discordant in the context established by the preceding chords (e.g., Koelsch, Schmidt, & Kansok, 2002). Instead of chord sequences, some studies have also used familiar and unfamiliar melodic phrases with "wrong notes" inserted (e.g., Miranda & Ullman, 2007). The stimuli were typically computer generated—except for Koelsch and Mulder's (2002) study which used brief excerpts from commercial CDs—and presented in blocks with each trial lasting for about 4 to 10 s. Each trial contained one violation of expectancy.

Few exceptions to the studies with blocked stimuli exist. For example, Janata et al. (Janata, Birk, Tillmann, & Bharucha, 2003; Janata et al., 2002) constructed a melody that systematically moved through the 24 major and minor keys, modulating at regular intervals. Though modulations as such were not the primary focus of the study, Janata et al. used modulations to insert target notes that were diatonic to some keys and nondiatonic to others. Participants responded if they perceived a target note as "wrong" and out-of-context. The results indicated that participants were sensitive to shifts in tonality, in that they responded to out-of-key notes in the context of the current tonality.

As far as we know, only two behavioral studies have directly investigated listeners' perception of modulations in music. Krumhansl and Kessler (1982) investigated Western musicians' internal representation of pitch relationships and how these representations changed over time while listening to a modulating sequence of chords. Results showed that participants identified the initial tonal center, and then tended to change the center towards the modulating key. This change happened faster when the modulation was to a related key than to a distant key (e.g., C major to G major was faster than when C major modulated to B \flat major). Toiviainen and Krumhansl (2003) further improved upon Krumhansl and Kessler's study by capturing in real time Western musicians' perception of changing tonality while listening to a computer-generated version of J.S. Bach's *Fourth Organ Duetto*.

Considering the extant literature, there is a paucity of studies investigating how listeners perceive and process modulations in natural music. Also, to our knowledge, there are no cross-cultural studies as yet examining listeners' perception of modulations in culturally familiar and unfamiliar music. Our study aims to fill these gaps by examining Indian and Western listeners' perception of modulations in recorded live performances of Carnātic music.

INTRODUCTION TO CARNĀTIC MUSIC

Carnātic music is ideal for cross-cultural studies in music because it contrasts with Western music in the complexity of its tonal system. We can describe the differences in terms of Dowling's (1978; see also Dowling & Harwood, 1986) levels of cognitive organization of tonal patterns, which conceptualizes each level arising from a selection of pitch classes from the preceding more general level. In Western music, the *tonal material* selects a chromatic scale of semitones from the psycho-physical continuum of pitches; a *tuning system* selects the white notes on the keyboard from the tonal material; and the *modal scale* establishes a tonal hierarchy on the tuning system. Carnātic music shares the tonal material of the Western system. But whereas Western music for the most part has only one tuning system and two modal scales (major and minor; note that there are also the two additional variations of the minor mode, four rarely used medieval church modes, and five pentatonic modes, making a total of 13 modes), Carnātic music can be said to have 72 tuning systems which generate approximately 350 modal scales (rāgams) currently in use, if we count five- and six-note scales as different from seven-note scales. Some rāgams use different notes in the ascending scale and the descending scale, somewhat like

the Western melodic minor. The distinction between tuning system and modal scale is not as sharp in Indian music as in Western music, since for the most part the tonic remains fixed on one pitch determined by the constant "sruthi" (drone).

A rāgam is different from a scale in that it is an abstract melodic entity based on a modal scale, but with internal embellishments and ornamentation with prolific use of graces (Janakiraman, 2008; Satyanarayana, 2004). Graces are subtle and expressive, and include oscillations between notes and expressive intonations. Every rāgam has a distinct emotional and tonal quality, called "rāgabhāvam" (Pesch, 2009; Satyanarayana, 2004), which is important in differentiating between rāgams with similar notes. Rāgabhāvam is creatively developed by the musician by the use of characteristic notes and phrases, and the introduction of microtonal-intervals used for ornamentation.

An important aspect of Carnātic music is that it is melody- and rhythm-oriented, and not harmony-based as is Western classical music. Sometimes two or more people sing together but there is no functional harmony involved. Also, Carnātic music is always performed with a sruthi (drone) consisting of the tonic-dominant-octave notes emitted by a thambura or an electronic sruthi box. The primary function of the sruthi is to establish the tonic, much like the function of Western harmony, which implies a tonal center. Most of what Carnātic musicians perform is improvised on the spot except for the part of the song with lyrics, which are further embellished through means of variations.

MODULATIONS IN CARNĀTIC MUSIC

A salient feature of Carnātic music is modulation, which are of two types—grahabēdham and rāgamālikā. Grahabēdham is similar to modulation in Western classical music. The tonal center of the scale, that is the "tonic," is shifted in the middle of the song to a "new tonic" in the same tuning system, much like the Western shift from C major to A minor. Now the musician is performing a new rāgam based on the new tonal center. This shift occurs while the sruthi is still set to the tonic-dominant-octave notes of the original tonal center. After a brief foray into the new key and new rāgam lasting about 1 min, the performer returns to the original scale. Only a few eminent musicians perform grahabēdham, as it requires tremendous training and implicit knowledge of the rāgams, and the skill to improvise spontaneously. It is very easy to get sidetracked into the new rāgam, which creates difficulties in getting back into the original rāgam.

