

Manodharmam: A Scientific Methodology for Improvisation and Cognition in Carnatic Music

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Abstract—Music is ubiquitous in human lives. Ever since the foetus hears the sound inside the mother's womb and later upon birth the baby experiences alluring sounds, the curiosity of learning emanates and evokes exploration. Music is an education than a mere entertainment. The intricate balance between music, education and entertainment has well been recognized by the scientific community and is being explored as a viable tool to understand and improve the human cognition. There are seven basic swaras (notes) Sa, Ri, Ga, Ma, Pa, Da and Ni in the Carnatic music system that are analogous to C, D, E, F, G, A and B of the western system. The Carnatic music builds on the conscious use of microtones, gamakams (oscillation) and rendering styles that evolved over centuries and established its stance. The complex but erudite raga system has been designed with elaborate experiments on srutis (musical sounds) and human perception abilities. In parallel, 'rasa' - the emotions evoked by certain srutis and hence the ragas been solidified along with the power of language in combination with the musical sounds. The Carnatic music branches out as Kalpita sangeetam (pre-composed music) and Manodharma sangeetam (improvised music). This article explores the Manodharma sangeetam and its subdivisions such as raga alapana, swara kalpana, neraval and ragam-tanam-pallavi (RTP). The intrinsic mathematical strategies in its practice methods toward improvising the music have been discussed in detail with concert examples. The techniques on swara weaving for swara kalpana rendering and methods on the alapana development are also discussed at length with an emphasis on the impact on the human cognitive abilities. The articulation of the outlined conscious practice methods not only helps to leave a long-lasting melodic impression on the listeners but also onsets cognitive developments.

Keywords—Carnatic, Manodharmam, music cognition, Alapana.

I. INTRODUCTION

IN many cultures, music is not a mere entertainment but an education. The Carnatic music, one of the Indian music systems that evolved over centuries, is not any exception. It is complex with experiments and improvisations designed and developed at different periods of time. Bharata's Natya Sastra, the universally accepted scientific system and foundation of Carnatic music, outlines the experimental details to formulate the 22 srutis (musical sounds) that are perceivable by the human ear [1]. The music that is termed as sangeetam is defined as the combination of vocal (e.g., Carnatic music), instrumental (e.g., Veena) and dance (e.g., Bharatanatyam): "Geetham vaadyam thadha nrutyam trayam sangeeta muchyate" as proclaimed in ancient Sanskrit verses [2]. In this set, Carnatic music bears the important components raga and tala; raga is the melodic form with ascending and descending patterns of swaras, gamakas

(oscillations) and chaya swaras (responsible for melody and emotion of raga), whilst tala asserts the rhythm.

There are two major branches of Carnatic music, namely kalpita sangeetam (precomposed music) and manodharma sangeetam (improvised music). The latter is based on the rules of ragas but explored and experimented to the best of artist's abilities. Raga alapana is one of these techniques wherein artist freely brings out the raga features. Certainly, it is challenging from the mathematical point of view but is emotionally enjoyable to the performer and listeners (rasikas) [3]. Improvisation is an acquired skill, indeed, and is attained with rigorous training that further gets empowered with the performer's creativity [4]. Such a process results in the execution of several real-time processes such as sensory, motor control and performance and memory retrievals in the human body. Toward this end, Sripada Pinakapani formulated several practice exercises on multiple ragas to build improvisation skills [5].

A. Kalpita Sangeetam

Kalpita sangeetam (KS) is predominantly precomposed by stalwarts Tyagaraja, Muthuswami Dikshitar, Syama Sastri and Muthiah Bhagavathar, to name a few. It includes initial practice verses such as saraliswaras, jantaswaras, alamkarams, varnams and kritis along with various other forms of musical compositions. A typical concert starts with a varnam and continues with kritis in various ragas. During the show, artist's artistry will be exhibited through improvisations. Toward this end, the intricacies of music forms are ascertainable by practicing kritis composed in different ragas and talas, which certainly paves the way for further exploration. More importantly, evaluation of phrases in varnams and kritis are foundation for improvisation.

