EFFECT OF PRESCRIPTIVE FORMULAE AND NUMBER OF CHANNELS (SIMULATED) ON PERCEPTION OF MUSIC PROCESSED THROUGH RECEIVER IN THE CANAL HEARING AID

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CERTIFICATE

This is to certify that this dissertation entitled **'Effect of prescriptive formulae and number of channels (simulated) on perception of music processed through receiver in the canal hearing aid'** is the bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 18AUD001. This has been carried out under the guidance of the faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this master's dissertation entitled **'Effect of prescriptive formulae and number of channels (simulated) on perception of music processed through receiver in the canal hearing aid'** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **'Effect of prescriptive formulae and number of channels (simulated) on perception of music processed through receiver in the canal hearing aid'** is the result of my own study under the guidance of Dr. Prashanth Prabhu P, Assistant Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
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Register No. 18AUD001

To Appa, Amma, Gayu,

YK thatha, and Girija paati

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ABSTRACT

Introduction: Music perception is one of the less-discussed topics when it comes to listening through a hearing aid. People with hearing loss who have more than mild degree, experience loss of audibility, and inability to appreciate music due to distortions in auditory processing (Gfeller and Knutson, 2003). Studies have shown that speech is processed much efficiently than music by hearing aids (Chasin & Russo, 2004; Divya, 2010). Hence there is a need to study the processing of music through the latest available technology of the hearing aids.

Aim: To study the effect of prescriptive formulae and the number of channels (simulated) on the perception of music processed through a Receiver-In-Canal (RIC) hearing aid.

Methods: Thirty participants were included in the present study, 15 musicians and 15 non-musicians, in the age range of 15-35 years. A RIC digital hearing aid was programmed to match the 'first fit', for four different conditions which include: 3-channel mode with the prescriptive formula NAL-NL2 (Tonal), 3-channel mode with the prescriptive formula NAL-NL2 (Non-tonal), 9-channel mode with the prescriptive formula NAL-NL2 (Tonal), and 9-channel mode with the prescriptive formula NAL-NL2 (Non-tonal). The output of the hearing aid was recorded from each condition, for six music stimuli (violin, flute, mridangam, ghatam, male vocal, and female vocal). Acoustical analysis, which included long term average spectrum and the perceptual analysis, which included perceptual quality rating on a 10-point rating scale under five domains were done.

Results and discussion: Data was analyzed individually for each of the music samples

used. Perceptual analysis revealed that for violin, mridangam, ghatam, male, and female vocal samples, both musicians and non-musicians preferred the NAL-NL2 Tonal formula over the NAL-NL2 Non-tonal formula. Among the different channels, 9-channel HA was preferred over 3-channel under few domains of flute, violin, and mridangam sample. In addition, the simulated music recordings had poorer ratings compared to the original music sample. Thus it can be inferred that slight increase in the lower frequency gain from the NAL-NL2 Tonal formula, proved to be beneficial for music perception, when the noise reduction, feedback monitor were not disabled with microphone set to omnidirectional mode. Also, in music samples that contained more of high frequency information, more number of channels improved their perception.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Music perception is one of the less-discussed topics when it comes to listening through a hearing aid, yet one cannot deny that music plays a prominent role in one's day-to-day life. Listening to songs is a go-to option for most when it comes to relaxation or dealing with stress. Yet once a person gets the hearing loss, this easy option is taken away from them, forcing them to adjust to a new life, devoid of the pleasure of quality music, which becomes one of the concerns.

People with hearing loss who have more than a mild degree, experience loss of audibility, and inability to appreciate music due to distortions in auditory processing (Gfeller & Knutson, 2003). People with sensorineural hearing loss usually have a poorer representation of a representation of musical characteristics such as the pitch of complex sounds (Larkin, 1983; Leek & Summers, 2001) and is often distorted (Arehart & Burns, 1999). Individuals with hearing loss often did not distinguish differences in dissonance among chord-like sounds as clearly as individuals with normal hearing, due to differences in roughness perception (Tufts & Molis, 2007). Also, the discrimination and detection of amplitude modulation have been inadequate in the presence of hearing loss (Grant, Summers & Leek, 1998).

Speech and music are very different signals concerning many aspects. The overall range of intensity of speech is around 65 dB SPL (Sound Pressure Level) [RMS (Root Mean Square)] while it is around 100dB (20 dB for brushes on the drum to 120 dB for guitars that are amplified) for music (Chasin & Hockley, 2018). LTASS (Long Term Average Speech Spectrum) of speech signals are well defined since immense data are available of the vocal tract characteristics, the resonances of the oral and nasal cavities. On the contrary, the LTASS of music is more similar to that of a low-pass noise in some cases, and that of high frequencies in the other, which makes it highly variable (Chasin & Hockley, 2018).

For a speech signal, the audibility is achieved by increasing the low frequencies, while the clarity is achieved by providing emphasis on higher frequencies. In the case of music, the F_0 (fundamental frequency) and its harmonics being heard across the frequency range, with considerable intensity, determine the quality of it. The difference between the peak amplitude and the RMS value (Crest factor) is around 12 dB for speech, but it goes up to 18-20 dB for music (Chasin & Hockley, 2018).

Manufacturers apply various approaches to developing superior music processing, such as providing a broad bandwidth, including more low frequencies in the response of the hearing aid (Punch, 1978; Franks, 1982). Franks (1982) showed that individuals with hearing impairment did not like a high-frequency emphasis when listening to music, but they liked having access to low frequencies.

The processing of speech and music signals via hearing aids is different. Studies have shown that speech is processed much well than music by hearing aids (Chasin & Russo, 2004; Divya, 2010). There have been various suggestions made for the modifications required in the settings of the hearing aid to perceive music better. They include: setting knee point higher, using the microphone in omnidirectional mode, switching off noise reduction algorithms and feedback analyzers, maintaining uniform compression ratio across all channels, using liner mode than non-linear settings, increasing the upper cut-off frequency, enabling slow compression (Chasin & Russo, 2004, Sushmit, 2007, Moore, 2012, Croghan, Arehart & Kates, 2014). However, when a hearing aid is prescribed to a client, these essential features are required by them to perceive speech better, especially in noisy conditions and hence can't be disabled for the sake of music. None of these studies have attempted to assess the processing of music without altering the prescribed default settings.

Hence there is a need to study the processing of music through the latest available technology of the hearing aids to provide the persons with hearing impairment a solution to perceive music. Also, as an audiologist, one shall be equipped with the knowledge of the best options available, thus making it easier to suggest to the clients when needed.

1.1 Aim of the study

To study the effect of prescriptive formulae and the number of channels (simulated) on the perception of music processed through a Receiver-In-Canal (RIC) hearing aid.

1.2 Objectives of the study

- To study the effect of NAL-NL2 (non-tonal) versus NAL-NL2 (tonal) prescriptive formula on the perception of music processed through RIC hearing aid.
- To study the effect of the number of channels (3-channel versus 9-channel) of RIC hearing aid on the perception of music processed through RIC hearing aid.

1.3 Null hypotheses

- There is no significant difference between NAL-NL2 (non-tonal) versus NAL-NL2 (tonal) prescriptive formula on the perception of music processed through RIC hearing aid.
- There is no significant difference between the number of channels (3-channel versus 9-channel) of RIC hearing aid on the perception of music processed through RIC hearing aid.

Chapter 2

Review of Literature

This section provides a brief review of the literature about music perception through hearing aid. The review has been divided into the following sections;

2.1 Music and its types

2.2 Music perception in individuals with normal hearing

2.3 Music perception in individuals with hearing impairment

2.4 Digital hearing aid and its developments

2.5 Effect of prescriptive formula

2.6 Music perception through the hearing aid

2.1 Music and its types

Music is defined as embodying, entraining, and transposably intentionalizing time in sound and action (Cross, 2003), typically expressed by voices and instruments that articulate patterns in pitch, rhythm, and timbre, and involving correlated gestural patterns of movement that may or may not be oriented towards sound production (Cross & Morley, 2008).

The musical instruments used in India have been classified into four types, according to *Natyashastra,* given by Sage Bharatha, which is one of the most widely accepted classifications even now (Ghosh, 2002; Rowell, 2015). They include:

a. Thatha vadhya (chordophones)

b. Sushira vadhya (aerophones)

c. Avanaddha vadhya (membranophones)

d. Ghana vadhya (idiophones)

A musical instrument, when played, standing waves are created within it (Schmidt-Jones, 2013). The fundamental frequency (F_0) of it depends on the structure and type of the instrument. The F_0 and its harmonics constitute the music produced. A few of these harmonics are enhanced (concerning the amplitude) by the build of the instrument, which gives each musical instrument their unique quality (Schmidt-Jones, 2013; Lenssen & Needell, 2014).

The music from different sources has a diverse frequency spectrum. The flute has a frequency range between 475 and 2100 Hz; the violin has a frequency range between 350 and 4000 Hz, phakwaj (similar to mridangam) has a frequency range between 65 and 1500 Hz, a male singer has a frequency range between 100 and 1800 Hz whereas a female singer has a frequency range between 150 and 3900 Hz (Ranade, 1964; Sharma & Mittal, 2016; Parimala, Munibhadrayya & Sudhindra, 2017). Also, studies on temporal modulation have shown that music has a typically lower modulation rate of 1-2 Hz compared to speech, which has a rate of 4-5 Hz (Ding, Patel, Chen, Butler, Luo & Poeppel, 2016; Ding, Patel, Chen, Butler, Luo & Poeppel, 2017).

The spectrally most intense region in speech stimuli is in the lower frequencies, and clarity, which has more to do with consonants, is derived from the higher frequencies (Chasin & Russo, 2004). Unlike speech, the phonemic spectrum of music is highly variable. Depending on the instrument, the perceptual needs of the musician or listener may vary, regardless of its physical output (Chasin & Russo, 2004).

Among the musicians, a violinist pays attention often to the relationship between the fundamental energy and the harmonics. A balance, both in relative intensity and the exact spectral location, is preferred. On the other hand, a clarinetist pays attention to the lower frequency (around 1500 Hz) inter-resonant breathiness. For a clarinet player, high-frequency information is not very important, other than to assist with loudness perception (Chasin & Russo, 2004).

Apart from the frequency, other factors such as intensity and crest factor also play an essential role in music perception. The typical range of intensity for speech is between 53-dB SPL and 83 dB SPL. But music can have an intensity range in the order of 100 dB SPL with peaks and valleys in the spectrum of ± 18 dB (Chasin & Russo, 2004; Chasin & Hockley, 2014).

A typical crest factor (the difference in decibels between the peaks in a spectrum, and the average or root mean square (RMS) value) with speech is about 12 dB, and musical instruments are on the order of 18 to 20 dB. With musical instruments, peaks tend to be sharper than for speech (Chasin & Russo, 2004; Chasin & Hockley, 2014).

Hence there is a need to assess the performance of the hearing aid processing for the different types of music (vocal and instrumental) as this would enable an audiologist to understand the requirements of the client and do the appropriate settings in programming, thus maximizing the utility and benefit of the hearing aid.

2.2 Music perception in individuals with normal hearing

Music perception occurs through a similar pathway like any other sound through the auditory system, starting from the external ear, middle ear, inner ear, auditory nerve, and finally reaching the cortex through the central auditory nervous system.

The increased volume of gray matter, increased size, and higher neural activity in Heschl's gyrus has been associated with musical aptitude (Schneider, Scherg, Dosch, Specht, Gutschalk, & Rupp, 2002; Limb, 2006). Through studies on melody and rhythm perception, mechanisms of hemispheric specialization have been explained (Limb, 2006; Parbery-Clark, Anderson & Kraus 2013). A significant (greater than 100%) increase in magnetoencephalography (MEG) activity within the primary auditory cortex was seen in professional musicians, compared to non-musicians. This was correlated with increased (130%) volume of gray matter within Heschl's gyrus in musicians compared to non-musicians (Schneider et al., 2002).

Acoustic change complex (ACC) measures were found to be significantly different between musicians and non-musicians. For the base frequency of 160Hz, a larger P2′ amplitude was seen in musicians than non-musicians (Liang, Earl, Thompson, Whitaker, Cahn, Fu, Xiang, et al., 2016).

In musicians (both vocalists and violinists), auditory memory and speech in noise perception abilities have found to be enhanced than in non-musicians, thus enhancing the overall auditory perceptual skills (Kumar & Krishna, 2019). Musicians outperformed non-musicians in detecting frequency changes in quiet and noisy conditions (Liang et al., 2016). Similarly, auditory stream segregation ability and the profile analysis thresholds were significantly better in musicians than non-musicians, along with a positive correlation between the performance and years of musical training (Johnson, Shiju, Parmar & Prabhu, 2020).

Musical training is associated with an enhancement in temporal fine structure (TFS) encoding and F_0 discrimination in young and older listeners with or without hearing impairment (Bianchi, Carney, Dau & Santurette, 2019). However, the musician's benefit decreased with an increase in hearing loss (Bianchi, Carney, Dau & Santurette, 2019). To understand the influence of speaking a tonal language (linguistic expertise) on music-related processing and perception, Bidelman, Gandour, and Krishnan (2011) did a study to compare brainstem responses of English-speaking musicians/non-musicians and native speakers of Mandarin Chinese. Stimuli used were tuned and detuned musical chords. The results showed that relative to non-musicians, both musicians and speakers of Mandarin Chinese had a more reliable brainstem representation of the defining pitches of musical sequences.