For example, Figures 1a and 1b show the Western notation of the two rāgams Sankarābharanam and

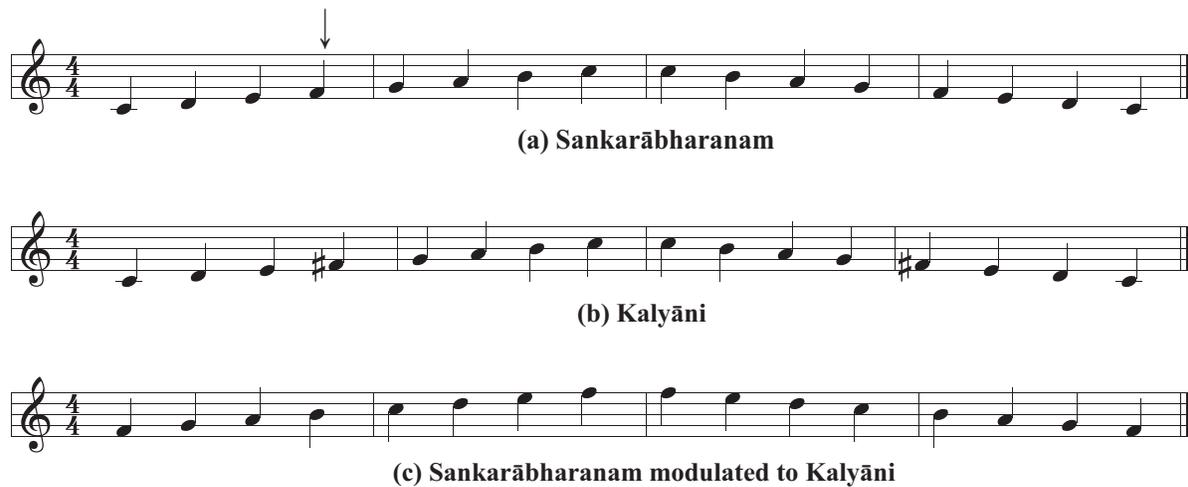


FIGURE 1. An example of two mēlakarthā rāgams (a) Sankarābharanam and (b) Kalyāni. Note that the two rāgams start on the same tonic and share the same notes except for the raised fourth (F♯) in Kalyāni. It is also an example of a rāgamālikā, Sankarābharanam followed by Kalyāni. (c) An example of a grahabēdham. In rāgam Sankarābharanam, the tonal center is shifted to the fourth note of the scale (arrow in panel a) while the pitches of the original scale remain unchanged. The new scale is rāgam Kalyāni, which has the raised fourth (B in this case). Reprinted from “Real-Time Probing of Modulations in South Indian Classical (Carnātic) Music by Indian and Western Musicians” by R. Raman and W. J. Dowling, 2016, *Music Perception*, 33, p. 369. Copyright 2016 by the University of California Press. Reprinted with permission.

Kalyāni, showing how they could be paired together in grahabēdham. Modulation to the subdominant (fourth note – arrow) in the rāgam Sankarābharanam will yield the rāgam Kalyāni as seen in Figure 1c. Note that when the tonal center is shifted to the fourth degree of the original scale, the pattern of whole and half step intervals relative to that new tonal center is the same as in the Kalyāni scale beginning on its original tonic. No accidental notes—temporary alterations of scale notes by one semitone—are introduced to signal a modulation. In fact, in Carnātic music the concept of accidental notes does not exist. Also no additional notes are included in the new scale, as for example in Western music a melodic or harmonic minor scale that includes sharps that were not present in its relative major scale. It is however permitted to omit the tonic and/or the dominant of the original rāgam in order to obtain a pentatonic or hexatonic (six-note) rāgam.

Grahabēdham is a controversial technique, and not all schools of music believe in using it. Many people are cynical about it because to a layperson grahabēdham sounds as though the musician is going off-key. Only an experienced listener comprehends the clash of tonalities. So musicians tend to perform grahabēdham very briefly, mostly for 1 to 1.5 min, and then they come back to the original scale. There are rules as to where it must be performed—usually at the beginning where the rāgam is vocalized and elaborated upon without rhythm, or in the solfège section in the middle segment

where the note names of the rāgam are elaborated upon with rhythm. Instances of grahabēdhams are not available in commercial CDs, largely because musicians perform them spontaneously in concerts, which are rarely recorded.

Rāgamālikās are more popular and several CDs devoted to rāgamālikā songs are commercially available. Here the tonal center remains unchanged while the rāgam changes. An example would be a shift from the rāgams Sankarābharanam to Kalyāni. Figures 1a and 1b give the notation of this shift. Note that the tonal center remains the same, as in the shift in Western music from the major scale to its parallel minor (e.g., C major to C minor). The rāgams in a rāgamālikā can have any number of note combinations in their scales. They are chosen by composers in such a way that each rāgam is very different in character from the one preceding or succeeding it.

PERCEPTUAL CUES TO MODULATIONS

Balkwill and Thompson’s (1999) cue-redundancy model provides a useful theoretical framework for understanding the various cues that participants, familiar and unfamiliar with a music style, use in order to perceive intended musical aspects. According to this model, acculturated listeners use both culture-specific and psychophysical cues, whereas unfamiliar listeners use the basic psychophysical cues. Balkwill and Thompson include the following as psychophysical cues: sound

intensity, rate (tempo), melodic complexity, melodic contour, pitch range, rhythmic complexity, dynamics, and timbre. However, in addition to these psychophysical cues, other types of cues are involved in perceiving a melody. Numerous studies (e.g., Curtis & Bharucha, 2009; Lantz & Cuddy, 1998; Krumhansl, Louhivuori, Toiviainen, Järvinen, & Eerola, 1999; Krumhansl et al., 2000; Oram & Cuddy, 1995) have shown that listeners use surface-level cues, such as frequency of note occurrence and note duration, along with schematic knowledge that they bring from their own culture, in perceiving culturally familiar and unfamiliar, as well as novel musical sequences, in order to form a generalized understanding of the music piece (Krumhansl & Cuddy, 2010).

Cognitively, modulations such as *grahabēdham* and *rāgamālikā* can be detected by means of surface-level and psychophysical cues; for instance, by becoming aware of certain changed notes in the modulated segment of the song and by the way the original emphasis on certain notes changes to other notes. The establishment of the new *rāgam* involves introducing characteristic melodic turns of phrase—that is, changes in the *rāgabhāvam*—different from the preceding *rāgam*, which provides culture-specific cues to participants familiar with this music system. This requires an internal representation of the pattern of pitch relationships, the tonal hierarchy, in the original *rāgam*. Castellano, Bharucha, and Krumhansl (1984) provide evidence of such a representation for North Indian music. In addition, *grahabēdhams* can be noticed by the presence of surface-level cues, such as the dissonance created by the shift of tonic with the constant drone. And both *grahabēdham* and *rāgamālikā* can be identified by rhythmic cues.

GOALS AND HYPOTHESES

Our study addressed the following questions: (1) Are listeners able to recognize modulations, or shifts of tonality, in culturally familiar and unfamiliar music? (2) If so, what cues do they use to discern such modulations? (3) Does the listener's age and music experience influence perception of modulation? The purpose of the study was to extend previous findings in the literature by using a cross-cultural approach with high ecological validity.