B. Manodharma Sangeetam

Manodharma is a composite of 'manah' and 'dharma', portraying 'mind' and 'in accordance', in that order. Manodharma sangeetam (MS) relies on the performer's innate abilities that are dynamically created and displayed during the performance. Several precomposed compositions such as varnam, kriti, padam, jāvali and tillāna are presented before expanding on specified ragas of the chosen compositions. In this regard, aspirants will be exposed to various systematic methods during the practice stages toward gaining creative skills with precocious talents. There are several components of

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the MS as described below.

- Ragalapana: Expanding raga melody without rhythmic boundaries
- Swarakalpna: Group of swara phrases that are sung in conjunction with rhythm and lyrical phrase of any chosen part of kriti but within the raga boundary
- Neraval: Lyrical prosodies and creativity within the rhythmic cycles
- Tanam: Raga improvisation with syllables 'tana' and 'ananta'
- Pallavi: Exploring a lyrical line of phrases into multiple tempos and variations

Ragalapana: It is one of the most exciting techniques, and the performer could transform composition phrases and present with his/her own imagination and understanding of the raga [6]. It allows raga expansion without boundaries of rhythm (tala) or accompanying instrument. Usually syllables 'ta-da-ri-na' will be sung in the allowed sruti frequencies of the raga. Generally, they are intoned before a kriti and also as part of the RTP. Indication of certain typical phrases at the beginning of the alapana is customary for listeners to get associated with the raga.

Swarakalpna: The patterns of swaras are sung for a chosen line of lyric in a particular kriti, usually one line from pallavi or charanam of the composition, in the predefined rhythm, and generally accompanied by percussion instruments.

Neraval: It is composed of a line of a lyric from a particular kriti (composition) and is sung in various permutations and combinations with adherence to meters and accompaniment of percussion instruments. The diction, meaning of words, raga and tala are critically important.

Tanam: It represents rhythmic syllables 'tanamta-anamta-namta' and rendering within the allowed raga boundaries. Similar to the raga alapana, there is no tala framework needed. It is performed after alapana and before the pallavi. It could also be sung before a kriti.

Pallavi: 'Pa'dam, 'La'yam and 'Vi'nyasam is one to two lines of the composition usually set to 1 or 2 cycles. Generally, RTP involves the raga alapana, tanam, swarakalpna and pallavi.

II. TRAINING METHODS FOR MANODHARMAM

The MS is an intellectual exercise with spontaneity that follows a logical pattern and orderly thought. The earlier generation of music aspirants was expected to learn MS by listening to kritis of stalwarts and creating their own style. However, some advocates such as Sripada Pinakapani believed that while foundation concepts could be instituted by teachers (gurus), explorations ought to be mastered by the learners. The basic technical lessons like saraliswarams, jantaswarams, alamkarams and varnams along with concert-oriented compositions provide the required foundation for the MS. Some of the exercises listed below provides a methodical process to form swara combinations spontaneously. The initial training also includes repetition of raga phrases and swara patterns with a teacher's guidance. The knowledge of raga, certainly, improves by the repertoire. The compositions expose the

learner to different raga bhavas depending on the context of the lyrics. The well-rounded emotions of a particular raga could also be accomplished by learning more compositions.

Initial stages of learning alapana include observing compositions and raga characteristics such as graha amsa swara (beginning and end notes), signature phrases and variation of the sthayis (octave), in addition to garnering alapana perspectives of masters.

The alapana phrases chosen for a particular raga depend on the type of MS aspect, i.e., some phrases could be suitable for swarakalpna while others are for alapana. More importantly, phrases of alapana should be carefully selected to not to resemble other ragas. Each raga has its own set of signature phrases and gamakas (deflection swara to produce range of frequencies around the swara). The kriti in a concert is a dynamic musical form with neraval and swarakalpna, and new additions of embellishments and combinational phrases. Listening to established compositions is key for furthering and strengthening the innovation. A few areas of expertise required for improvisation are described below.

A. Mastering Laya (Tempo)

TABLE I
SYLLABLES BY NUMBER OF NOTES

Number of notes	Syllable
3	Ta-ki-ta
4	Ta-ka-dhi-mi
5	Ta-ka Ta-ki-ta
7	Ta-ki-ta Ta-ka-dhi-mi
9	Ta-ka Ta-ki-ta Ta-ka-dhi-mi

Tala refers to the measure of musical time and has components called laghu that has 3 or 4 or 5 or 7 or 9 beats and depends on jati and anu-dhrutam with 1 beat and dhrutam with 2 beats. Gathi refers to the number of notes in a beat. The concept of laya must be practiced with various gathi's. The syllable outlined in Table I aids significantly for the practice.