Hence there is a need to consider musicians as well as non-musicians to evaluate the outcome of music processed through a hearing aid, as it can help to understand the perceptual differences and preferences between musicians and non-musicians.

2.3 Music perception in individuals with hearing impairment (HI)

Music perception differs in an individual having a hearing impairment. Individuals with hearing impairment struggled in music quality perception (Cai, Zhao, Chen, Liang, Chen, Yang, et al., 2016), understanding melodies, distinguishing timbre, meter, harmony and other musical features (John, Rajan & Sajeev, 2018) compared to individuals with normal hearing.

The perception of changes in the pitch is one of the essential factors of music perception. Primary pitch relationships regarding music are coded in the initial stages of auditory neural processing (Bidelman & Heinz, 2011). Western music theory states that auditory nerve pitch-salience extents are correctly predicted by the ordering of hierarchical pitch and chordal sonorities (Bidelman & Heinz, 2011). Cochlear hearing impairment is found to compress pitch salience estimates between consonant and dissonant pitch relationships, causing the inability of listeners with hearing impairment to distinguish music as clearly as individuals with normal-hearing (Plomp & Levelt, 1965; Kameoka & Kuriyagawa, 1969; Bidelman & Heinz, 2011).

The perception of pitch changes is affected among the individuals with hearing loss, especially having low frequency loss, and is not overcome even after aiding with appropriate hearing aid (Schauwers, Coene, Heeren, Del Bo, Pascu, Vaerenberg, et al., 2012). Enhanced neural encoding of the speech sound's fundamental frequency than its upper harmonics is seen in musicians with hearing loss, along with a greater ability to hear in noise, compared to non-musicians (Parbery-Clark, Anderson & Kraus 2013).

Sharpness (related to brightness) is a dominant timbre feature for both, individuals with normal-hearing and those with hearing loss, using which the dominance of acoustic energy at high frequencies is perceived. Roughness is the perception of temporal envelope modulations in the range of 20-200 Hz that is thought to contribute to the perception of musical dissonance. Among individuals with hearing loss, sharpness and roughness perception are affected (Fitz & McKinney, 2010), which could be restored through the careful reestablishment of specific loudness and general audibility. This can lead to the restoration of the overall perception of music for individuals with hearing impairment (Fitz & McKinney, 2010).

Thus, it can be concluded that individuals with hearing impairment have poor music perception ability, including the perception of pitch, loudness, and timbre compared to individuals with normal hearing.

2.4 Digital hearing aid and its developments

Hearing aids (HAs) are designed to increase and restore the audibility of acoustic sounds through amplification, especially those parts of the speech spectrum that are below the listener's threshold (Ching, Dillon, & Byrne, 1998; Dillon, 2001). Research suggests that HAs can enhance the quality of life of adults with hearing impairment (Mulrow, Aguilar, Endicott, Tuley, Velez, Charlip, et al., 1990; Yueh, Souza, McDowell, Collins, Loovis, Hedrick, et al., 2001; Cohen, Labadie, Dietrich, & Haynes, 2004).

Digital HAs use digital signal processing (DSP), which is a signal sampling technique. A series of mathematical computations are used in DSP that changes the acoustic signal, as shown in Figure 2.1. In the central processing unit of the amplifier, the digital sample of the signal is processed according to an encoding algorithm. The signal is manipulated in terms of predetermined frequency response and overall level of gain. Algorithms include the rules for the digital calculations concerning the signal detection and analysis unit, decision rule, and time constants involved in the execution of the decisions of HAs during sound processing (Chung, 2004).

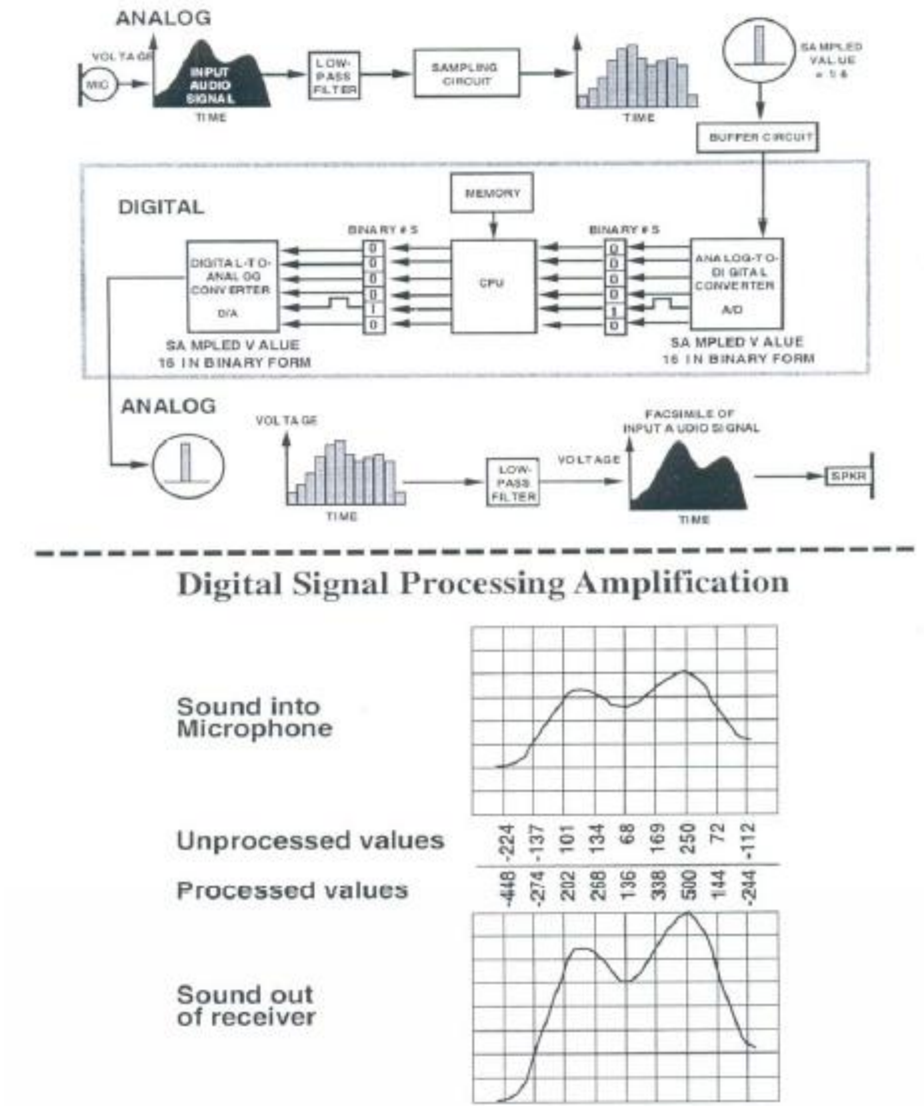

Figure 2.1: Digital Hearing Aid Block Diagram and Digital Signal Amplification (Staab, 2002)

Usually, digital HAs use wide dynamic range compression (WDRC) to amplify sounds. WDRC improves speech intelligibly through fast, automatic gain adjustments. It provides a lower amount of gain at higher input levels to improve comfort and higher gain for lower intensity sounds to improve audibility (Davies-Venn, Souza, & Fabry, 2007).

Noise reduction is one of the strategies that aim to improve listening comfort and speech intelligibility. Noise reduction strategies can be utilized through the use of directional microphones or through digital noise reduction (DNR) algorithms. Directional microphones focus on speech than noise, utilizing spatial differences between them. DNR algorithms focus on temporal separation and spectral differences between speech and noise (Chung, 2004).

Feedback cancellation systems are another feature that is intended to increase the comfort of the HA user. Feedback occurs when sound escapes from the ear canal and is fed back to the microphone, through which this sound is amplified along with other signals arriving simultaneously (Dillon, 2001). Even though these algorithms are aimed at maximizing the listening comfort, the activation of these features may reduce the sound quality of the signal of interest. For example, feedback reduction systems may reduce tonal components from the incoming signal, which can have an adverse effect on sound quality, especially harmonically rich signals such as music (Parsa, 2006).

The frequency responses of HAs may also impact on the sound quality of output. It is widely accepted that frequencies between 500 and 4000 Hz are essential for speech intelligibility (Dudley, 1939; Dunn & White, 1940; Fletcher & Galt, 1950; French & Steinberg, 1947; Mueller & Killion, 1992). Although this frequency range and output may be suitable for speech, they may not be sufficient for other acoustic stimuli such as music. A wider range of frequencies is essential for music perception and satisfaction than required for speech perception (Gfeller & Knutson, 2003).

For compression, individuals with mild-to-moderate degree hearing loss, binaurally fitted with behind-the-ear (BTE) hearing aids, showed a significant preference for WDRC for music perception compared to peak clipping and compression limiting (Davies-Venn, Souza & Fabry, 2007).

Van Buuren, Festen, and Houtgast, (1999) compared linear processing to varying degrees of compression when the signal was divided into 1, 2, or 16 processing bands. When 1 and 4 signal processing bands were compared across compression ratios of one (linear) to four, quality ratings were similar. When 16 processing bands were used, the same quality ratings were significantly poorer for compression ratios of two and four, compared to linear processing.

In general, the lesser number of channels is attributed to lower distortion of information and more clarity (Croghan, Arehart & Kates, 2014). There has been no consensus on the contribution of the number of channels required for ideal music perception. In a study done by Sushmit (2007) 15 channel hearing aid is recommended, while in the study done by Croghan, Arehart, and Kates (2014), the 3-channel hearing aid is recommended.

Hence, the effects of compression and the number of channels on music quality found mixed results (van Buuren, Festen & Houtgast, 1999; Davies-Venn, Souza & Fabry, 2007; Sushmit, 2007; Croghan, Arehart & Kates, 2014).

A study by Feldmann and Kumpf (1988) comprised a questionnaire investigation regarding the music enjoyment, and listening habits of 265 adults with postlingual hearing impairment using HAs. Thirty-six percent of the participants had formerly played an instrument or enjoyed singing. The majority (79%) of the participants felt that their hearing loss hampered their enjoyment of music. Common criticisms included difficulty understanding words of songs as well as distortions in pitch and melody. Besides, having to repeatedly adjust the volume on their HAs following volume changes in music was reported to be the 'most annoying feature.' Other reported problems were that overall the music was either too loud or soft (40%) and difficulty with melody recognition (37%). Nevertheless, in spite of this, 67% of participants indicated that HAs have made listening to music enjoyable again, and 74% of them used their HA 'more or less regularly' when listening to music.

As the technological improvements in hearing aids have grown enormously, there is a need to understand their efficacy in the field of music processing.

2.5 Effect of prescriptive formula

NAL-NL2 being a more recent formula and widely accepted, the salient features that have caused this improved fitting are listed below.

- NAL-NL2, like its predecessors, is primarily based on hearing thresholds (Keidser, Dillon, Flax, Ching & Brewer, 2011).
- In NAL-NL2, the results of optimization process can be selected to produce a prescription optimized for either tonal or non-tonal languages (Keidser et al., 2011).
- Compression ratios greater than those prescribed by NAL-NL1 is incorporated in NAL-NL2, at low and high input levels (Keidser et al., 2011).
- When compared between NAL-NL1 and NAL-NL2, NL2 provides greater gain for unilateral fittings than for bilateral fittings, but is less than NAL-NL1 (Keidser et al., 2011).

There are two versions of NAL-NL2: Tonal and Non-tonal, where slightly more gain is prescribed across the low frequencies for tonal than for non-tonal (Keidser et al., 2011) (Figure 2.2).

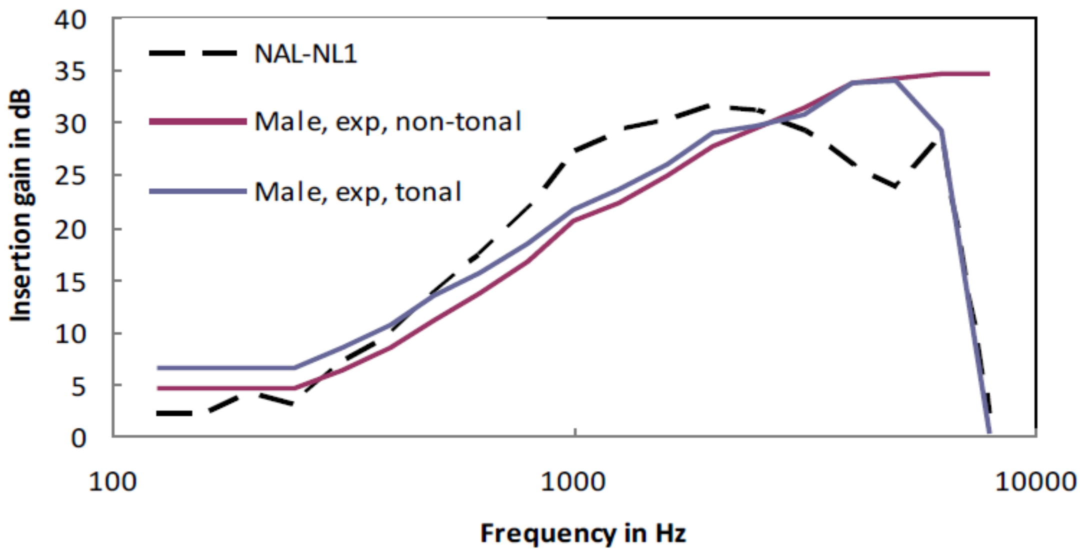

Figure 2.2: The gain at different frequencies for NAL-NL2 Tonal and NAL-NL2 Non-tonal prescriptive formulae for a male speaker (Keidser, Dillon, Häberle & Kristensen).