Cross-cultural studies involving music will be complete only when systematic research identifies those aspects of music susceptible to acculturation and those that are universals. Such studies need two components—cross-cultural participants and cross-cultural music. Much research in recent years has used Western music with Western and non-Western participants. Our study complemented earlier research by using non-Western

music—that is, Carnātic music—with South Indian and Western participants, much like the design used in Castellano et al. (1984).

In contrast to the previous studies, our stimuli were natural, and not edited or manipulated in any way. The songs were either recordings of live performances or excerpted from commercial recordings. Participants listened to an entire song while identifying the modulations that occurred in it. Our stimuli were longer than those in Koelsch and Mulder's (2002) study, lasting between 1 and 10 min, and unlike the shorter excerpts, they started and ended naturally without fading in or out. And the target notes or chords in the earlier studies using shorter stimuli were highly predictable in occurrence. In the present study, the occurrence of a shift was not easily predictable. Sometimes there were rhythmic cues—such as, phrase endings—but most transitions occurred smoothly from one *rāgam* to the next. The duration between two shifts ranged from 2 to 298 s, giving the participants in most cases enough time to establish the tonal hierarchy of each *rāgam*.

We hypothesized that Indian participants would perform better with *rāgamālikās*, which shifts key retaining tonal center, than with *grahabēdhams*, where the tonal center shifts, whereas the reverse would be true for Western participants. The basis for our hypothesis was that whereas Indian listeners are familiar with *rāgamālikā*-type modulations because of their popularity, Western listeners are more familiar with shifts of tonal center in modulation, which is similar to *grahabēdham*. That is, we expected Western listeners to apply their Western schematic knowledge of recurrent commonalities in music to the unfamiliar music.

Our second hypothesis was that teachers, from both cultures, having more applied music experience than students, would be more accurate in identifying both types of modulation. Previous research has shown that professional musicians perceive musical structures differently from amateur musicians (Dowling, 1986), with experts performing better than amateurs at a variety of musical tasks (Krampe & Ericsson, 1996).

Listener age and music experience may also play a role in determining abilities pertaining to music. To our knowledge, however, there are no systematic studies that have been undertaken to explore the contribution of age and experience on the recognition of different tonality shifts in music. Halpern and Bartlett (2002) address the dearth of evidence in the field of music cognition relating to experience and aging. Although both older and younger musicians have strong representations of the tonal hierarchy (Halpern, Kwak, Bartlett, & Dowling, 1996), older listeners have slower processing times

(Krampe & Ericsson, 1996), problems with working memory, and higher false-alarm rates (Halpern, Bartlett, & Dowling, 1995), and these problems are especially pronounced after age 60.

Music studies have occasionally found interactions of age and music experience (Halpern & Bartlett, 2002; Halpern et al., 1995, Experiment 2), in which age-related cognitive deficits were reduced due to experience, but this effect did not consistently appear. Studies have also shown the importance of regularly practicing a skill in order to preserve it in old age (Burke, 2006). For instance, age-related deficits were not found in the performance of older and younger experts in skills such as piano playing (Krampe & Ericsson, 1996). Our final prediction was that age and experience would interact in terms of both accuracy and response time. We expect performance in general to decline with age but that participants with more music training would show less of a decline than those with less training.

In this study, we compared Indian and Western groups of older (61 to 81 years) and younger (17 to 60 years) listeners with two levels of music expertise in their ability to recognize shifts of rāgam. We chose these two age groups since most previous music studies have observed the greatest age-related differences in task performance to occur over age 60. We employed 18 Carnātic songs performed by famous musicians as stimuli. Each song included on an average about five rāgam changes, that is, modulations. We also identified passages in each song that could serve as lures, passages which were not actual modulations but non-modulating shifts of emphasis in pitch that sounded like possible changes of rāgam. The listener was thus confronted with the problem of discriminating actual modulations from similar sounding passages.

Method

All Indian participants were from Chennai, India, and all Western participants were of non-Indian origin

living in Dallas, Texas. Many Indian participants reported that they neither listened to Western classical nor popular music, nor to Indian film music influenced by Western music. And Western participants reported that they had never heard Carnātic music before. All participants reported having normal hearing and a regular school education of at least 12 years. The study included two experiments with Experiment 1 tracking participants' responses to rāgamālikās and Experiment 2 studying their responses to grahabēdhams.

EXPERIMENT 1: RĀGAMĀLIKĀ

Indian participants. Forty-four participants (age range = 17 to 81 years), who had received a minimum of 4 years of Carnātic music lessons, took part in the study. Participants were divided into two groups based on their music expertise: Students and performers constituted the first group, which included individuals who had learnt or were currently learning music but had never taught music before. The second group consisted of music teachers with a minimum of four years of teaching experience. Participants were further divided at the age of 60 years into two groups to make a total of four groups (see Table 1).

Western participants. Forty-four Western participants (age range = 22 to 76 years), who had received a minimum of four years of Western music lessons, took part in the study. Participants were divided into four groups corresponding to the Indian cohort (see Table 1).

Stimuli. Stimuli consisted of seven rāgamālikā songs with a total of 45 instances of modulations (see Appendix A). Each rāgamālikā included at least three different rāgams: that is, a minimum of three scale shifts, including the return to the same tonal center. The first shift occurred after at least 51 s. The shortest time between shifts was 2 s and the longest time was 298 s; the average time was 60 s. We also identified 42 instances of lures in the stimuli, which were not actual modulations but shifts of emphasis in pitches that sounded similar to

TABLE 1. Indian (I) and Western (W) Participant Variables in Experiment 1: Rāgamālikā

| | Below 60 years | | | | | Above 60 years | | | | |
|-----------|----------------|---|---------------|-------|-------|----------------|---|---------------|-------|-------|
| | F | M | A.Age(Range) | MT | YT | F | M | A.Age(Range) | MT | YT |
| I Student | 8 | 3 | 35.36 (17-55) | 12.55 | 0.41 | 9 | 2 | 71.27 (63-81) | 11.64 | 0.23 |
| I Teacher | 10 | 1 | 47.82 (38-60) | 18.45 | 12.36 | 7 | 4 | 69.73 (61-78) | 14.82 | 34.91 |
| W Student | 6 | 5 | 38.91 (22-60) | 8.95 | 0.00 | 6 | 5 | 66.73 (62-75) | 11.95 | 0.00 |
| W Teacher | 7 | 4 | 39.55 (22-58) | 15.82 | 14.36 | 8 | 3 | 67.55 (61-76) | 16.36 | 23.27 |

Note. F = no. of female participants; M = no. of male participants; A.Age = average age; MT = average years of formal music training; YT = average years of music teaching experience.

changing rāgams. The duration of the whole sequence of stimuli was approximately 55 min. All songs were played sequentially in a pseudo-random order on iTunes software version 10.6.3. No two participants heard the same sequence of songs.