B. Swaras Practice/Weaving Swara Patterns

In Carnatic music, the seven swaras are represented by the consonants Sa, Ri, Ga, Ma, Pa, Da and Ni (referred as S, R, G, M, P, D and N, for brevity, in the rest of the discussion). In this system, S and P are prakruti swaras and are fixed notes, while R, G, M, D and N have two variants R1, R2, G1, G2, M1, M2, D1, D2 and N1 and N2 each making a total of 12 swaras. The melakarta raga schema evolved by adding another 4 swaras positions R3, G3, D3 and N3 as in Table II.

The swara combinations can be arranged in multiple patterns. The weaving patterns are known as yati. There are various types of yati, as listed below:

1. Gopuchha yati: As the name represents, the pattern resembles a cow tail; broad at the top and tapers as it reaches the end (Fig. 1).
2. Shrotovaha yati: It represents the pattern of a river; starts small at the beginning and expands as it progresses (Fig. 2).

TABLE II
SHODASA SWARA STHANAS

Swara name	Swaras	Possible varieties
Shadjamam	Sa	S Shadjamam
Rishabham	Ri	R1 Sudda rishabham
		R2 Chatusruti rishabham
		R3 Shatchutri rishabham.
Gandharam	Ga	G1 Sudda gandharam
		G2 Sadharana gandharam
		G3 Antara gandharam
Madhyamam	Ma	M1 Sudda madhyamam
		M2 Prati madhyamam
Panchamam	Pa	P – No variations
Dhaivatam	Da	D1 Sudda dhaivatam
		D2 Chatusruti dhaivatam
		D3 Shatchutri dhaivatam
Nishadam	Ni	N1 Sudda nishadam
		N2 Kaisiki nishadam
		N3 Kakali nishadam

SRGMPDNSRGMPDNŠ
RGMPDNSRGMPDN
GMPDNSRGMPD
MPDNSRGMP
PDNSRGM
DNSRG
NSR
S

Fig. 1 The gopuchha yati. The dot under or above the note indicates lower or upper octaves, respectively

S
NSR
DNSRG
PDNSRGM
MPDNSRGMP
GMPDNSRGMPD
RGMPDNSRGMPDN
SRGMPDNSRGMPDNŠ

Fig. 2 The shrotovaha yati. The dot under or above the note indicates the lower or upper octaves, respectively

3. Damaruka yati: This is an amalgamation of Gopuchha yati and Shrotovaha yati (Fig. 3).

SRGMPDNSRGMPDN
SRGMPDNSRGMPDN
RGMPDNSRGMPDN
GMPDNSRGMPD
MPDNSRGMP
PDNSRGM
DNSRG
NSR
NSR
DNSRG
PDNSRGM
MPDNSRGMP
GMPDNSRGMPD
RGMPDNSRGMPDN
SRGMPDNSRGMPDN
SRGMPDNSRGMPDN

Fig. 1 The damaruka yati. The dot under the note indicates the lower octave

4. Mrudanga yati: It represents the percussion instrument mrudangam. It is also a combination of Gopuchha yati and Shrotovaha yati, but in the reverse order (Fig. 4).

The following exercises are formulated based on the above concepts and imparted to aspirants during the training phase.

NSR
DNSRG
PDNSRGM
MPDNSRGMP
GMPDNSRGMPD
RGMPDNSRGMPDN
SRGMPDNSRGMPDNŠ
SRGMPDNSRGMPDNŠ
RGMPDNSRGMPDN
GMPDNSRGMPD
MPDNSRGMP
PDNSRGM
DNSRG
NSR

Fig. 4 The mrudanga yati. The dot under the note indicates the lower octave

i. Creative Patterns for Improving Manodharmam

Progression patterns: The progression patterns of exercises, as highlighted in Fig. 5, extend to three octaves from lower panchamam (P) to upper panchamam (P). They offer the ability to efficiently render swaras either in vocal or hand movements as in veena, the instrumental music.