As there is a dearth of studies to understand the effect of tonal and non-tonal variations of NAL-NL2 formula in music processing in the hearing aid, there is a need to study it.

2.6 Music perception through the hearing aid

The use of compression in hearing aids is vital for the music signal due to its characteristically wide dynamic range. However, the overuse of compression may minimize intensity differences, making meaningful pitch relationships less apparent (Russo, 2006). A mild gain increase in the low frequencies can enhance music sound quality (Vaisberg, Folkeard, Parsa, Froehlich, Littmann, Macpherson, et al., 2017).

The compression settings for a music program in a hearing aid need to be no different from a speech in a quiet program (Chasin & Hockley, 2018). The use of a linear setting has been recommended when listening to recorded music through hearing aid compared to NAL-NL2 and semi-compression settings (Kirchberger & Russo, 2016).

For the perception of music, specific modifications in hearing aid settings are recommended such as setting knee point higher, omnidirectional microphone use, switching off noise reduction algorithms and feedback analyzers, maintaining uniform compression ratio across all channels (linear), increasing the upper cut-off frequency and enabling slow compression (Chasin & Russo, 2004; Sushmit, 2007; Moore, 2012; Croghan, Arehart & Kates, 2014; Moore, 2016).

Regarding the loudness aspects, a bass or cello player with hearing impairment would require less low- and mid-frequency amplification to establish equal or normal loudness perception. On the other hand, those who play instruments with more treble, such as the violin and flute, have each of their harmonics in different critical bandwidths, thus requiring the manipulation of amplification in those frequencies for the perception of loudness (Chasin & Russo, 2004).

Studies have shown that individuals with bilateral moderate to severe sensorineural hearing loss, preferred using hearing aids with non-linear frequency compression feature (in the form of multi-band compression) for listening to music. Non-linear frequency compression is believed to enhance the timbre and melody percept significantly (Uys, Pottas, Vinck & Van Dijk, 2012; Uys, Pottas, Van Dijk & Vinck, 2013). However, the adaptive linear response of the ADRO (Adaptive Dynamic Range

Optimization) processing, i.e., fewer fluctuations in output with the change in sound dynamics is quoted as the explanation for the superior music quality ratings, perceived sharpness, and improved clarity of sound compared to WDRC hearing aids (Higgins, Searchfield & Coad, 2012).

Looi, Rutledge and Prvan (2019) studied music perception across different degrees of hearing loss between mild to severe. The results indicated that the participants with a greater degree of HL reported poor perception of music, and that HAs made music sound significantly less melodic. Among individuals with mild and moderate loss, there was little difference in music perception, while a significantly poorer perception was seen with participants with severe hearing loss. Also, concerning musical preferences for the pitch range of music, the participants with severe hearing loss preferred male singers and lower-pitched instruments.

Individuals with symmetrical hearing loss perceived music to be more pleasant and natural compared to individuals with asymmetrical hearing loss (Cai, et al., 2016). Also, the higher the degree of hearing loss, the poorer was the perception of pleasantness and naturalness in individuals with symmetrical hearing loss. Hence it can be concluded that bilateral symmetrical hearing is essential to achieve an enhanced perception of music quality among the listeners with HI (Cai, et al., 2016).

Johnston (2009) did a study on music perception through hearing aid. A specific 'Music program' was used, where WindBlock Management, EchoBlock System, and WhistleBlock Technology were disabled. SoundRelax feature, which reduces impulse sounds, was set to 'Light.' The microphone was kept in omnidirectional mode. The results showed that the perception of music was enhanced upon using this setting, and at the same time, speech perception in quiet was unaffected. But since all the features that were disabled are required in a noisy condition and to reduce the listening effort in everyday life, these findings cannot be generalized.

Hockley, Bahlmann and Chasin (2010) did a study to assess the Bernafon's Live Music Plus program. It utilizes Live Music Processing to preserve the dynamic characteristics of music. Channel-free processing is used to amplify music accurately so that it is within the user's dynamic range, along with wideband frequency response to help make the music sound natural. A fixed directional microphone is also utilized to focus on performing musicians. They found that these settings enhance music perception and their overall listening experience.

But we can note that the highlights regarding the settings recommended, do not match between the studies and thus are controversial (Johnston, 2009; Hockley, Bahlmann, & Chasin, 2010). Leek, Molis, Kubli and Tufts (2008) did a telephone interview-based study to understand the prevalence of music-listening difficulties on sixty-eight elderly hearing aid users with mild to moderately severe bilateral sloping hearing loss. The results showed that almost 30% of the respondents stated that their hearing losses affected their enjoyment of music. About half of the respondents indicated that music was either too loud or too soft, although only about one-third reported difficulties with level contrasts within musical pieces.

Rutledge (2009) did a questionnaire-based study on music perception through HA. HA users with mild and moderate degrees of loss were taken, and the assessment was done across different types of music and musical instruments. The results showed that the style of music, which was listened to often by the participant, was rated to be sounding the best with HAs. In addition, the piano was rated as the instrument to sound the most natural and pleasant, and drum kit as the least natural. In terms of preferences of singer and pitch of the instrument, the male singer was significantly preferred over female singers, and low-pitched instruments were preferred considerably over high-pitched instruments. Upon comparing the mild and moderate subgroups, the participants in the mild subgroup rated instruments to be significantly less noisy and less sharp than the participants in the moderate subgroup. Also, it was seen that the moderate subgroup gave higher ratings for the overall enjoyment of listening to music with HAs than the mild subgroup.

In a survey done on hearing aid users by Madsen and Moore (2014), they found that only 40% of their participants had a music program in their aids. The similar listening experience was quoted by the participants with and without a specific music program in their aids (Madsen & Moore, 2014; Vaisberg, et al., 2017). This result questions the effectiveness of music programs in improving music perception.

A study was done on instrumentalists having hearing impairment and their reason to use the hearing aid. The findings showed that the primary motivation for their HA use was the need to hear the conductor's directions to meaningfully participate in music rehearsals (Vaisberg, Martindale, Folkeard & Benedict, 2019). This shows the importance of optimizing the hearing aid setting for listening to both speech and music inputs, without compromising each other. Also, highlighting the need to achieve this within the same program of the hearing aid, as switching between different programs, would not be feasible owing to the unpredictability of the music and speech inputs.

Thus, music perception is affected in individuals with hearing loss and is further deteriorated as the degree of loss increases above a moderate degree. More difficulties are seen with individuals with asymmetrical loss compared to the symmetrical loss. In the hearing aid's platform, music perception has not been established yet with precise setting recommendations to optimize the musical experience through them. With continually evolving technology, there is a need to assess, validate, and arrive at a consensus regarding the best possible solution to minimize listening effort and maximize enjoyment of music through hearing aids.

Chapter 3

Methods

3.1 Research Design: Cross-sectional Randomized Block Design

3.2 Sampling: Purposive Sampling

The present study aimed at studying the effect of prescriptive formulae and the number of channels (simulated) on the perception of music processed through a Receiver-In-Canal (RIC) hearing aid.

3.3 Participants

Thirty participants were included in the present study in the age range of 15-35 years. The musicians and non-musicians were grouped based on the questionnaire on music perception ability (Kumar, Devi, Arpitha & Khyathi, 2017). A score of >16 classified a person as a musician and a score of <16 classified a person as non-musician. The musician group data were collected from 15 participants (N=15) with a mean age of 21.26 years (age range of 15 to 35 years). The non-musician group data were collected from 15 participants (N=15) with a mean age of 21.55 years (age range of 15 to 35 years). Participants in both groups were age-matched.

3.4 Inclusion criteria

Participants of both the groups had normal hearing sensitivity, with pure tone thresholds of ≤15 dB HL at 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz for air-conduction and bone-conduction in both ears. Speech identification scores (SIS) of > 90 % at 40 dB SL (ref: speech recognition threshold, SRT) in both ears. Normal middle ear function, assessed by the middle ear analyzer with Type A tympanogram (middle ear peak pressure ranging from +50 to -100 daPa, & the admittance ranging from 0.5 to 1.75

ml), with the probe tone frequency of 226 Hz. The acoustic reflex, present bilaterally (ipsi & contra) at 500 Hz, 1000 Hz, and 2000 Hz (Wiley, Oviatt & Block, 1987). The participants having any complaint or history of psychological problems, otological problems, and neurological problems were excluded from the study.

3.5 Test Environment

The testing was carried out in a sound-treated room with ambient noise within permissible limits (ANSI S.3.1, 1991)

3.6 Instrumentation

For the programming of the hearing aid, a laptop installed with NOAH software, NOAH wireless hardware, and the RIC hearing aid was used. A personal computer connected with Lynx Sound card (Lynx AES 16 card, two Aurora 16 A to D convertor) and Genelec (Model 8020B Bi-Amplified) loudspeaker with a built-in amplifier were used to present the stimuli. G.R.A.S. 45BB KEMAR with the ear simulator RA0045, with the RIC hearing aid placed on its pinna and the hand-held analyzer (Brüel & Kjær Type 2270) was used to record the output from the hearing aid. A calibrated audiometer and immittance meter were used to carry out pure tone audiometry, speech audiometry, and immittance evaluation, respectively.

For the acoustic analysis of the music sample, to understand the frequency spectrum, a laptop installed with Praat software was used.

3.7 Procedure

3.7.1 Programming of Hearing aid (Simulation)

The characteristics of the Receiver-In-Canal (RIC) hearing aid used for hearing aid simulation are listed in Table 3.1

Table 3.1: *The characteristics of the RIC hearing aid used in the present study.*

Characteristics	**RIC Hearing aid**	**RIC Hearing aid**
Number of channels (Simulation)	3-channels	9-channels
Prescriptive formulae	NAL-NL2 (Tonal) NAL-NL2 (Non-tonal)	NAL-NL2 (Tonal) NAL-NL2 (Non-tonal)
Frequency response	<100Hz to >8kHz	<100Hz to >8kHz
Type of receiver	M Receiver	M Receiver
Dome	Double dome (M size)	Double dome (M size)
Maximum Power output (dB SPL)	114	114
Maximum Gain (dB)	50	50
Working current (mA)	2.1	2.1
Battery size	312	312

A RIC digital hearing aid with the features, as explained in table 3.1, was programmed using the hearing aid specific software that was installed in the personal computer, connected through NOAH software via NOAHwireless Link. The audiogram was simulated to a flat 50 dB sensorineural hearing loss.

The hearing aid was programmed to match the 'first fit' as prescribed by the respective prescriptive formula. The acclimatization level was set to 'new hearing aid user.' The microphone was set to Omni-directional mode. The feedback monitor and the digital noise reduction was set to the default recommended level.

Programming was done for four different conditions which include:

- Simulated to 3-channel mode with the prescriptive formula NAL-NL2 (Tonal).
- Simulated to 3-channel mode with the prescriptive formula NAL-NL2 (Non-tonal).
- Simulated to 9-channel mode with the prescriptive formula NAL-NL2 (Tonal).
- Simulated to 9-channel mode with the prescriptive formula NAL-NL2 (Non-tonal).

The gain curves of the hearing aid after programming are represented in figure 3.1; figure 3.2; figure 3.3 and figure 3.4.

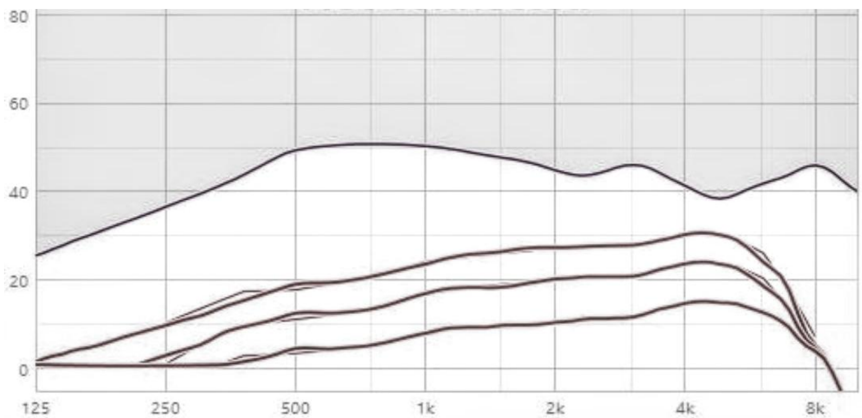

Figure 3.1: The gain curves of RIC HA of 3-channels with NAL-NL2 Tonal formula

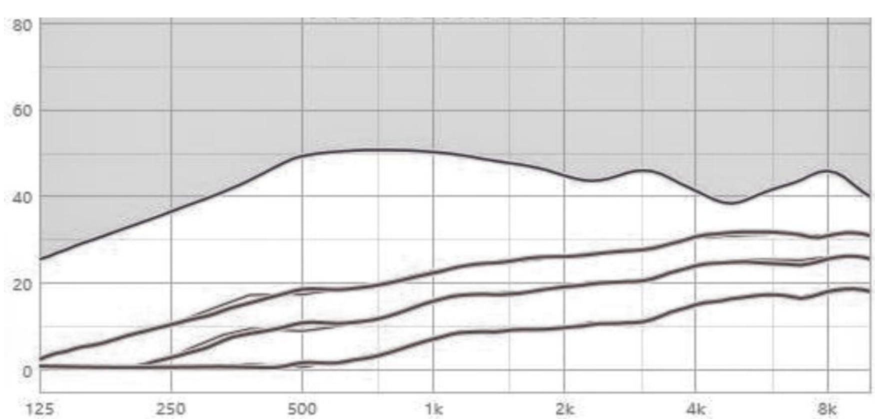

Figure 3.2: The gain curves of RIC HA of 3-channels with NAL-NL2 Non-tonal formula