Procedure. All participants were taken to a quiet room and seated in a comfortable chair with an Apple Mac-Book placed either on a small table in front of them or on their lap, according to their preference. The laptop was connected to a pair of good speakers. The sound level on the speakers was checked by playing a popular Tamil (a South Indian language) film song and care was taken to ensure that each participant was comfortable. They were also told to adjust the sound level during a song if they felt it was necessary.

We then explained rāgamālikā modulations with an example, which we presented over the speakers. We instructed participants to press the “spacebar” key on the laptop whenever they heard a change in rāgam, including every time that it shifted back to the original rāgam. The function of the spacebar key was to pause the song so that the exact moment of recognition of the shift in seconds could be noted. Once the time was noted, the participants pressed the spacebar key again so they could continue listening from the point where they paused. The pause lasted only for about 1 to 2 s to minimize disruption in listening. Participants had to discriminate modulations from the similar-sounding lures, and their responses were scored in terms of accuracy and latency.

We then played the sample excerpt again and during it the participants practiced pressing the spacebar key while responding to shifts. At this point, any doubts regarding the experiment were clarified. In order to ensure the sustained concentration of the participants during testing, we asked the Indian participants to call out the names of the rāgams as and when they recognized them. The rāgam names they called out were recorded as well. We asked the Western participants to call out the names of the instruments (e.g., violin) if they recognized them. Care was taken to ensure that the participants understood that identifying the change in rāgams was the main focus rather than identifying the rāgam name or the instruments. We asked all participants after every song to share briefly any particular strategies they used to identify shifts.

At the end of the listening session, participants answered a few questions on their personal and music background and on any special techniques they used to discern rāgam changes (see Appendix B). Their responses were recorded.

Scoring. We identified 45 instances of actual modulations a priori and recorded the exact time in seconds at which new rāgams were introduced. The response time was noted every time the participants pressed the spacebar key. This response time for each shift was then compared to the actual time of the shift, and the time delay (in seconds) was calculated for each participant on each shift. We used a 20-s window following each shift to calculate accuracy and latency. A 20-s window is an appropriate duration to perceive a modulation because tonality changes in Carnātic music occur without the introduction of harmonic cues (see Introduction), unlike in Western music. Also, the establishment of the rāgabhāvam as different from that of the preceding rāgam by means of characteristic melodic turns of phrase and ornamentations occurs over several seconds following the point of actual modulation; that is, the introduction of the first new pitch in rāgamālikā.

If the participant pressed the spacebar key within 20 s of the actual occurrence of a shift, it was considered a hit. A miss was defined as the failure of a participant to identify the shift correctly within 20 s of its occurrence; misses were computed as complementary to hits. Very rarely, Indian participants responded less than 2 s prior to the actual shift due to their familiarity with the song leading to the expectation of a shift. Such early responses were also included as hits.

We also identified 42 instances of lures in six of the seven songs and recorded the exact time (in seconds) at which they occurred. These instances were all outside the 20-s windows of the actual modulations, so that they did not overlap. If a participant’s response occurred within 20 s of the occurrence of a lure, it was considered a false alarm.

EXPERIMENT 2: GRAHABĒDHAM

Indian participants. Forty-eight participants (age range = 17 to 83 years, 43 women) took part in the study. Recruitment and categorization of participants were similar to Experiment 1. Out of the 48 participants, 31 participants had not participated in Experiment 1, whereas the remaining 17 had participated in both experiments. The main analyses have been performed only on the 31 new participants (age range = 17 to 75 years; see Table 2) in order to prevent any confounding effects of learning carried over from Experiment 1.

Western participants. Forty-eight participants (age range = 20 to 77 years, 30 women) took part in the study. Recruitment and grouping of participants was similar to Experiment 1. Out of the 48 participants, 30 participants had not participated in Experiment 1, whereas the

TABLE 2. Indian (I) and Western (W) Participant Variables in Experiment 2: Grahabēdham

| | Below 60 years | | | | | Above 60 years | | | | |
|-----------|----------------|---|---------------|-------|-------|----------------|---|---------------|-------|-------|
| | F | M | A.Age(Range) | MT | YT | F | M | A.Age(Range) | MT | YT |
| I Student | 10 | 2 | 40.33 (17-59) | 14.46 | 0.83 | 7 | 0 | 68.43 (61-74) | 14.14 | 1.36 |
| I Teacher | 7 | 0 | 42.29 (33-53) | 18.64 | 14.43 | 4 | 1 | 67.20 (62-75) | 17.40 | 22.10 |
| W Student | 3 | 5 | 36.25 (20-58) | 9.31 | 0.81 | 3 | 3 | 65.00 (62-75) | 6.42 | 1.08 |
| W Teacher | 5 | 4 | 41.89 (23-60) | 17.11 | 18.94 | 6 | 1 | 67.14 (62-74) | 15.29 | 29.29 |

Note. F = no. of female participants; M = no. of male participants; A.Age = average age; MT = average years of formal music training; YT = average years of music teaching experience.

remaining 18 had participated in both experiments. As with the Indian participants in Experiment 2, the main analyses have been performed only on the 30 new participants (age range = 20 to 75 years; see Table 2).