Middle Octave	Lower – Middle – Upper Octave Ascending	Higher - Middle - Lower Octave Descending
S	P	P
SR	PD	PM
SRG	PDN	PMG
SRGM	PDNS	PMGR
SRGMP	PDNSR	PMGRŠ
SRGMPD	PDNSRG	PMGRŠN
SRGMPDN	PDNSRGM	PMGRŠND
SRGMPDNŠ	PDNSRGM P	PMGRŠNDP
SRGMPDNŠ	PDNSRGM P D	PMGRŠNDPM
SRGMPDN	PDNSRGM P DN	PMGRŠNDPMG
SRGMPD	PDNSRGM P DNŠ	PMGRŠNDPMGR
SRGMP	PDNSRGM P DNŠ R	PMGRŠNDPMGRŠ
SRGM	PDNSRGM P DNŠ R G	PMGRŠNDPMGRŠN
SRG	PDNSRGM P DNŠ R G M	PMGRŠNDPMGRŠND
SR	PDNSRGM P DNŠ R G M P	PMGRŠNDPMGRŠNDP
S	PDNSRGM P DNŠ R G M P	
Š	PDNSRGM P DNŠ R G M	PMGRŠNDPMGRŠNDP
SN	PDNSRGM P DNŠ R G	PMGRŠNDPMGRŠND
SND	PDNSRGM P DNŠ R	PMGRŠNDPMGRŠN
SNDP	PDNSRGM P DNŠ	PMGRŠNDPMGRŠ
SNDPM	PDNSRGM P DN	PMGRŠNDPMGR
SNDPMG	PDNSRGM P D	PMGRŠNDPMG
SNDPMGR	PDNSRGM P	PMGRŠNDPM
SNDPMGRS	PDNSRGM	PMGRŠNDP
SNDPMGRS	PDNSRGM	PMGRŠND
SNDPMGR	PDNSR	PMGRŠN
SNDPMG	PDNS	PMGRŠ
SNDPM	PDN	PMGR
SNDP	PD	PMG
SND	P	PM
SN		P
S		

Fig. 5 An example of the progression pattern of exercises. The dot under or above the note represents the lower or upper octave, respectively

Ladder patterns: The ladder patterns of exercises (Fig. 6) build on swara groups using a minimum of 2 swaras and extend up to 3, 4, 5, 7 and 9 combinations.

SRG ŠRGM
GMP MPDN
PDN NSRG
NSR MPDN
RGM NSRG
MPD GMPD
DNŠ DNŠR

Fig. 6 An example of the ladder pattern of exercises. The dot under the note represents the lower octave

These exercises can be stretched to multiple talas like dhruva, matya, jhampa and ata with different jati variations such as tisra (3 beats), chaturasra (4 beats), khanda (5 beats), misra (7 beats) and sankeerna (9 beats) of laghu.

The ladder patterns can be further extended with janta and dhatu combinations as shown in Fig. 7.

G G | P , P , || D P | Š , Š , ||
 va ra vee - na - Mru du pa - ni -
 Ğ S | D D P , || D P | G G R , ||
 va na ru ha lo - cha na raa - ni -
 G P | D Š D , || D P | G G R , ||
 su ru chi ra Bam - bha ra Ve - ni -
 G G | D P G , || P G | G R S , ||
 su ra nu tha Kal - ya - - ni -

Fig. 10 Notation of a part of a geetam in Mohana raga. The dot above the note represents the higher octave

Pallavi:
 G,G, R,, SSRR GGRR | SRGR SRSD | SRGP GRSR ||
 Ni.nnu. ko... ri... yu... nna... nu... ra... ..
 GPGG RSRG RRSR SRGR | GPGP DPDS | D,PG DPGR ||
 Ni... .. khi... .. la... .. lo. ka .. na. .. ya .. ka.
 Anupallavi:
 G,G, P,, GGPP DDP, | DŠDD PGDP | DGDP GRSR ||
 Na.nnu. pa.. lim.. .. pa. sa... .. ma.. .. ya.. mu ra.
 GGPP DPDS D ŠRŠ ĞR,Š | DŠRŠ ,DPD | ŠD,P GRSR ||
 na... .. mee. da.. kri. pa ju. . da. ra.....