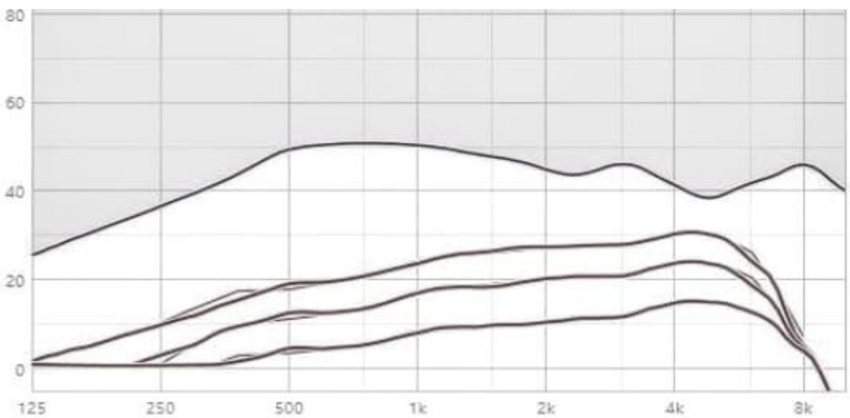

Figure 3.3: The gain curves of RIC HA of 9-channels with NAL-NL2 Tonal formula

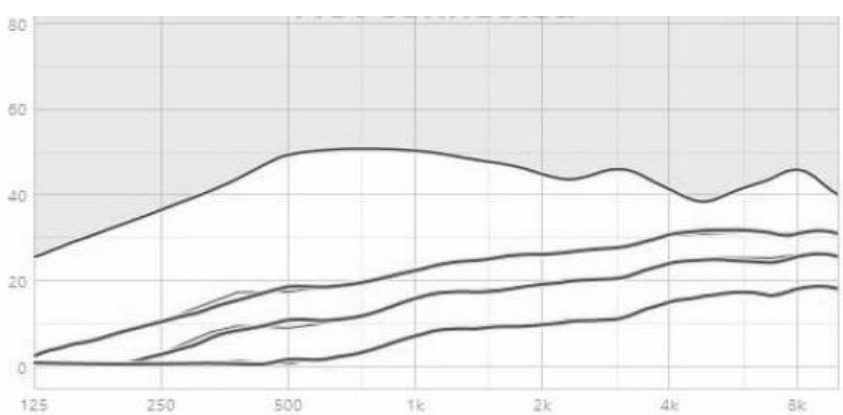

Figure 3.4: The gain curves of RIC HA of 9-channels with NAL-NL2 Non-tonal formula

The output of the hearing aid was recorded in all the four simulated conditions (3-channel NAL-NL2-tonal, 3-channel NAL-NL2-non-tonal, 9-channel NAL-NL2-tonal, and 9-channel NAL-NL2-non-tonal) for the following six music stimuli:

1. Thatha vadya/Chordophones (Violin)
2. Sushira vadya/Aerophones (Flute)

3. Avanaddha vadya/Membranophones (Mridangam)
4. Ghana vadya/Idiophones (Ghatam)
5. Male Vocal
6. Female Vocal

These six stimuli were considered as they covered all the different types of musical input one can perceive, in terms of the variety. A computer installed with Adobe Audition 3.0 was used to edit the chosen music samples, for the duration of 45sec, with a sampling rate of 44100 and a sampling format of 32-bit.

The output of the hearing aid (for all six stimuli) in all the four simulated hearing aid conditions were recorded using the following procedure:

3.7.2 Recording of the output from the hearing aid

The G.R.A.S. 45BB KEMAR with the ear simulator RA0045 was placed at the center of the test room, and the programmed RIC hearing aid with moderate (M) receiver and M size double dome was placed in its ear. The target stimulus was played through a personal computer routed via Lynx Sound card (Lynx AES 16 card, two Aurora 16 A to D convertor) and presented through Genelec (Model 8020B Bi-Amplified) loudspeaker with a built-in amplifier. The loudspeaker was placed at a distance of one meter and 0-degree Azimuth from the KEMAR. Figure 3.5 shows the instrumental set-up.

The output from the hearing aid was recorded using ½ inch microphone (Type 40AG) located in the KEMAR, monitored, recorded, and stored using the hand-held analyzer (Brüel & Kjær Type 2270). The level of the input stimulus was also monitored through Brüel & Kjær 2270 hand-held analyzer, maintaining the L_{eq} of 70dB peSPL in the duration of 45s for all the six stimuli, during the recording process.

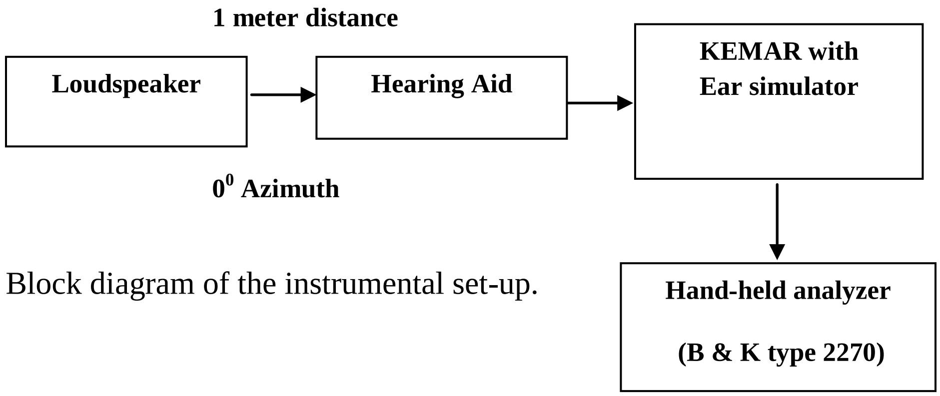

Figure 3.5: Block diagram of the instrumental set-up.

3.8 Analysis of the recorded samples

3.8.1 Acoustical analysis

The acoustical analysis included long term average spectrum. Original music samples (violin, flute, mridangam, ghatam, male vocal, and female vocal) were fed into the computer with Praat software (version 5.3.56). Spectral measures like frequency range (Hz) and the frequency with the maximum amplitude (Hz) were noted through the long term average spectrum.

3.8.2 Perceptual analysis

The perceptual quality rating was obtained from the participants using the 10-point rating scale given by Davies-Venn, Souza and Fabry (2007). The rating was done in five major domains which include:

- Loudness

How loud, strong, or forceful is the sound? The opposite of loud is soft, weak or timid/faint

- Fullness

How full is the sound? The opposite of full is thin.

- Sharpness

How hard, keen, or shrill is the sound? The opposite of sharp is gentle and soft.

- Pleasantness

How pleasing is the tonal quality of the music? The opposite of pleasant is unpleasant.

- Overall Impression

Considering everything that you have heard, what do you think about the music?

The participants were provided with the description and synonyms as recommended by Davies-Venn, Souza, and Fabry (2007) for each of the domains under which they had to rate the music samples. The participants were asked to rate the samples only after ensuring that they understood the description of the different domains appropriately.

The scores obtained were compared and analyzed between the variables considered for the study in both the groups.

3.9. Statistical Analyses

The perceptual and acoustical analysis data obtained were analyzed using the Statistical Package for Social Sciences (SPSS) software (version 21). Shapiro Wilks test of normality was performed to determine whether the data were normally distributed or not. Following this, the descriptive statistics (mean, standard deviation (SD), median, and range) of the ratings were done. To check for significant difference between the conditions, repeated measures ANOVA and Sidak post hoc analysis was done.

Chapter 4

Results

The objective of the study was to understand the effect of prescriptive formulae and the number of channels on the perception of music processed through a RIC hearing aid. Six different music samples were considered in this study.

4.1 Results of Acoustic Analysis

Acoustic analysis (long term average spectrum) was done for all the original music samples to understand the frequency range and the frequency with maximum amplitude in each of the samples used using Praat software. The details of the samples used are given in Table 4.1.

Table 4.1
Details of the music samples used in the study

Music sample	**Frequency range (Hz)**	**The frequency with the maximum amplitude (Hz)**
Violin	425 – 9,372	425
Flute	757 – 9,713	1,239
Mridangam	160 – 9,420	160
Ghatam	114 – 14,774	1,709
Male vocal	231 – 13,647	530
Female vocal	295 – 11,547	295

4.2 Results of Perceptual Analysis

The musicians and non-musicians rated a total of 30 samples each (6 music samples*5 conditions/sample). The rating was done on a 10-point rating scale in five domains (loudness, fullness, sharpness, pleasantness, and overall impression) where:

- Loudness: a rating of 10 implies the sample had comfortable loudness, and 1 implies uncomfortable loudness (either too loud or too soft).
- Fullness: a rating of 10 implies the sample felt full (had superior quality of the target), and 1 implies thin (poorer quality of the target).
- Sharpness: a rating of 10 implies the notes played were soft/ gentle, and 1 implies they were shrill/flat.
- Pleasantness: a rating of 10 implies the sample was pleasant, and 1 implies it was unpleasant.
- Overall impression: a rating of 10 implies the sample had a good overall impression, and 1 implies a poor overall impression.

Statistical analyses were done separately for the two groups: musicians and non-musicians, under each domain of the rating scale. Shapiro-Wilk test for normality was carried out, and it showed that the data followed a normal distribution.

4.2.1 Results of Violin Perception

The mean, standard deviation (SD), median, and range of the ratings for the violin sample are tabulated in Table 4.2. The graphical representation of the mean and SD are shown in Figure 4.1.

Table 4.2. *The mean, standard deviation, median, and range of the ratings for the violin sample*

Violin		Loudness		Fullness		Sharpness		Pleasantness		Overall Impression	
Conditions		NM	M	NM	M	NM	M	NM	M	NM	M
Tonal, 9-channel	Mean	8.47	8.60	8.07	8.33	7.73	8.33	8.53	8.27	8.27	8.40
	SD	1.13	0.99	1.10	1.40	1.58	1.29	0.83	1.16	1.16	1.12
	Median	8.00	9.00	8.00	8.00	7.00	8.00	8.00	8.00	8.00	8.00
	Range	7-10	7-10	7-10	5-10	4-10	6-10	7-10	7-10	7-10	7-10
Non-tonal, 9-channel	Mean	7.73	8.07	7.27	7.53	7.13	7.80	7.33	7.53	7.53	7.80
	SD	1.44	1.71	1.58	1.69	1.69	1.32	1.35	1.46	1.30	1.47
	Median	8.00	8.00	7.00	7.00	7.00	8.00	7.00	8.00	7.00	8.00
	Range	6-10	4-10	5-10	4-10	3-10	6-10	5-10	5-10	6-10	5-10
Tonal, 3-channel	Mean	7.87	8.13	7.80	7.40	7.33	7.60	8.00	7.47	7.87	7.60
	SD	1.36	1.73	1.32	2.03	1.50	1.96	1.31	2.03	1.25	1.81
	Median	8.00	9.00	7.00	8.00	7.00	8.00	8.00	8.00	8.00	7.00
	Range	5-10	4-10	6-10	4-10	5-10	4-10	6-10	3-10	6-10	4-10
Non-tonal, 3-channel	Mean	6.93	7.53	7.13	6.60	6.33	6.40	6.87	6.47	6.93	6.87
	SD	1.94	2.10	1.30	1.88	1.80	2.44	1.55	2.17	1.34	2.07
	Median	7.00	7.00	7.00	6.00	7.00	6.00	7.00	7.00	7.00	7.00
	Range	3-10	3-10	5-9	4-10	3-9	2-10	4-9	3-10	5-9	4-10
Without HA	Mean	8.80	8.87	8.60	8.93	8.53	8.80	8.67	8.73	8.60	8.93
	SD	1.15	1.06	1.30	1.03	1.55	1.08	1.18	1.28	1.24	1.22
	Median	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
	Range	7-10	7-10	7-10	7-10	5-10	7-10	7-10	6-10	7-10	7-10

Note - NM: Non-musicians, M: Musicians, HA: Hearing aid.