Stimuli. Participants heard 11 grahabēdham songs with 46 instances of modulations (see Appendix A). Each song had a minimum of two tonal shifts; that is, the original key shifted to a new tonic and then it shifted back to the original. Each key change constituted a change to a new rāgam. The first shift occurred after at least 23 s. The shortest time between shifts was 5 s and the longest time was 249 s; the average time was 65 s. Here again as with rāgamālikās, we identified 42 lures in nine out of the 11 songs on the basis of shifts of emphasis in pitch similar to those of true grahabēdhams. The duration of the whole sequence of stimuli was approximately 60 min. We improved upon Experiment 1 by presenting all songs using MATLAB software version 7.9.0.529 (R2009b). MATLAB was programmed to present the songs via Winamp software version 5.623. Songs were played sequentially in a pseudo-random order. No two participants heard the same sequence of songs.

Procedure and scoring. The procedure and scoring were similar to that in Experiment 1 except that all data were recorded on MATLAB. Hence there was no pause in the song after pressing the spacebar as in Experiment 1; participants heard each song continuously without any gaps. Here the spacebar key press recorded the moment of behavioral recognition of the shift in seconds. The only difference from Experiment 1 was that an additional spacebar press was not required to continue playing the song.

Results

We performed two between-groups 4-way analyses of variance (ANOVA), which had a 2 Ages x 2 Music Experience levels x 2 Types of Modulation x 2 Nationalities

design separately for response times and area scores. We used A' to estimate the area under the ROC. Area scores provide an unbiased estimate of proportion correct where chance is .50 (Verde, Macmillan, & Rotello, 2006). Finally, we performed a set of planned one-tailed t tests with the Bonferroni correction for multiple comparisons in order to elaborate upon the results of the ANOVAs. (The Bonferroni correction applied to the t tests for $p < .10$ is $p = .025$. All p values between .013 and .025 were considered as approaching significance. All p values less than .013 were considered as significant.) Age did not have a significant effect on the results. Therefore, the discussion below only includes music experience, type of modulation, and nationality.

To examine whether participants were discriminating between actual modulations and superficially similar lures, we used A' to calculate area scores from hit and false-alarm rates—positive responses to modulations and lures in rāgamālikās and grahabēdhams (see Figure 2). The results indicated that there were significant main effects of music experience, $F(1, 133) = 13.11$, $MSE = 54.65$, $\eta^2 = .03$, $p < .001$, and nationality, $F(1, 133) = 251.74$, $MSE = 54.65$, $\eta^2 = .61$, $p < .001$, and a significant interaction of Type of Modulation x Nationality, $F(1, 133) = 6.11$, $MSE = 54.65$, $\eta^2 = .01$, $p = .01$. Overall, teachers ($M = 84.22\%$) were better at discriminating between modulations and lures than students ($M = 80.29\%$), $t(147) = 1.88$, $p = .03$. Also, Indian participants ($M = 92.29\%$) scored higher than Western participants ($M = 71.95\%$), $t(147) = 15.74$, $p < .001$. Western participants, though their discrimination performance was above chance, had much higher false-alarm rates than Indian participants. Cross-cultural comparisons (Bonferroni critical value: $p = .013$) showed that Indian participants performed better than Western participants both with rāgamālikās ($M = 93.70\%$ vs. $M = 70.70\%$), $t(86) = 12.49$, $p < .001$, and with grahabēdhams ($M = 90.29\%$ vs. $M = 73.77\%$), $t(59) = 10.19$, $p < .001$. Comparing performance on the two types of modulation suggested that Indian participants performed better on rāgamālikās

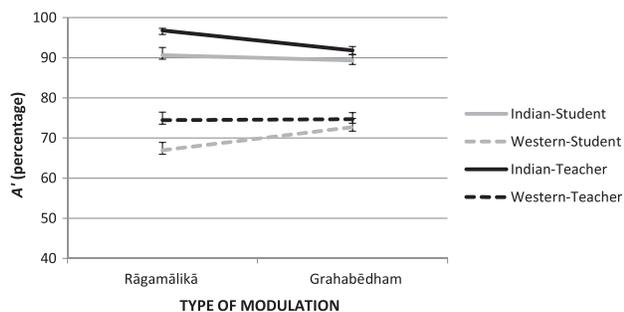


FIGURE 2. Area scores (A') in estimated percentage correct by music experience, nationality, and type of modulation—rāgamālikā (targets = 45, lures = 42), grahabēdham (targets = 46, lures = 42). Error bars indicate the standard error of the mean.

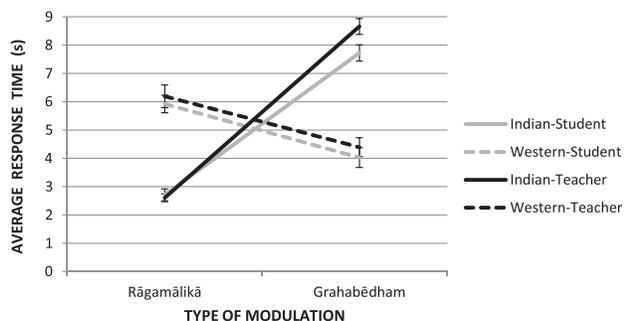


FIGURE 3. Average response time (in seconds) for correct positive responses (hits) by music experience, nationality, and type of modulation. Error bars indicate the standard error of the mean.

($M = 93.70\%$) than on grahabēdhams ($M = 90.29\%$), $t(73) = 2.25$, $p = .01$. On the other hand, Western participants' responses were about the same on grahabēdhams ($M = 73.77\%$) and rāgamālikās ($M = 70.70\%$), $t(72) = 1.45$, which was much better than chance.

With response time for hits (see Figure 3), there was a significant effect of type of modulation, $F(1, 133) = 72.57$, $MSE = 1.63$, $\eta^2 = .14$, $p < .001$, and a significant interaction of Type of Modulation \times Nationality, $F(1, 133) = 290.24$, $MSE = 1.63$, $\eta^2 = .57$, $p < .001$. Overall, participants responded faster to shifts in rāgamālikās ($M = 4.36$ s) than to shifts in grahabēdhams ($M = 6.24$ s), $t(147) = 5.08$, $p < .001$. Comparing performance on the two types of modulation (Bonferroni critical value: $p = .013$) indicated that Indian participants were faster at identifying rāgam changes in rāgamālikās ($M = 2.66$ s) than in grahabēdhams ($M = 8.15$ s), $t(73) = 23.12$, $p < .001$. On the other hand, Western participants were faster at identifying rāgam changes in grahabēdhams ($M = 4.26$ s) than in rāgamālikās ($M = 6.06$ s), $t(72) = 5.01$, $p < .001$. Western participants, while much slower than Indian participants on rāgamālikās

($M = 6.06$ s vs. $M = 2.66$ s), $t(86) = 12.18$, $p < .001$, were in fact approximately twice as fast as the Indian cohort on grahabēdhams ($M = 4.26$ s vs. $M = 8.15$ s), $t(59) = 12.09$, $p < .001$.