Fig. 11 Notation of a part of a varnam in Mohana raga. The dot under or above the note represents the lower or upper octave, respectively

The 'a' sound practice of the geetam can provide a lead to the possible alapana as in Figs. 12 and 13. The alapana does not adhere to a meter but obeys the underlying raga characteristics of gamakas (oscillation), signature phrases and emotion.

GG P, P, D P, D Š DPGRS, GG P, P, D P, D, Š D, PGRS,
 ta da ri na. na na - - - - - ta da na - - - - - na
 Ğ, Š D, G P DP GG R, RG GP GP GRS,
 ta na ta. da ri nana na na . na
 GG D, P, D, P G, G R, DP G, R, G R, S,
 tada ri na na . ta na na na ta na , na
 SR, G, G, GR R, G P, P, DP D, D DSDPŠ,Š, DĞRŠRŠDŠ DRŠDŠD,P
 ta da ri na na ta da ri na na na na na ta na tada na.....
 GP DŠ D, P P G, G R, S D, P, D, S
 tada ta da na ,na na. na...

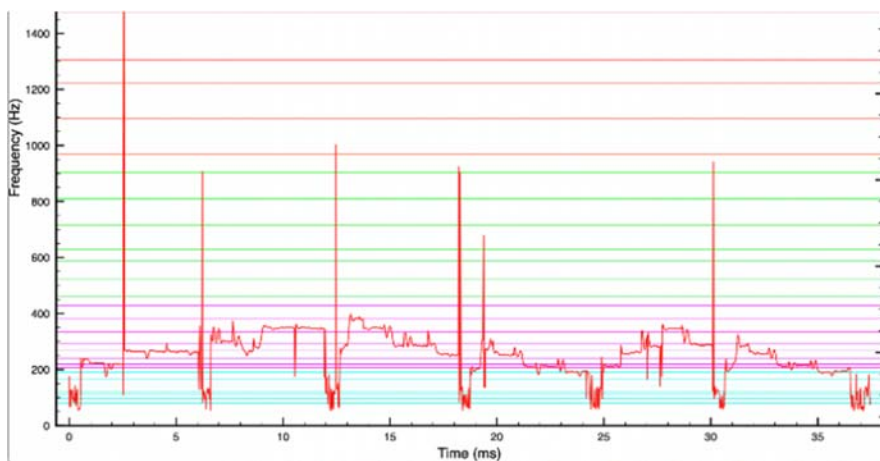


Fig. 14 Snipped sample geetam in Mohana raga. The frequencies on the y-axis are grouped into multiple octaves: lower - teal, middle - purple, higher - green and upper higher – red

IV. ANALYSIS OF MANODHARMAM WITH A RAGA

Mohana raga is the 28th Melakarta Harikambhoji janya raga,

Fig. 12 Snippet of alapana derived from Geetam in Mohana raga. The dot above the note represents the higher octave

GG R, R, SRGR,, SRGR SRSD SRGP, G, RSR G,
 Ta da . ri na Ta da ri na ta da ri na ta da na na
 GPGP DPDS D, PG DPGRR,
 ta da ri na.....ta da rina
 GG G, PP D, P, DŠD, PGDPD,
 ta da na..... na ta da na.....
 DPDS - D ŠR, Š - ĞR, Š DŠRŠ D,
 ta da na. na na
 DŠ ĞRŠ - DDP, GPDŠD, PGRS, D, P, D, S,
 ta da na na tada na..... na

Fig. 13 Snippet of alapana derived from Varnam in Mohana raga. The dot above or below represents the higher or lower octave, respectively

Both the compositions are bound to a rhythmic pattern with 6 beats structure and 32 beats structure. With this knowledge, the freeform of singing the notes of a raga with gamakas and the signature phrases associated with the raga are practiced with 'a' vowel tone and phrases like 'tadari', 'tana', etc. The sample graphs of geetam and alapana are highlighted in Figs. 14 and 15, respectively. This is the foremost step in learning and practicing the freeform of improvised music MS. Critical knowledge of existing kritis and signature phrases aids significantly to the on-the-fly exploration of a raga during the advanced phase of the practice.

an ancient raga with worldwide popularity. It is an audava-audava raga with only 5 swaras in the murchana. Its swaras

could be used as graha (beginning note) swara or nyasa (end note) swara. There are several popular compositions such as ‘O Rajivaksha’, ‘Rama Ninne Nammina’ and ‘Rara Rajavilochana’. Herein, ‘Rama Ninne Nammina’ has been chosen as a test example to explore the MS intricacies. The Praat tool was used to extract frequency, amplitude and *textEdit* feature to add the swara group for the frequency plot [7]. The Plot2 software has been used to compare multiple plots in a graph [8].