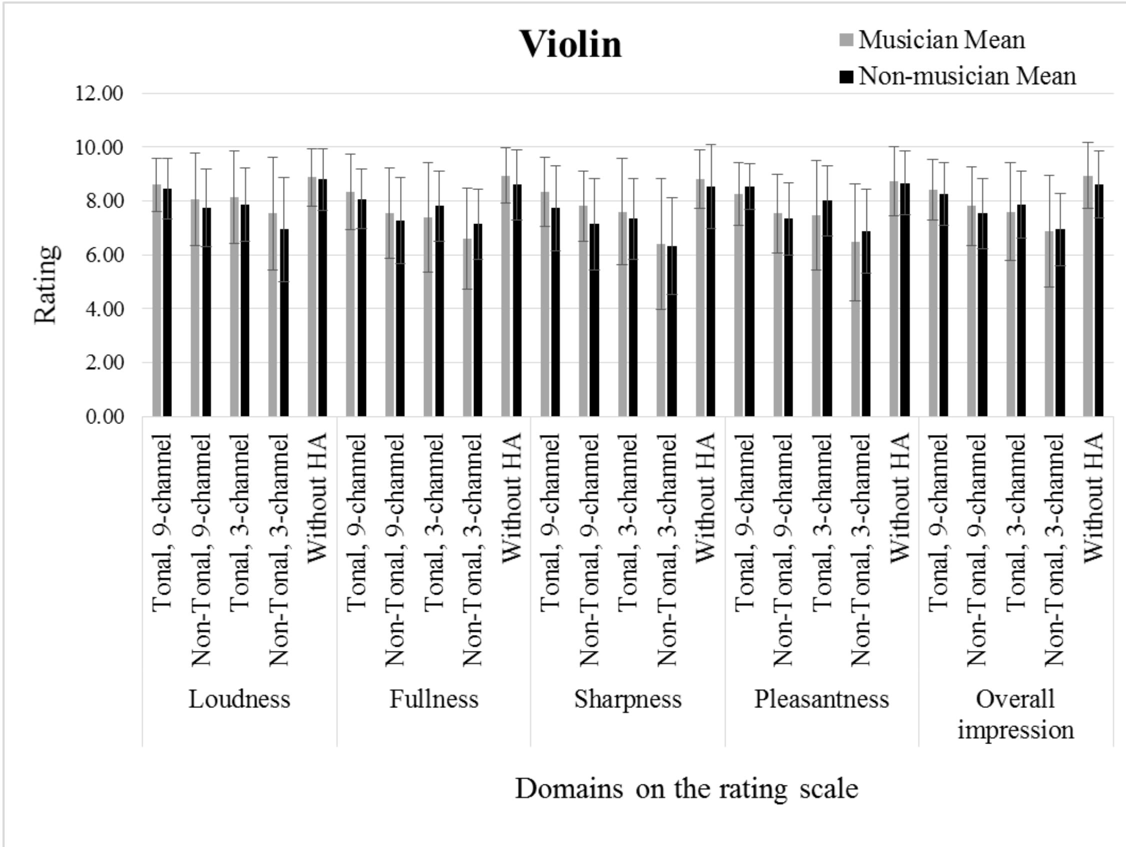

Figure 4.1: The graphical representation of the mean and SD, under each domain of rating for the violin sample.

4.2.1.1 Violin loudness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

In order to check for significant differences between the conditions, repeated-measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 8.50$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher 9-channel tonal compared to 9-channel non-tonal and 3-channel non-tonal conditions. In addition, scores were significantly poorer for 3-channel non-tonal and 9-channel non-tonal compared to without simulation condition. Thus, it shows that the scores were better for tonal compared to non-tonal, and 9-channel was better than 3-channel for loudness perception.

4.2.1.2 Violin loudness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean scores. Among the simulated conditions, the 9-channel tonal condition had the highest mean scores, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

In order to check for significant differences between the conditions, repeated-measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 5.30$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of loudness was similar across all simulated conditions.

4.2.1.3 Violin fullness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, a similar trend was observed with a 9-channel tonal condition having the highest mean and the 3-channel non-tonal condition having the least.

To check for significant differences between the conditions, repeated-measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 7.53$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness ratings were significantly higher for 9-channel tonal compared to 3-channel non-tonal conditions. In addition, scores were significantly poorer for 3-channel non-tonal compared to without simulation. There were no significant differences between other pairs. Thus, it shows that the scores were better for tonal compared to non-tonal for fullness perception.

4.2.1.4 Violin fullness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 9-channel non-tonal, 3-channel tonal, and the 3-channel non-tonal condition.

In order to check for significant differences between the conditions, repeated-measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 14.90$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness ratings were significantly higher for 9-channel tonal compared to 3-channel non-tonal conditions. In addition, compared to without simulation condition, the scores were significantly poorer for 3-channel tonal, 3-channel non-tonal and 9-channel non-tonal. Thus, it shows that the scores were better for tonal compared to non-tonal, and 9-channel was better than 3-channel for fullness perception.

4.2.1.5 Violin sharpness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

In order to check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 10.44$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Perception of sharpness was significantly higher for 9-channel tonal condition than 9-channel non-tonal and 3-channel non-tonal conditions. Additionally, the scores of the 3-channel tonal condition were significantly higher than the 3-channel non-tonal condition. Thus, the perception of sharpness was better for the tonal condition than the non-tonal condition.

4.2.1.6 Violin sharpness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 9-channel non-tonal, 3-channel tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated-measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 11.06$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for 9-channel tonal and without simulation conditions compared to 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of sharpness was better for 9-channel tonal condition than 3-channel non-tonal condition.

4.2.1.7 Violin pleasantness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated-measures ANOVA was carried out. It showed that there was a significant difference between

conditions [F (4, 56) = 10.39, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for the 9-channel tonal condition than 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of pleasantness was better for tonal than non-tonal conditions.

4.2.1.8 Violin pleasantness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 9-channel non-tonal, 3-channel tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated-measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 12.59, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness were significantly higher for without simulation compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for the 9-channel tonal condition than 9-channel non-tonal and 3-channel non-tonal conditions. In addition, higher scores were obtained for the 3-channel tonal condition than 3-channel non-tonal condition. Similarly, 9-channel non-tonal condition had significantly higher scores than the 3-channel non-tonal condition. Thus, the perception of pleasantness was better for tonal than non-tonal condition, and 9-channel was better than the 3-channel condition.

4.2.1.9 Violin overall impression: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 8.79$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for the 9-channel tonal condition than 9-channel non-tonal and 3-channel non-tonal conditions. In addition, higher scores were obtained for the 3-channel tonal condition than 3-channel non-tonal condition. Thus, the tonal condition had a better overall impression than non-tonal condition, and 9-channel was better than the 3-channel condition.

4.2.1.10 Violin overall impression: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 9-channel non-tonal, 3-channel tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F (4, 56) = 13.74$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal, 3-channel tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 9-channel tonal and 9-channel non-tonal conditions compared to 3-channel non-tonal conditions. Thus, the tonal condition had a better overall impression than non-tonal condition, and 9-channel was better than the 3-channel condition.

Observing the results obtained above, under each domain, it can be concluded that for violin perception, tonal formula and 9-channel was preferred over non-tonal formula and 3-channel.

4.2.2 Results of Flute Perception

The mean, standard deviation (SD), median, and range of the ratings for the flute sample are tabulated in Table 4.3. The graphical representation of the mean and SD is shown in Figure 4.2.

Table 4.3. *The mean, standard deviation, median and range of the ratings for the flute sample.*

Flute		Loudness		Fullness		Sharpness		Pleasantness		Overall Impression	
Conditions		NM	M	NM	M	NM	M	NM	M	NM	M
Tonal, 9-channel	Mean	8.60	7.80	8.20	7.40	7.60	7.33	7.73	6.80	8.00	7.40
	SD	0.99	1.82	1.08	1.77	1.40	1.88	1.49	1.97	0.85	1.45
	Median	9.00	8.00	8.00	7.00	8.00	8.00	7.00	7.00	8.00	7.00
	Range	7-10	4-10	6-10	4-10	5-10	4-10	6-10	3-10	7-10	5-10
Non-tonal, 9-channel	Mean	7.73	7.07	6.87	6.47	6.47	6.80	6.47	6.47	6.80	7.33
	SD	1.67	1.49	1.64	1.55	1.46	1.01	2.03	1.60	1.47	1.29
	Median	8.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
	Range	4-10	5-9	4-10	3-9	4-9	5-8	2-10	3-8	4-9	6-9
Tonal, 3-channel	Mean	8.13	7.87	7.67	7.73	7.53	7.07	7.80	7.60	7.80	7.73
	SD	1.19	1.13	1.68	1.83	1.60	2.15	1.66	1.55	1.52	1.44
	Median	8.00	8.00	8.00	8.00	8.00	7.00	8.00	8.00	8.00	8.00
	Range	7-10	6-9	5-10	4-10	5-10	3-10	5-10	5-10	5-10	6-10
Non-tonal, 3-channel	Mean	7.07	8.07	6.93	7.67	6.60	7.67	7.00	7.80	7.13	8.00
	SD	1.75	1.58	1.71	1.29	1.84	1.72	1.77	1.52	1.46	1.46
	Median	7.00	8.00	7.00	7.00	7.00	7.00	7.00	8.00	7.00	8.00
	Range	4-10	4-10	4-10	6-10	4-10	5-10	4-10	6-10	5-10	6-10
Without HA	Mean	8.73	8.20	8.40	7.67	8.00	7.80	8.47	8.27	8.33	8.07
	SD	0.80	1.15	1.06	2.02	1.07	1.86	1.69	1.53	1.11	1.39
	Median	9.00	8.00	8.00	8.00	8.00	8.00	9.00	8.00	9.00	8.00
	Range	7-10	6-10	7-10	4-10	7-10	4-10	5-10	4-10	7-10	5-10

Note – M: Musicians, NM: Non-musicians, HA: Hearing Aid.

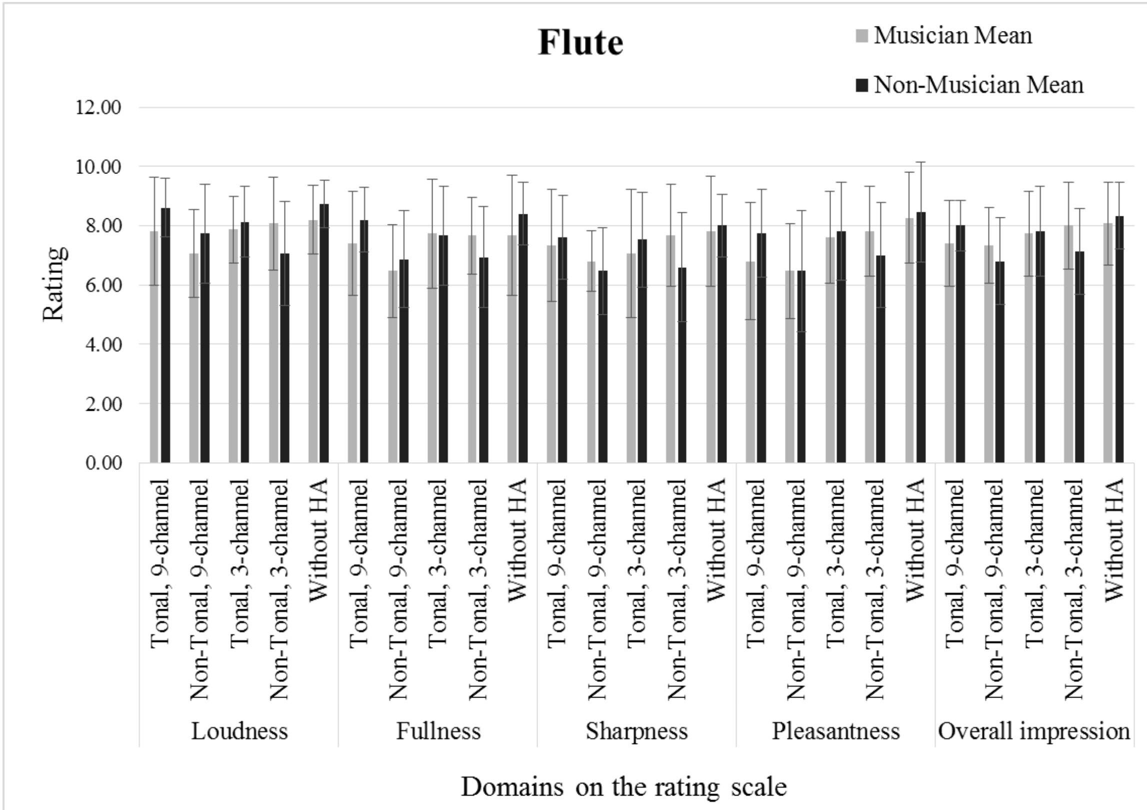

Figure 4.2: The graphical representation of the mean and SD, under each domain of rating for the flute sample.

4.2.2.1 Flute loudness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 8.01$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher 9-channel tonal compared to 3-channel non-tonal conditions. In addition, scores were significantly poorer for 3-channel non-tonal compared to without simulation condition. There were no significant differences between other pairs. Thus, it shows that the scores were better for 9-channel was better than 3-channel and tonal compared to non-tonal for loudness perception.

4.2.2.2 Flute loudness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, 3-channel non-tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F (4, 56) = 4.67$, $p<0.05$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of loudness was similar across all simulated conditions.

4.2.2.3 Flute fullness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel

tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 7.75$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness ratings were significantly higher for 9-channel tonal compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 3-channel tonal condition compared to 3-channel non-tonal condition. In addition, scores were significantly poorer for 9-channel non-tonal and 3-channel non-tonal conditions compared to without simulation. Thus, it shows that the scores were better for tonal compared to non-tonal, and 9-channel was better than 3-channel for fullness perception.

4.2.2.4 Flute fullness rating: Musicians

The descriptive statistics showed that among all the conditions, the 3-channel tonal condition had the highest mean score, followed by without HA and 3-channel tonal, 9-channel tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 3.71$, $p<0.05$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness ratings were significantly higher for without simulation condition compared to the 9-channel non-tonal condition. There were no significant differences between other pairs. Thus, it shows that fullness perception was similar across all simulated conditions.