Discussion

The objective of this study was to examine whether age, music training, and nationality exert an influence on the perception of two types of modulation in Carnātic music, using a cross-cultural approach with high ecological validity.

INDIAN PARTICIPANTS

As predicted, Indian participants were more accurate and faster at identifying shifts of tonality in rāgamālikās than in grahabēdhams (see Figures 2 and 3). Indian participants' better performance on rāgamālikās can be attributed to the following factors: (1) Veridical (i.e., piece-specific—see Bharucha, 1987) knowledge of rāgamālikās probably aided Indian participants in detecting the modulations. This was evident from their performance on the task. In some of the more familiar songs, Indian participants anticipated a change even before the shift actually occurred, in some cases pressing the spacebar key a bit prematurely; that is, 1 or 2 s prior to the shift. As explained in the Method section, those cases were scored as hits. Also at the end of the task, Indian participants reported that they were familiar with at least four of the seven rāgamālikā songs. Some students and teachers were familiar with all seven. In order to learn the songs, the students and teachers first learned the structure of the rāgams in the songs which would account for their good mental representation for the different rāgams. (2) Schematic knowledge of Carnātic music probably helped detect modulations in less familiar rāgamālikā songs. Due to participants' high exposure to rāgamālikās in general, familiarity with the modulation technique itself and with cues that indicated the shifts helped Indian participants respond more accurately and quickly on less familiar songs. Indian participants reported that culture-specific cues, such as structural knowledge of the rāgams and rāgabhāvam (emotional quality of the rāgam), helped them differentiate between two rāgams. Also, surface-level cues, such as phrase endings and a change in rhythmic pattern on the percussion, helped with their recognition of a shift. Note that these cues probably overlapped with culture-specific cues, in that only the acculturated Indian participants could utilize these cues to discern changes in unfamiliar songs.

In order to verify whether Indian participants' better performance on the rāgamālikā songs was only due to veridical knowledge and not at all due to schematic knowledge or a combination of both, we used *A'* to calculate area scores from hit and false-alarm rates of four songs—two songs that all participants considered as highly familiar (Chinnanchiru kiliyē and Theerādhavillaiyātu; see Appendix A) and two songs that most of them were not familiar with (Ranjanimālā and Bhāvaiyāmi). We found a main effect of familiarity, $F(1, 40) = 12.38$, $MSE = 23.50$, $\eta^2 = .05$, $p = .001$, wherein participants detected modulations more accurately on the highly familiar melodies ($M = 96.07\%$) when compared to the less familiar melodies ($M = 92.43\%$), but note that both scores were above 90%. Hence there is some evidence that although veridical knowledge influenced the task for Indian participants, their schematic knowledge of the rāgams and familiarity with the modulation technique facilitated the detection of modulations in less familiar songs.

With grahabēdhams, a different picture emerged: Indian students and teachers were less accurate and nearly four times slower in their response to these shifts when compared to those of the rāgamālikās. Indian participants reported that they encountered several problems while identifying modulations in grahabēdham songs, as we noted in the Introduction. First, in contrast to rāgamālikās, Indian participants were unfamiliar with most, if not all, of the grahabēdham stimuli. Thus, their difficulty in identifying grahabēdham shifts could be due to their lack of veridical knowledge of the stimuli. Second, since grahabēdham is not particularly popular, many of the student and teacher participants had not been exposed to it. Many Indian participants reported discomfort in responding to grahabēdham shifts because of their unfamiliarity with the modulation technique, leading to their being more cautious and taking longer to decide. Some participants were cynical about the technique and others were dubious about the musicians whose songs were used in this study, and their ability to demonstrate the technique. Third, since grahabēdham is a creative improvisatory skill, it puts unusual demands on the listener. Participants had to be aware of the tonal hierarchy of each rāgam in the song to determine the new tonic with each shift. Finally, grahabēdham passages are very brief, making them hard to detect.

The cue-redundancy model (Balkwill & Thompson, 1999) proposed that listeners use both psychophysical and culture-specific cues when perceiving music from their culture. Our findings supported the model, in that Indian participants who were familiar with the rāgams

used in grahabēdhams but not with the songs themselves reported that they waited for the new rāgam to be established before acknowledging the shift. Some participants reported that they waited until the emotional quality—rāgabhāvam—of the new rāgam was established in terms of the characteristic melodic turns of phrase and other subtleties. Thus their slower responses could be a compromise between accuracy and speed, wherein they aimed for accurate identification of the shifts, rather than speed of response. In conclusion, the difference in Indian participants' performance on the two types of modulation could be attributed to veridical knowledge of the rāgamālikā songs and familiarity with the modulation technique.

WESTERN PARTICIPANTS

Western participants, on the other hand, were more accurate and faster at identifying shifts of tonality in grahabēdhams than in rāgamālikās (see Figures 2 and 3), thus supporting our prediction. With rāgamālikās, many Western students and teachers reported that they could not understand the structure of the rāgams and that the melodies sounded "strange" to them. This is consistent with earlier studies that showed that sometimes, with culturally unfamiliar music, listeners report hearing strange tones, which they may perceive as wrong notes (Curtis & Bharucha, 2009). Also, due to their unfamiliarity with rāgamālikās, the Western participants were mostly unsure of whether they had identified the shift correctly.