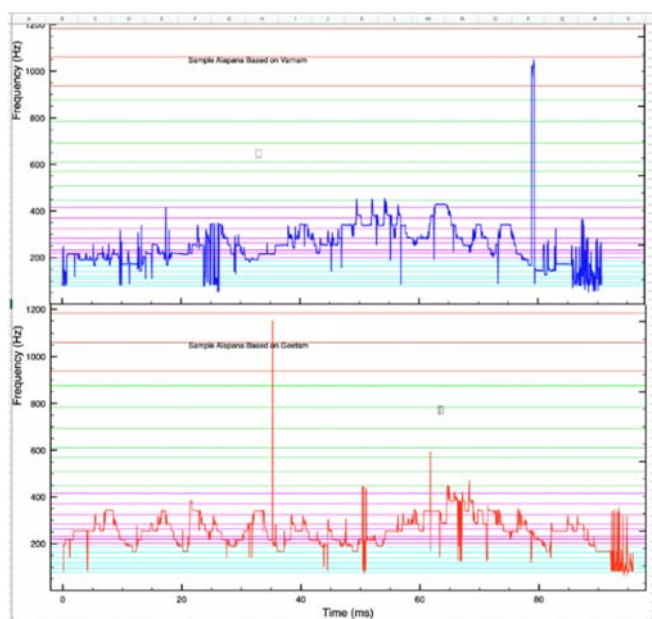


Fig. 15 Beginner version of alapana based on the Mohana raga varnam and geetam. The frequencies on the y-axis are grouped into multiple octaves: lower - teal, middle - purple, higher - green and upper higher - red

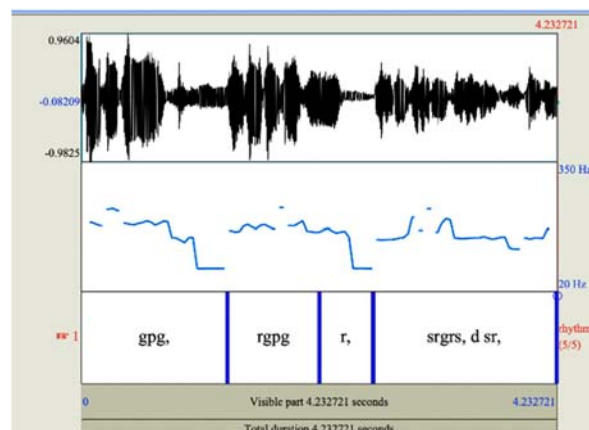


Fig. 16 Swarakalpana phrases for Mohana raga

A. Swarakalpana Analysis

The Swarakalpana has the nyasa swara as *Ri*. It is performed at the line ‘Rama Ninne’ in the composition. Some of the swara phrases from the kriti are shown in Figs. 16 and 17. The corresponding musical phrases are listed below:

- grs s,r, gpgr sd,s,r
- gpg, rgpg, srgrs, ds,r
- Janta swara prayogas like ggddp, rppgr, dsgrs, r
- Progression series like dś – pdś – gpds – pdg,pg,rsr
- Tisra swara combinations like dśś – pdd – gpp- rgg – srr – dss

Typically, performers explore 10-15 swara patterns that extend from the quarter cycle to more than 3 full octaves and concludes with a nearly 2 or more minutes of swara combinations at a stretch as highlighted in Fig. 15. This iteration extends to the 3 octaves and includes phrases of muktyai swaras, like ḡ,r,- ḡrśdp – ṛ,ś, ṛśdpḡ. – ś,d, śdpgr, etc.