4.2.2.5 Flute sharpness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 7.60$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal conditions. Also, scores were significantly higher for 9-channel tonal condition than 9-channel non-tonal condition. Additionally, the scores of the 3-channel tonal condition were significantly higher than 9-channel non-tonal and 3-channel non-tonal conditions. Thus, the perception of sharpness was better for the tonal condition than non-tonal condition.

4.2.2.6 Flute sharpness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, 3-channel non-tonal condition had the highest mean score, followed by 9-channel tonal, 3-channel tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was no significant difference between conditions [$F (4, 56) = 1.78$, $p>0.05$]. Thus, the perception of sharpness was similar across all conditions.

4.2.2.7 Flute pleasantness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F (4, 56) = 6.83$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 3-

channel tonal condition compared to 3-channel non-tonal condition. There were no significant differences among the other pairs. Thus, the perception of pleasantness was better for tonal than non-tonal conditions.

4.2.2.8 Flute pleasantness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, 3-channel non-tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 8.00$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation compared to 9-channel tonal and 9-channel non-tonal conditions. Also, a significantly higher score was obtained for 3-channel non-tonal condition than 9-channel non-tonal condition. Thus, the perception of pleasantness was better through 3-channel than 9-channel condition.

4.2.2.9 Flute overall impression: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel

tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 5.89, p<0.05]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal condition. Also, significantly higher scores were obtained for the 9-channel tonal condition than 9-channel non-tonal condition. There were no significant differences among the other pairs. Thus, tonal conditions had a better overall impression than non-tonal conditions.

4.2.2.10 Flute overall impression: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, 3-channel non-tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was no significant difference between conditions [F (4, 56) = 2.48, p>0.05]. Thus, the overall impression was similar across all conditions.

Observing the results obtained above under each domain, it can be concluded that for flute perception, tonal formula and 9-channel was preferred over non-tonal formula and 3-channel, except in case of musicians who preferred 3-channel for pleasantness.

4.2.3 Results of Mridangam Perception

The mean, standard deviation (SD), median and range of the ratings for the mridangam sample are tabulated in Table 4.4. The graphical representation of the mean and SD is shown in Figure 4.3.

Table 4.4. *The mean, standard deviation, median and range of the ratings for the mridangam sample.*

Mridangam		Loudness		Fullness		Sharpness		Pleasantness		Overall Impression	
Conditions		NM	M	NM	M	NM	M	NM	M	NM	M
Tonal, 9-channel	Mean	6.87	7.27	6.93	6.93	6.53	6.47	6.73	7.27	6.80	7.13
	SD	1.55	1.58	1.49	1.83	1.51	2.36	1.62	2.15	1.47	1.85
	Median	7.00	8.00	7.00	7.00	7.00	7.00	7.00	8.00	8.00	8.00
	Range	4-9	4-9	4-9	4-10	4-8	1-9	4-9	4-10	4-8	4-10
Non-tonal, 9-channel	Mean	6.33	6.87	5.87	6.00	5.20	5.67	5.53	6.07	5.60	6.13
	SD	1.63	1.89	1.55	1.51	1.74	2.09	1.55	1.87	1.68	1.69
	Median	7.00	7.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	Range	3-9	4-10	2-8	4-9	2-7	1-9	3-8	4-10	3-8	4-9
Tonal, 3-channel	Mean	6.40	6.40	6.80	6.60	6.20	6.07	6.53	6.47	6.47	6.60
	SD	1.64	1.92	1.57	1.72	1.86	2.37	1.69	2.26	1.51	1.88
	Median	7.00	6.00	7.00	7.00	7.00	6.00	7.00	6.00	7.00	7.00
	Range	3-9	3-9	4-9	4-10	3-8	1-10	4-9	3-10	4-9	4-10
Non-tonal, 3-channel	Mean	6.00	6.33	5.93	5.93	5.40	5.47	5.47	6.00	5.67	5.93
	SD	1.60	1.72	1.44	1.91	1.68	2.26	1.73	2.54	1.80	1.94
	Median	6.00	7.00	6.00	6.00	6.00	5.00	5.00	5.00	6.00	6.00
	Range	2-9	3-9	4-8	3-9	3-8	1-10	3-8	3-10	1-8	3-9
Without HA	Mean	7.60	8.13	7.67	8.07	7.13	7.80	7.33	7.87	7.40	8.27
	SD	1.50	1.60	1.29	1.39	1.69	1.66	1.45	1.89	1.35	1.22
	Median	8.00	8.00	7.00	8.00	7.00	8.00	8.00	8.00	7.00	8.00
	Range	5-10	5-10	5-9	6-10	5-10	4-10	5-9	3-10	5-9	7-10

Note: M; Musicians, NM: Non-musicians, HA: Hearing Aid.

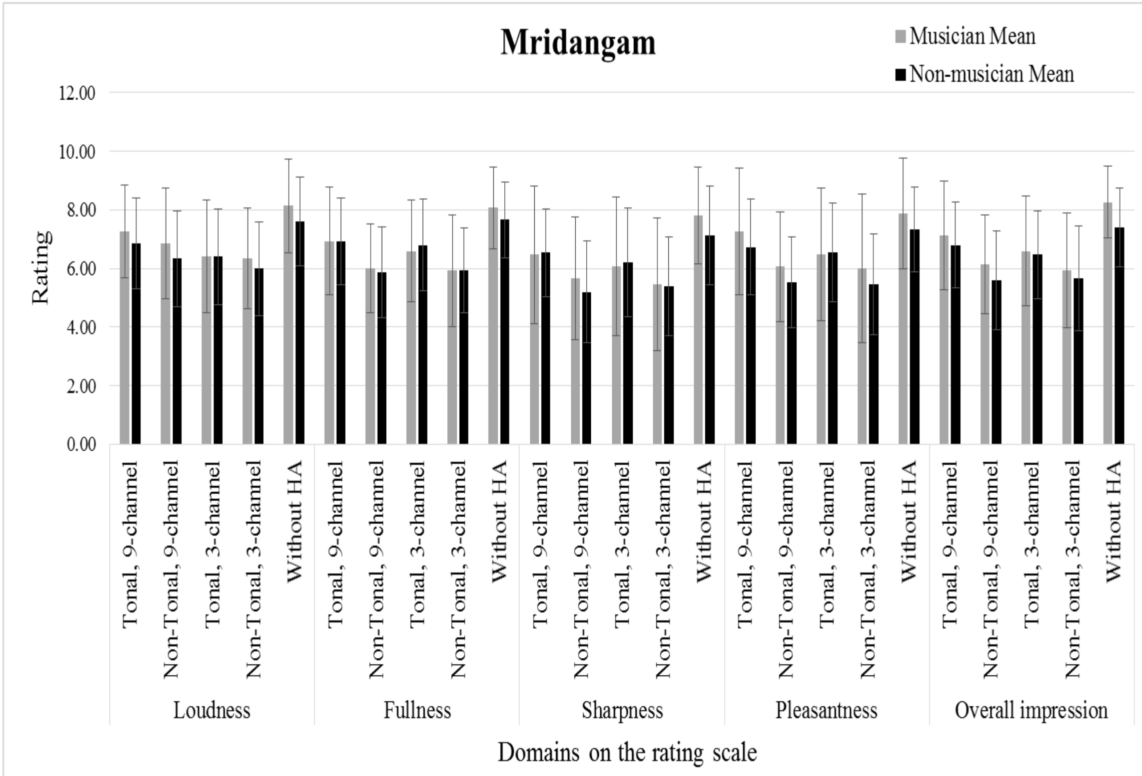

Figure 4.3: The graphical representation of the mean and SD, under each domain of rating for the mridangam sample.

4.2.3.1 Mridangam loudness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 7.36$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 3-channel non-tonal condition. There were no significant differences between other pairs. Thus, the perception of loudness was similar across all simulated conditions.

4.2.3.2 Mridangam loudness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 9-channel non-tonal, 3-channel tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 9.74$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal, 3-channel tonal, and 3-channel non-tonal conditions. In addition, the 9-channel tonal condition had significantly higher scores than the 3-channel tonal condition. There were no significant differences between other pairs. Thus, the perception of loudness was better for 9-channel and tonal conditions.

4.2.3.3 Mridangam fullness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 8.24$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, the scores of the 3-channel tonal condition were significantly higher than the 9-channel non-tonal condition. There were no significant differences between other pairs. Thus, it shows that the scores were better for tonal compared to non-tonal for fullness perception.

4.2.3.4 Mridangam fullness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 14.09$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness ratings were significantly higher for 9-channel tonal compared to 9-channel non-tonal and 3-channel non-tonal conditions. Similarly, the scores were significantly higher for 3-channel tonal compared to 3-channel non-tonal conditions. In addition, compared to without simulation condition, the scores were significantly poorer for 3-channel tonal, 3-channel non-tonal and 9-channel non-tonal conditions. Thus, it shows that the scores were better for tonal compared to non-tonal, and 9-channel was better than 3-channel for fullness perception.

4.2.3.5 Mridangam sharpness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 7.66$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal condition. The perception of sharpness was significantly higher for 9-channel tonal condition than 9-channel non-tonal condition. Additionally, the scores of the 3-channel tonal condition were significantly higher than 9-channel non-tonal and 3-channel non-tonal conditions. Thus, the perception of sharpness was better for the tonal condition than non-tonal condition.

4.2.3.6 Mridangam sharpness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 7.98$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of sharpness was similar across all simulated conditions.

4.2.3.7 Mridangam pleasantness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel

tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 8.51, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for the 9-channel tonal condition than 9-channel non-tonal condition. In addition, significantly higher scores were obtained for the 3-channel tonal condition than 3-channel non-tonal condition. Thus, the perception of pleasantness was better for tonal than non-tonal conditions.

4.2.3.8 Mridangam pleasantness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 6.54, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for 9-channel tonal condition than 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of pleasantness was better for tonal than non-tonal conditions.

4.2.3.9 Mridangam overall impression: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 9.44$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 9-channel tonal and 3-channel tonal conditions than 9-channel non-tonal conditions. Thus, the tonal conditions had a better overall impression than non-tonal conditions.

4.2.3.10 Mridangam overall impression: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel

tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F (4, 56) = 19.15$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal, 3-channel tonal, and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 9-channel tonal and 9-channel non-tonal conditions compared to 3-channel non-tonal conditions. In addition, significantly higher scores were obtained for 3-channel tonal condition compared to 3-channel non-tonal condition. Thus, the tonal condition had a better overall impression than non-tonal condition, and 9-channel was better than the 3-channel condition.

Observing the results obtained above under each domain, it can be concluded that in most domains, the perception through tonal formula was better than non-tonal. Among the preference for the number of channels, 9-channel was preferred for loudness and fullness among musicians and had a better overall impression among the non-musicians for the perception of mridangam.

4.2.4 Results of Ghatam Perception

The mean, standard deviation (SD), median, and range of the ratings for the ghatam sample are tabulated in Table 4.5. The graphical representation of the mean and SD are shown in Figure 4.4.

Table 4.5. *The mean, standard deviation, median and range of the ratings for the ghatam sample.*

Ghatam		Loudness		Fullness		Sharpness		Pleasantness		Overall Impression	
Conditions		NM	M	NM	M	NM	M	NM	M	NM	M
Tonal, 9-channel	Mean	7.40	7.27	7.33	6.47	6.67	6.40	6.67	6.33	7.13	6.73
	SD	1.60	1.83	1.50	1.55	1.88	1.55	2.23	1.80	1.73	1.58
	Median	8.00	7.00	7.00	7.00	7.00	6.00	7.00	6.00	7.00	7.00
	Range	3-9	4-9	3-9	4-9	3-10	4-9	2-10	3-9	3-9	4-9
Non-tonal, 9-channel	Mean	6.13	6.80	6.40	6.07	5.87	5.80	6.33	6.00	6.20	6.07
	SD	1.81	1.86	1.77	1.44	2.07	1.27	1.72	1.65	1.57	1.44
	Median	6.00	7.00	7.00	6.00	6.00	6.00	7.00	6.00	7.00	6.00
	Range	2-8	3-9	3-9	4-9	2-9	3-8	3-9	3-9	3-9	4-9
Tonal, 3-channel	Mean	6.80	7.33	6.67	6.60	6.40	6.60	6.40	6.47	6.60	6.73
	SD	1.61	1.54	1.92	1.81	2.32	1.55	2.29	1.64	2.10	1.22
	Median	7.00	8.00	7.00	6.00	7.00	6.00	7.00	6.00	7.00	7.00
	Range	3-9	4-9	3-9	4-10	2-9	5-10	2-9	4-10	2-9	5-9
Non-tonal, 3-channel	Mean	6.07	6.67	6.07	5.80	5.87	6.27	5.73	6.00	6.07	6.20
	SD	1.94	1.72	2.12	1.52	1.81	1.71	1.94	1.73	1.67	1.27
	Median	7.00	7.00	6.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00
	Range	1-9	4-9	1-9	4-8	3-8	4-10	2-8	4-10	3-8	4-8
Without HA	Mean	7.67	7.67	7.27	7.60	7.27	7.33	7.60	7.67	7.47	7.60
	SD	1.59	1.63	1.67	1.96	1.79	2.41	1.50	1.99	1.36	1.88
	Median	8.00	8.00	7.00	7.00	8.00	7.00	8.00	8.00	7.00	8.00
	Range	5-10	6-10	5-10	5-10	4-10	3-10	5-10	4-10	6-10	5-10

Note – NM: Non-musicians, M: Musicians, HA: Hearing Aid.