In contrast, Western participants reported that they enjoyed listening to songs with grahabēdham and could easily identify the shifts. They attributed this to their familiarity with the procedure of shift of tonal center (which is often employed in Western classical and popular music). The two most important cues for them were the sounding of a note for long durations and the clash of the new tonic with the original drone from the sruthi box that is present throughout each song. Hearing this distinct clash between the original drone and the new tonic gave them the cue to respond and they did not wait to confirm if the note actually converted into the new tonic. Many Western participants reported that identifying shifts in grahabēdhams was easier due to this dissonance. Since no accidentals or harmonic progressions preceded a shift (see Introduction), they relied on basic surface-level cues. Although Western participants' use of surface-level cues helped them identify the target shifts accurately, they also responded to lures—temporary pitch shifts in the melody that did not lead to a new tonality—thus resulting in more false alarms. Here, their errors could be a compromise between speed and

accuracy; that is, Western participants, due to their familiarity with the technique of shifting tonality, were faster at identifying shifts in grahabēdhams when compared to rāgamālikās, but due to lack of culture-specific cues made more false alarms. Thus, this provides some evidence of Western participants applying their schematic knowledge of Western music, along with sensitivity to surface-level cues, to the unfamiliar Carnātic music.

INDIAN VERSUS WESTERN PARTICIPANTS

Overall, Indian participants were more accurate than Western participants at identifying shifts of tonality in both types of modulation, but Westerners were twice as fast as Indian participants with grahabēdhams. Surprisingly, Indian and Western participants had similar hit rates on grahabēdhams ($M = 73.85\%$ vs. $M = 74.13\%$), $t(59) = 0.08$. Note that Indian participants were unfamiliar with most of the grahabēdham stimuli in this study. In order to verify if participants were simply responding to surface-level cues, we compared the proportion of hits and false alarms of modulations and lures (see Figure 2). The results indicated that Western participants were responding to the lures more than the Indian cohort, providing further evidence that they relied on surface-level cues. Note that Western participants' area scores were well above chance performance.

There are two principal explanations for the differences in performance between Indian and Western participants on the two types of modulations. First, for Indian participants, veridical knowledge of the rāgamālikās and familiarity with the modulation technique probably influenced performance on the task. Western participants, on the other hand, were at a disadvantage in terms of both lack of familiarity with the music and relative inexperience with the concept of rāgamālikās where shifts occur while retaining the tonal center. Western classical music has some instances of such shifts—for example, Franz Schubert's *String Quartet No. 13 in A Minor "Rosamunde"* which shifts in and out of A major in Movement 1, but the occurrence of such shifts is relatively rare. Often accidental notes are introduced which does not necessarily indicate a shift of keys. Western participants reported that sometimes they heard a new note in the melody which they considered an accidental note and thus dismissed it as an actual shift.

A second factor could be differences in performance related to Indian and Western participants' mental representation of each rāgam's tonal hierarchy and structure. When asked about it, Indian participants replied that in unfamiliar songs, they were able to ascertain differences in rāgams by employing their knowledge

of the notes and the characteristic phrases of the various rāgams. By identifying shifts more accurately and making fewer errors overall, Indian participants demonstrated having a better mental representation of the tonal hierarchy of the rāgams than the Western participants. However, Western participants showed some evidence of comprehending the structure of the unfamiliar melodies as indicated by the high hit rate with grahabēdhams ($M = 74.13\%$), and high A' scores with both grahabēdhams ($M = 73.77\%$) and rāgamālikās ($M = 70.70\%$), which were all well above chance performance. This conforms to the prediction based on Dowling's (1978) cognitive organization of scales in Western music that Western and Indian music are similar at the level of tonal material, and to some extent in the tuning system and some modal scales.

Participants also made fewer errors overall on rāgamālikās when compared to grahabēdhams probably due to three reasons: (1) Indian participants were primarily using their veridical knowledge along with schematic cues with the rāgamālikā stimuli, (2) Western participants reported that in some rāgamālikā songs, they did not understand the initial rāgam of the song, and hence they could not respond to any shifts, whether actual or apparent, and (3) songs with grahabēdham had more instances of notes held for longer duration that could indicate a plausible shift, thereby leading Western participants to respond prematurely.

Music training had an impact only on false alarms. The more experienced participants, the teachers, made fewer errors than the students, in both Indian and Western groups. The smaller variability in the responses of the Indian teachers as a group may indicate that they were using similar techniques to identify modulations and thus were consistent in their responses (see Figure 2). The use of common techniques was confirmed based on the responses collected in the interview at the end of the session. For instance, some of the Indian students said that they mostly identified rāgams by matching them with other songs that they knew in the same rāgam. On the other hand, Indian teachers said that they identified rāgams based on the notes and the rāgabhāvam rather than by comparing them with other songs in the same rāgam, which they added is a technique used by lesser experienced students and aficionados. Teaching and practicing music on a regular basis probably helps keep rāgam-identifying skills honed. With culturally unfamiliar music as well, it probably facilitates application of schematic knowledge learned in one's own culture to the unfamiliar music. Krampe and Ericsson (1996) observed that expert pianists performed better than amateur pianists at a variety of musical tasks.

Memory representations of musical structures were noticeably different in experts. Dowling (1986) also compared performance among nonmusicians, amateur, and professional musicians and found that the experts' memory encoding of melodic structures was different from both that of the amateur group and the group without music training.

Surprisingly, age did not influence this task. We predicted that older participants would be less accurate and slower at detecting modulations when compared to younger participants, but our results did not support our prediction. One plausible reason is that the effects of age could have been mitigated by music training wherein all participants received at least 4 years or more of formal music lessons. Future research should investigate the effects of age and music experience in a modulation-detection task by including participants with no formal training. Towards this, we have already acquired the data from Carnātic aficionados and are currently analyzing it.

One concern in this study that we would like to address is the use of different secondary tasks for Indian and Western participants. As mentioned in the Method, Indian participants called out the names of rāgams, which perhaps encouraged them to focus more closely on structural aspects of the rāgams and the modulations. On the other hand, Western participants called out the names of the instruments, which perhaps directed their attention to more surface-level features. Note that the primary task for both groups was to detect the modulations. Though this difference in tasks might have aided Indian participants in identifying modulations, we found minimal evidence of disruption in Western participants' performance. Almost all Western participants called out the instrument names soon after the melody began and before the first modulation occurred. Thus, they were able to focus on the actual primary task of identifying modulations. Also, Western participants' overall accuracy scores and response times showed their sensitivity in their comprehension to some extent the underlying structural pattern of the modulation and the tonal hierarchy in the Carnātic system. And the Western participants performed much better than chance.