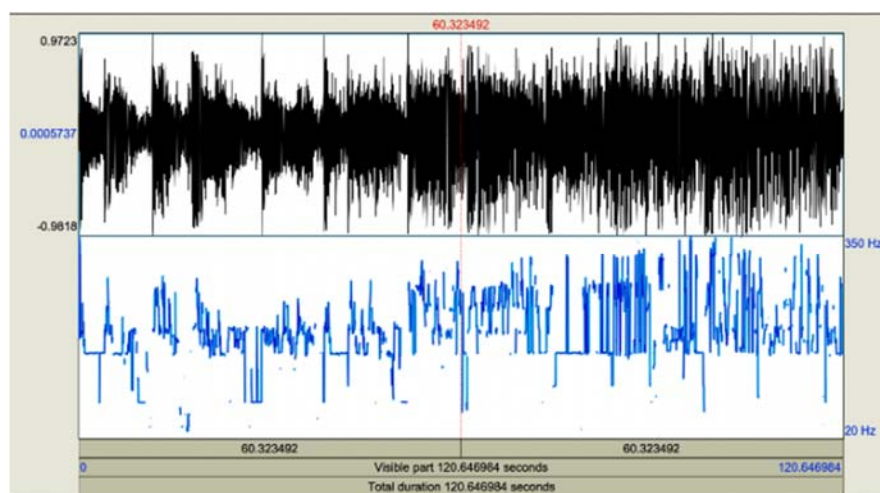


Fig. 17 Final iteration of the swarakalpana of Mohana raga

B. Raga Alapana

Raga alapana for the first 2 mins by the artist Balamurali Krishna for the composition Samaja varagamana at two concerts is illustrated in Fig. 18. The two alapanas are very

contrasting, portraying the improvisation ability of the artist.

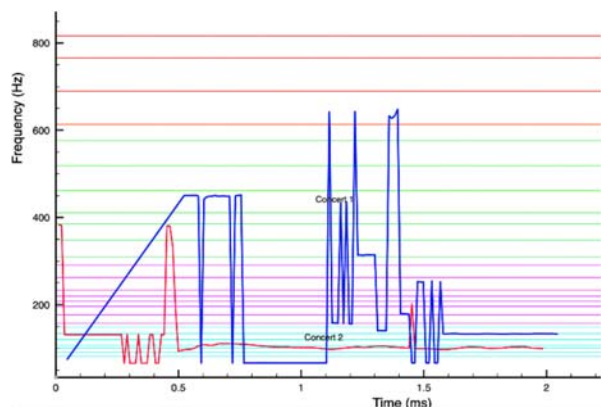


Fig. 18 Raga alapana for the composition Samaja varagamana by Balamurali Krishna at two concerts. The frequencies on the y-axis are grouped into multiple octaves: lower - teal, middle - purple, higher - green and upper higher - red

V. MUSIC COGNITION: IMPACT OF IMPROVISATION SKILLS

The amazing property of the brain is to perceive the complex patterns of audible sounds in split seconds. For example, in an orchestra involving multiple music players and a range of instruments, the audience can listen to a specific timbre at their will. The disentangling of individual components from a single audio signal is a bit complex and time consuming even for the modern generation computers but the human brain could accomplish it due to its intricate learning skills and intrinsic capabilities [9]. The decoding of melodic and acoustic music information is processed in the brain using both left and right hemispheres. The left hemisphere controls the perception of the speech prosody of the language. However, the musical melodies engage the right auditory cortex more than the left [10]. The cerebral morphology analysed through voxel-based morphometry brings out the importance of the right auditory cortex in musicians compared to non-musicians [11]. The functional magnetic resonance imaging (fMRI) clearly highlights the brain region networks linked to the improvisatory behaviours [12]. Although, there is limited research on the impact of Carnatic music improvisation on the brain functionality, experiments on trained pianists with musical improvisation similar to the permutation combinations up to 5 note melodic possibilities but with endless rhythmic combinations suggest the triggering activity in the brain regions [13]. The improved mathematical ability of school children with the Carnatic music training clearly stresses the power of music training to enhance the brain power [14]. Similarly, neural processes related to improvisations on guitar establish increased activity in the theta, alpha and beta frequency range of the brain regions [15]. All these findings inadvertently promote the ideology of using music improvisation protocols to increase the brain power with a positive impact on the cognitive abilities and Manodharma sangeetam is not any exception and warrants further explorations and in-depth study.