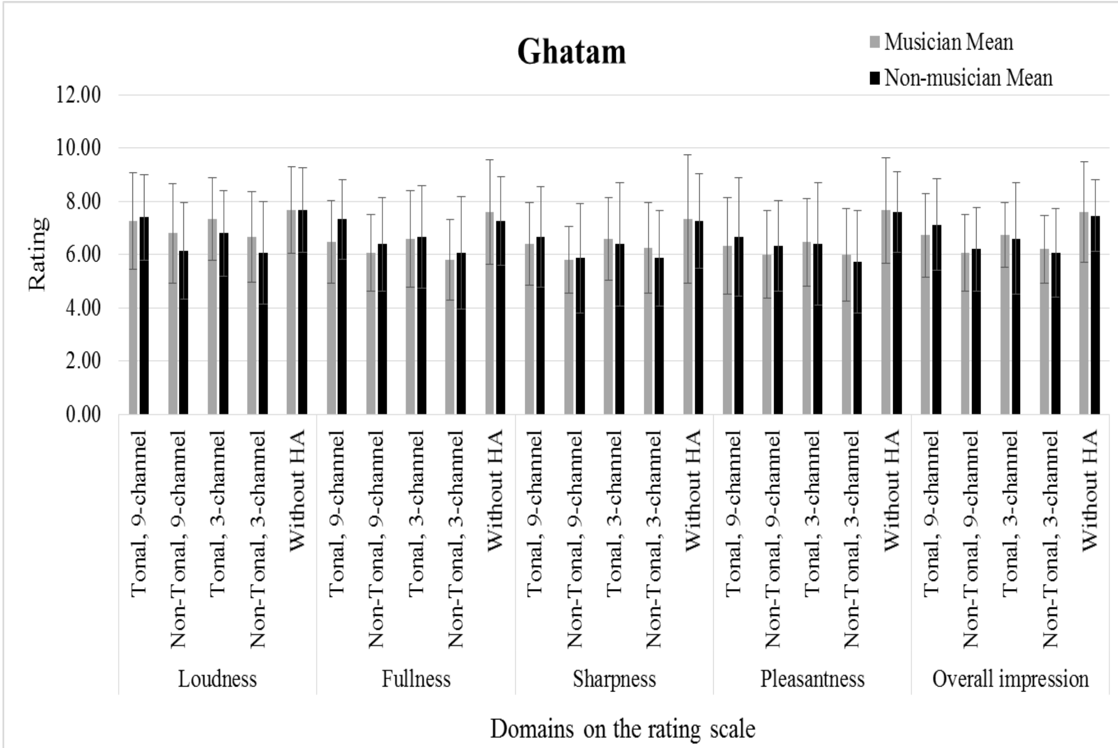

Figure 4.4: The graphical representation of the mean and SD, under each domain of rating for the ghatam sample.

4.2.4.1 Ghatam loudness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 8.97$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, the 9-channel tonal condition had significantly higher scores than the 9-channel non-tonal condition. In addition, the 3-channel tonal condition had significantly higher scores than the 3-channel non-tonal condition. Thus, the perception of loudness was better for tonal than non-tonal conditions.

4.2.4.2 Ghatam loudness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was no significant difference between conditions [$F(4, 56) = 1.71$, $p>0.05$]. Thus, the perception of loudness was similar across all conditions.

4.2.4.3 Ghatam fullness rating: Non-musicians

The descriptive statistics showed that among all the conditions, the 9-channel tonal condition had the highest mean score, followed by without HA, 3-channel tonal, 9-channel non-tonal, and 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between

conditions [F (4, 56) = 4.11, p<0.01]. Sidak Post hoc analysis showed that the scores for fullness were similar across all conditions. Thus, the perception of fullness was similar across all conditions.

4.2.4.4 Ghatam fullness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 4.16, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness were significantly higher for 3-channel tonal compared to 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, it shows that the scores were better for tonal compared to non-tonal for fullness perception.

4.2.4.5 Ghatam sharpness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal and 9-channel non-tonal, the 3-channel non-tonal conditions.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F (4, 56) = 5.62, p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of sharpness was similar across all simulated conditions.

4.2.4.6 Ghatam sharpness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F (4, 56) = 3.98, p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of sharpness was similar across all simulated conditions.

4.2.4.7 Ghatam pleasantness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F (4, 56) = 4.95, p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for the 3-channel tonal condition than 3-channel non-tonal condition. Thus, the perception of pleasantness was better for tonal, than non-tonal condition.

4.2.4.8 Ghatam pleasantness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal and 9-channel non-tonal, the 3-channel non-tonal conditions.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between

conditions [F (4, 56) = 4.39, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of pleasantness was similar across all simulated conditions.

4.2.4.9 Ghatam overall impression: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 4.80, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the overall impression was similar across all simulated conditions.

4.2.4.10 Ghatam overall impression: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, 3-channel tonal and 9-channel tonal conditions had the highest mean score, followed by 3-channel non-tonal and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F (4, 56) = 3.90$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal condition. Also, significantly higher scores were obtained for 9-channel tonal than 9-channel non-tonal conditions. Thus, tonal conditions had a better overall impression than non-tonal conditions.

Observing the results obtained above under each domain, it can be concluded that, the tonal formula was preferred over non-tonal, while such preference was not seen between 3-channel and 9-channel settings for ghatam perception.

4.2.5 Results of Male Vocal Perception

The mean, standard deviation (SD), median and range of the ratings for the male vocal sample are tabulated in Table 4.6. The graphical representation of the mean and SD is shown in Figure 4.5.

Table 4.6. *The mean, standard deviation, median and range of the ratings for the male vocal sample.*

Male vocal		Loudness		Fullness		Sharpness		Pleasantness		Overall Impression	
Conditions		NM	M	NM	M	NM	M	NM	M	NM	M
Tonal, 9-channel	Mean	7.33	8.07	7.33	7.27	6.93	7.67	7.47	7.40	7.40	7.33
	SD	1.35	1.28	1.50	1.58	1.75	1.45	1.36	1.64	1.24	1.45
	Median	8.00	8.00	7.00	7.00	7.00	8.00	7.00	7.00	7.00	7.00
	Range	5-9	6-10	4-10	5-10	3-10	5-10	5-10	5-10	5-10	5-10
Non-tonal, 9-channel	Mean	6.33	6.87	6.13	6.67	5.33	6.60	5.73	6.20	6.00	6.40
	SD	1.68	1.41	1.81	1.76	1.72	1.50	1.94	1.86	1.46	1.50
	Median	7.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	6.00	6.00
	Range	3-9	4-9	3-9	4-10	3-8	4-10	3-9	2-10	3-8	4-10
Tonal, 3-channel	Mean	7.60	7.53	7.40	7.47	6.93	7.60	7.00	7.20	7.33	7.07
	SD	1.55	1.64	1.24	1.19	1.22	1.30	1.73	1.27	1.50	1.34
	Median	8.00	8.00	8.00	8.00	7.00	7.00	8.00	7.00	8.00	7.00
	Range	4-10	5-10	5-9	6-10	4-8	6-10	3-9	5-10	4-9	5-10
Non-tonal, 3-channel	Mean	6.73	6.60	6.40	6.40	5.80	6.20	6.27	6.20	6.53	6.53
	SD	1.39	1.77	1.64	1.96	1.78	1.94	1.62	1.94	1.73	1.41
	Median	7.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	7.00	6.00
	Range	4-9	4-10	4-9	3-10	2-8	2-10	3-8	2-10	2-9	5-10
Without HA	Mean	8.53	8.67	8.40	8.53	7.93	8.67	8.20	8.80	8.27	8.60
	SD	1.41	0.90	1.30	0.99	1.58	0.82	1.47	1.08	1.16	0.91
	Median	8.00	9.00	8.00	8.00	8.00	8.00	8.00	9.00	8.00	9.00
	Range	5-10	7-10	6-10	7-10	5-10	8-10	6-10	6-10	6-10	7-10

Note – NM: Non-musicians, M: Musicians, HA: Hearing Aid.

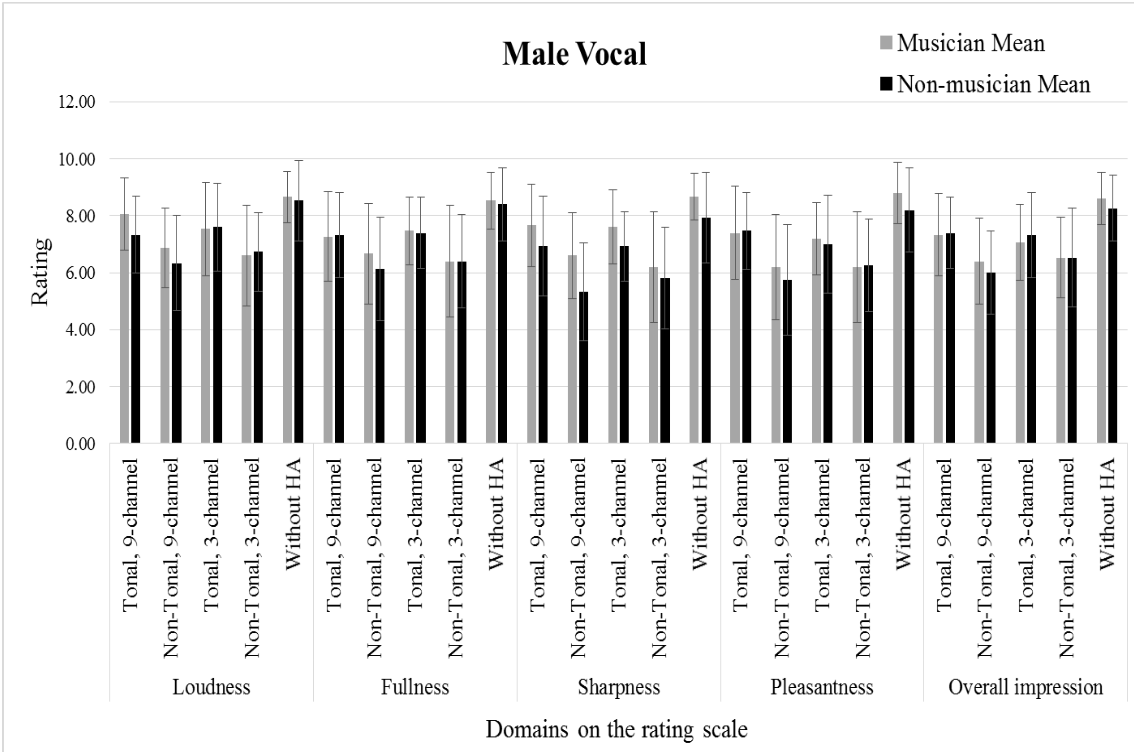

Figure 4.5: The graphical representation of the mean and SD, under each domain of rating for the male vocal sample.

4.2.5.1 Male vocal loudness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 17.41$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 9-channel tonal, 9-channel non-tonal, and 3-channel non-tonal conditions. Also, the scores were significantly higher for 9-channel tonal condition compared to 9-channel non-tonal condition. In addition, the scores were significantly higher for 3-channel tonal condition compared to 3-channel non-tonal and 9-channel non-tonal conditions. Thus, it shows that the scores were better for tonal compared to non-tonal conditions for loudness perception.

4.2.5.2 Male vocal loudness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 17.43$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, the scores were significantly higher for 9-channel tonal condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Thus, the perception of loudness was poorer for non-tonal conditions.

4.2.5.3 Male vocal fullness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out and it showed that there was a significant difference between conditions [$F(4, 56) = 19.19$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness rating were significantly higher for without simulation condition compared to 9-channel non-tonal, tonal as well as 3-channel non-tonal and tonal conditions. Also, the scores were significantly higher for 3-channel tonal condition compared to 9-channel non-tonal condition. In addition, 9-channel tonal had significantly higher scores than 9-channel non-tonal conditions. Thus, it shows that the scores were better for tonal compared to non-tonal for fullness perception.

4.2.5.4 Male vocal fullness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [F (4, 56) = 11.24, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, it shows that the scores were similar across all simulated conditions for fullness perception.

4.2.5.5 Male vocal sharpness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, 3-channel tonal and 9-channel tonal conditions had the highest mean scores, followed by 3-channel non-tonal and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 17.84, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. The perception of sharpness was significantly higher for 3-channel tonal condition than 9-channel non-tonal and 3-channel non-tonal conditions. Additionally, the scores of the 9-channel tonal condition were significantly higher than the 9-channel non-tonal condition. Thus, the perception of sharpness was better for the tonal condition than non-tonal condition.

4.2.5.6 Male vocal sharpness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 10.72$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal, 3-channel tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of sharpness was similar across all simulated conditions.

4.2.5.7 Male vocal pleasantness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel

tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out and it showed that there was a significant difference between conditions [F (4, 56) = 24.69, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal, 3-channel tonal, and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 9-channel tonal and 3-channel tonal conditions than 9-channel non-tonal and 3-channel non-tonal conditions. Thus, the perception of pleasantness was better for tonal than non-tonal conditions.

4.2.5.8 Male vocal pleasantness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal and 3-channel non-tonal, the 9-channel non-tonal conditions.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [F (4, 56) = 16.65, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation compared to all four simulated conditions. There were no significant differences between other pairs. Thus, the perception of pleasantness was similar across all simulated conditions.