Future studies should be directed at replicating this study using stimuli that are completely unfamiliar to Indian listeners. Veridical knowledge of most of the rāgamālikā and some of the grahabēdham songs was more advantageous to Indian participants than to Westerners

and this could have biased the results, especially for the rāgamālikās. Future studies should also look at tracking listener perception of modulations in real time and at more closely examining the cues as in Raman and Dowling (2016). And clearly future studies should use the automated data collection method of Experiment 2.

Conclusion

Responses to two types of modulations in Carnātic music were analyzed among groups of participants based on two levels of age, music expertise, and nationality. The results indicated five key conclusions: (1) Age did not have an effect overall. (2) Music training helped teachers in both groups to accurately discriminate between actual modulations and lures when compared to students. (3) Western participants could understand the unfamiliar Carnātic rāgams and melodies to some extent as predicted by Dowling's (1978) model. (4) They could transfer certain aspects of their schematic knowledge of Western music to a culturally unfamiliar music. And (5) both Indian and Western participants used surface cues, such as note duration and dissonance between new tonic and drone in grahabēdham, but only Indian participants could employ their culture-specific and veridical (piece-specific) knowledge, thus supporting the cue-redundancy model (Balkwill & Thompson, 1999).

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Appendix A

LIST OF SONG TITLES AND ARTISTS

TABLE A1. Experiment 1: Rāgamālikā

| Title | Artist | Instrument | Tempo(MM) |
|-----------------------------------|-------------------------|------------|------------------|
| Chinnanchiru kiliyē ^a | Chitti Babu | Veenā | 98 ^h |
| Ranjanimālā ^b | Chitti Babu | Veenā | 102 ^h |
| Manavē Manthralāyā ^c | Maharajapuram Santhanam | Vocal | 81 ⁱ |
| Bhāvaiyāmi ^d | Maharajapuram Santhanam | Vocal | 85 ⁱ |
| Ksheerābdhi kannikē ^e | Maharajapuram Santhanam | Vocal | 70 ⁱ |
| Rāgamālikā Thillānā ^f | M. Balamuralikrishna | Vocal | 80 ⁱ |
| Theerādha villaiyātu ^g | Lalgudi G. Jayaraman | Violin | 220 ^j |

Note. MM = Mälzel's Metronome; number of beats per minute.

^aA version of the song: <https://www.youtube.com/watch?v=zZCTVJKKYtQ> (last accessed December 4, 2015).

^bActual version of the song: <https://www.youtube.com/watch?v=eUrikZHhGSY> (last accessed December 4, 2015).

^cA version of the song: <https://www.youtube.com/watch?v=qb7TNoCydek> (last accessed December 4, 2015).

^dActual version of the song: <http://mio.to/album/Maharajapuram+Santhanam/Majestic+Renditions+Of+Maharajapuram+Santhanam> (last accessed December 5, 2015).

^eA version of the song: <https://www.youtube.com/watch?v=rpdyWv-Y4Ns&list=PLd7utnsdckLamIljMFA2vzQGOv2RIBWJB&index=30> (last accessed December 5, 2015).

^fActual version of the song: <https://www.youtube.com/watch?v=ybXxjiZAvIY> (last accessed December 5, 2015).

^gA version of the song: <https://www.youtube.com/watch?v=BY8rkIKPP1c> (last accessed December 5, 2015).

^hThe tempo is for every dotted quarter, that is every beat.

ⁱThe tempo is for every quarter, that is every beat.

^jThe tempo is for every eighth note, that is every beat.

TABLE A2. Experiment 2: Grahābēdham

| Title | Artist | Instrument | Tempo (MM) |
|---|----------------------|------------|-----------------|
| Grahābēdham Thillānā ^a | M. Balamuralikrishna | Vocal | 83 ^c |
| Grahābēdham in Hamsānandhi (to Hindhōlam) ^b | S. Kalyanaraman | Vocal | 97 ^c |
| Grahābēdham in Madhyamāvathi (to Hindhōlam) – 1 ^b | T.N. Seshagopalan | Vocal | 87 ^d |
| Grahābēdham in Madhyamāvathi (to Hindhōlam) – 2 ^b | T.N. Seshagopalan | Vocal | 87 ^d |
| Grahābēdham in Natabhairavi (multiple rāgams) ^b | M. Balamuralikrishna | Vocal | 84 ^c |
| Grahābēdham in Panthuvārāli (to Mōhanam) ^b | E. Gayathri | Veenā | 78 ^d |
| Grahābēdham in Shanmukapriyā (multiple rāgams) ^b | S. Kalyanaraman | Vocal | 83 ^d |
| Grahābēdham in Subhapanthuvārāli (multiple rāgams) ^b | T.N. Seshagopalan | Vocal | 83 ^d |
| Grahābēdham in Thōdi (multiple rāgams) ^b | S. Kalyanaraman | Vocal | 83 ^d |
| Grahābēdham in Thōdi (to Kalyāni) – 1 ^b | T.N. Seshagopalan | Vocal | 83 ^d |
| Grahābēdham in Thōdi (to Kalyāni) – 2 ^b | T.N. Seshagopalan | Vocal | 83 ^d |

Note. MM = Mälzel's Metronome; number of beats per minute.

^aActual version of the song: <https://www.youtube.com/watch?v=wnwzO1dQxuU> (last accessed December 5, 2015)

^bPrivate recordings.

^cThe tempo is for every quarter, that is every beat.

^dSince these are unmetred, the tempo is an approximation.

Appendix B

QUESTIONS ON IDENTIFYING MODULATIONS

1. In which mode is it easier to identify rāgam changes – instrumental or vocal?
2. How do you identify rāgam changes in singing/instrument? By swaram (notes)? By ear? Or how else?
3. To find out the name of a particular rāgam, do you compare with other known songs of the same rāgam? How often do you do this?*
4. Do you use jeeva swaram (characteristic notes) or prayōgam (characteristic phrases) to identify a rāgam?*
5. Is grahabēdham easier to identify in an instrument or in vocal music? Why?
6. Does familiarity of songs help develop expectation of rāgam changes?*
7. Does familiarity of progression of notes of a rāgam help develop expectation of changes in an unfamiliar song?*

*Only for Indian participants.