VI. CONCLUSION

This article outlines the music improvisation and music

cognition in the context of Carnatic music. The practical approaches to strengthen the creativity skills that improve the mathematical ability by dynamically forming the swara groups while adhering to the rules of the raga system have been explored in detail. A comprehensive review of the brain development is beyond the scope of this article. However, the neurobiology of music learning, especially with the improvisation process that involves mathematics, as in manodharmam of the Carnatic music, toward modulating the brain cognition is of special interest. The cerebral cortex, hippocampus and cerebellum continue to develop throughout the childhood, though the vast majority of the neurons are present at birth [16]. The plasticity of the brain and associated benefits encourage the need for the advancement of research on the music induced cognition. Designing and implementing novel pedagogical aspects related to improvisations for therapeutic benefits are the focus of current and future research.

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GLOSSARY

- Graha swara: Beginning note for raga exploration
- Nyasa swaras: End note for usually the raga is ended
- Amsa swara: Key note that usually brings out the raga bhava
- Audava ragam: Raga that contains 5 notes in the murchana (in the arohana/avarohana)
- Arohana: Sequence of swaras in ascending order
- Avarohana: Sequence of swaras in descending order
- Murchana: Arohana and avarohana of the raga
- Geetam: Simple composition learnt during the initial learning phase
- Varnam: Medium level of composition to strengthen the raga signature phrases, and the voice culture
- Kriti: The compositions with the raga emotion with lyrical prosodies

REFERENCES

- [1] P. Sambamoorthy, "History of Indian Music", *The Indian Music Publishing House*, 1960.
- [2] P. Sambamoorthy, "South Indian Music. Vol 1", *The Indian Music Publishing House*, 2007.
- [3] R. N. Iyengar, "Concept of Śruti, Svāra and Rāga of Classical Music in Sanskrit Texts", *Indian Journal of History of Science*, vol. 53.2, pp. 131-147, 2018.
- [4] Pressing, J., 1988. Improvisation: methods and models. In: Sloboda, J.A. (Ed.), *Generative Processes in Music: The Psychology of Performance, Improvisation, and Composition*. Clarendon Press, Oxford, pp. 129-178.
- [5] S. Pinakapani, "Manodharma Sangeetham", Telugu University, 1992.
- [6] Viswanathan, "The Analysis of Rāga Ālāpana in South Indian Music", *Asian Music*, vol. 9, pp. 13-71, 1977.
- [7] <https://praat.en.softonic.com/>.
- [8] <https://apps.micw.org/apps/plot2/>.
- [9] J. Fauvel., R. Flood., R. Wilson, "Music and Mathematics From Pythagoras to Fractals", Oxford University Press, 2006.
- [10] S. Koelsch, "Toward a neural basis of music perception – a review and updated model", *Frontiers in Psychology*, vol. 2, pp. 1-20, 2011.
- [11] P. Bermudez, R. J. Zatorre, "Differences in Gray Matter between Musicians and Nonmusicians", *N.Y. Acad. Sci.*, 1060, pp. 395-399, 2005

- [12] R. E. Beaty, "The neuroscience of musical improvisation, *Neuroscience and Biobehavioral Reviews*", vol. 51, pp. 8-117, 2015.
- [13] A. L. Berkowitz, D. Ansari, "Generation of novel motor sequences: The neural correlates of musical improvisation", *NeuroImage*, vol. 41, pp. 535-543, 2008.
- [14] V. Raja., D. O. Bhalla, "Impact of Carnatic music training on the mathematical ability of children", *Early Child Development and Care*, 2020.
- [15] M. Sasaki, J. Iversen, D. E. Callan, "Music Improvisation Is Characterized by Increase EEG Spectral Power in Prefrontal and Perceptual Motor Cortical Sources and Can be Reliably Classified From Non-improvisatory Performance", *Frontiers in Psychology*, vol.13, pp. 1-16, 2019.
- [16] P. Rakic, "Corticogenesis in human and nonhuman primates", *The cognitive neurosciences*, The MIT Press, pp. 127-145, 1995.