4.2.5.9 Male vocal overall impression: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 16.76$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 9-channel tonal and 3-channel tonal conditions compared to 9-channel non-tonal conditions. Thus, the tonal condition had a better overall impression than the non-tonal condition in the 9-channel, while this difference was not seen in the 3-channel condition.

4.2.5.10 Male vocal overall impression: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F (4, 56) = 15.03$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to all four simulated conditions. Also, significantly higher scores were obtained for 9-channel tonal condition compared to 9-channel non-tonal condition. Thus, the overall impression was better for tonal than non-tonal conditions.

Observing the results obtained above under each domain, it can be concluded that tonal formula is preferred over the non-tonal formula for the vocal (male) perception.

4.2.6 Results of Female Vocal Perception

The mean, standard deviation (SD), median, and range of the ratings for the female vocal sample are tabulated in Table 4.7. The graphical representation of the mean and SD is shown in Figure 4.6.

Table 4.7. *The mean, standard deviation, median and range of the ratings for the female vocal sample.*

Female vocal		Loudness		Fullness		Sharpness		Pleasantness		Overall Impression	
Conditions		NM	M	NM	M	NM	M	NM	M	NM	M
Tonal, 9-channel	Mean	8.00	8.33	7.47	7.93	7.47	7.87	7.60	7.67	7.53	8.00
	SD	1.20	1.23	1.30	1.44	1.19	1.46	1.18	1.63	1.25	1.25
	Median	8.00	8.00	7.00	8.00	8.00	8.00	8.00	7.00	7.00	8.00
	Range	6-10	6-10	5-10	5-10	5-9	6-10	5-10	5-10	5-10	6-10
Non-tonal, 9-channel	Mean	7.47	7.93	6.87	7.13	6.73	7.27	6.93	7.00	7.00	7.20
	SD	1.36	1.49	1.25	2.00	1.39	1.49	1.16	1.96	1.00	1.78
	Median	7.00	8.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00
	Range	5-10	5-10	5-9	4-10	4-9	5-10	5-9	4-10	5-9	5-10
Tonal, 3-channel	Mean	8.07	8.00	8.00	7.20	7.87	7.67	8.20	7.80	8.07	7.73
	SD	1.03	1.56	0.93	2.01	1.25	1.80	1.01	1.74	0.88	1.49
	Median	8.00	9.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
	Range	6-10	4-10	6-10	3-10	5-10	3-10	6-10	4-10	6-9	4-10
Non-tonal, 3-channel	Mean	7.47	7.47	7.27	6.67	6.67	7.13	6.87	7.13	7.00	7.20
	SD	1.36	1.85	1.34	1.95	1.59	1.85	1.81	1.92	1.51	1.52
	Median	7.00	8.00	8.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
	Range	6-10	4-10	4-9	3-10	4-9	3-10	3-10	4-10	3-9	4-10
Without HA	Mean	8.80	8.80	8.53	8.73	8.33	8.73	8.80	8.80	8.67	8.67
	SD	1.15	1.27	1.19	0.88	1.63	1.16	1.21	1.15	1.23	0.90
	Median	9.00	9.00	9.00	9.00	8.00	9.00	9.00	9.00	9.00	9.00
	Range	7-10	6-10	7-10	7-10	5-10	6-10	7-10	6-10	7-10	7-10

Note – NM: Non-musicians, M: Musicians, HA: Hearing Aid.

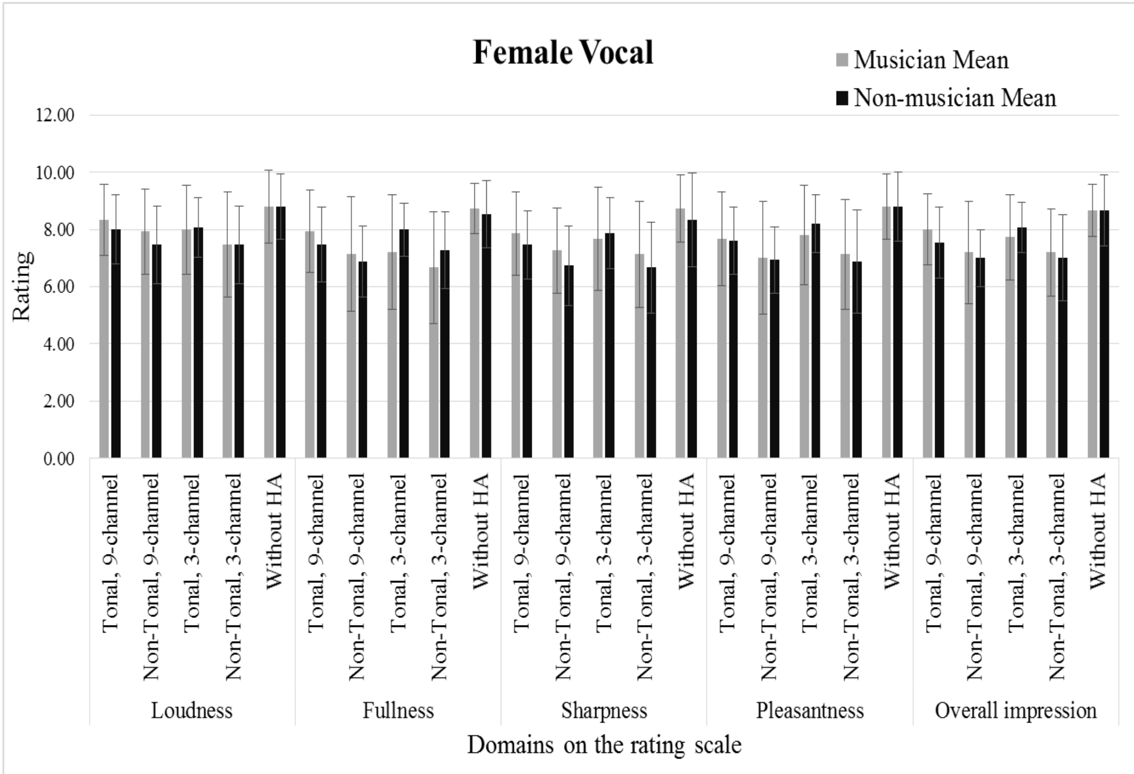

Figure 4.6: The graphical representation of the mean and SD, under each domain of rating for the female vocal sample.

4.2.6.1 Female vocal loudness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal and 3-channel non-tonal, the 9-channel non-tonal conditions.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 9.62$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, it shows that the scores were better for tonal compared to non-tonal conditions for loudness perception.

4.2.6.2 Female vocal loudness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 4.96$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of loudness was similar across all simulated conditions.

4.2.6.3 Female vocal fullness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel

tonal condition had the highest mean score, followed by 9-channel tonal, 3-channel non-tonal, and the 9-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 10.41$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for loudness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, the scores were significantly higher for 9-channel tonal and 3-channel tonal conditions compared to 9-channel non-tonal conditions. Thus, it shows that the scores were better for tonal compared to non-tonal for fullness perception.

4.2.6.4 Female vocal fullness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 14.90$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for fullness ratings were significantly higher for 9-channel tonal compared to 3-channel non-tonal conditions. In addition, scores were significantly poorer for 3-channel non-tonal compared to without simulation. There were no significant differences between other pairs. Thus, it shows that the scores were better for tonal compared to non-tonal for fullness perception.

4.2.6.5 Female vocal sharpness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [$F(4, 56) = 14.48$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. The perception of sharpness was significantly higher for 3-channel tonal condition than 9-channel non-tonal and 3-channel non-tonal conditions. Additionally, the scores of the 9-channel tonal condition were significantly higher than the 9-channel non-tonal condition. Thus, the perception of sharpness was better for the tonal condition than non-tonal condition.

4.2.6.6 Female vocal sharpness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel tonal condition had the highest mean score, followed by 3-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between conditions [F (4, 56) = 5.22, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for sharpness ratings were significantly higher for without simulation condition compared to 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the perception of sharpness was similar across all simulated conditions.

4.2.6.7 Female vocal pleasantness rating: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out. It showed that there was a significant difference between

conditions [F (4, 56) = 14.04, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation condition compared to 9-channel tonal, 9-channel non-tonal, and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for the 9-channel tonal condition than 9-channel non-tonal condition. Similarly, the 3-channel tonal condition had significantly higher scores than 9-channel non-tonal and 3-channel non-tonal conditions. Thus, the perception of pleasantness was better for tonal than non-tonal conditions.

4.2.6.8 Female vocal pleasantness rating: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal, 9-channel non-tonal, and the 3-channel non-tonal condition.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [F (4, 56) = 8.21, p<0.01]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for pleasantness ratings were significantly higher for without simulation compared to 9-channel non-tonal and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for the 3-

channel tonal condition than 3-channel non-tonal condition. Thus, the perception of pleasantness was better for tonal than non-tonal conditions.

4.2.6.9 Female vocal overall impression: Non-musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 3-channel tonal condition had the highest mean score, followed by 9-channel tonal and 3-channel non-tonal, the 9-channel non-tonal conditions.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F (4, 56) = 12.68$ $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel tonal, 9-channel non-tonal, and 3-channel non-tonal conditions. Also, significantly higher scores were obtained for 9-channel tonal and 3-channel tonal conditions compared to 9-channel non-tonal conditions. Thus, tonal conditions had a better overall impression than non-tonal conditions.

4.2.6.10 Female vocal overall impression: Musicians

The descriptive statistics showed that among all the conditions, without HA condition had the highest mean score. Among the simulated conditions, the 9-channel

tonal condition had the highest mean score, followed by 3-channel tonal and 3-channel non-tonal, the 9-channel non-tonal conditions.

To check for significant differences between the conditions, repeated measures ANOVA was carried out, and it showed that there was a significant difference between conditions [$F(4, 56) = 6.52$, $p<0.01$]. Sidak post hoc analysis was done to understand which of the pairs had a significant difference between them.

Sidak Post hoc analysis showed that the scores for overall impression ratings were significantly higher for without simulation compared to 9-channel non-tonal and 3-channel non-tonal conditions. There were no significant differences between other pairs. Thus, the overall impression was similar across all simulated conditions.

Observing the results obtained above under each domain, it can be concluded that for the perception of vocal (female) music, the tonal formula was preferred over the non-tonal formula.

Chapter 5

Discussion

The aim of this study was to study the effect of prescriptive formula, and the number of channels of the Receiver-In-Canal (RIC) type hearing aid on the perception of music. This was achieved through the subjective rating of different music samples, which included the instruments (violin, flute, mridangam, and ghatam) and vocals (male and female).

The perceptual analysis was done, consisting of perceptual rating, obtained from musicians and non-musicians, on a 10-point rating scale, under the domains of loudness, fullness, sharpness, pleasantness, and overall impression. In addition, acoustical analysis, which consisted of LTASS was done, to understand the frequency range and the frequency with the maximum amplitude of each of the music stimuli used for better correlation of the findings.

Both musicians and non-musicians gave poorer ratings to the simulated music recordings compared to the original music sample. This is in agreement with Chasin and Russo (2004), Sushmit (2007), Divya (2010), and Moore (2012).

The findings are discussed separately for each of the samples used in the study, along with the integration of the results of both types of analyses.

5.1 Violin

Participants who were non-musicians preferred NAL-NL2 Tonal formula compared to NAL-NL2 Non-tonal among all five domains of the perceptual rating. Also, the participants preferred 9-channel more than 3-channel HA, for better loudness and overall impression. Similarly musicians, also preferred NAL-NL2 Tonal formula compared to NAL-NL2 Non-tonal and 9-channel more than 3-channel, among four domains of the perceptual rating perception except for loudness.

Since F_0 and its harmonics are important for music percept (Schmidt-Jones, 2013), the enhancement (increased gain) of the lower frequency in NAL-NL2 Tonal has been beneficial compared to its Non-tonal variant, for violin perception, which has maximum energy at 425Hz, with a range of 425 – 9,372 Hz. The preference of 9-channel HA compared to 3-channel is in agreement with studies done by Mishra, Kunnathur, and Rajalakshmi (2005) and Sushmit (2007), where multiple channels have proven to be beneficial, due to compression adjustments across the different frequencies.

5.2 Flute

Participants who were non-musicians preferred NAL-NL2 Tonal formula compared to NAL-NL2 Non-tonal in all five domains of the perceptual rating. As music requires good representation across all frequencies, which is achieved by enhanced lower frequencies in the NAL-NL2 Tonal formula, which may be lost due to the activation of DNR stings, thus enhancing the overall quality of music perceived. Also, the participants preferred 9-channel more than 3-channel HA, for better loudness and fullness, implying adjusting gains across more number of channels has improved the music perception.

Among the musicians, they found 3-channel HA to be more pleasant than 9-channel HA. In the other domains, there was no specific preference of any particular simulated condition. This is in agreement with Croghan, Arehart, and Kates (2014), where the lower number of channels was recommended to effectively process music.

With respect to prescriptive formula, similar ratings were obtained for NAL-NL2 Tonal and Non-tonal formulae. Acoustic analysis of the flute sample showed a frequency range of 757 – 9,713 Hz with a peak amplitude at 1239 Hz.

Musicians perform better than non-musicians in detecting frequency changes in quiet and noisy conditions (Liang et al., 2016), and musical training is associated with an enhancement of both temporal fine structure (TFS) cues encoding and F0 discrimination (Bianchi, Carney, Dau & Santurette, 2019). As the major difference between tonal and non-tonal formulae is their lower frequency gain, and flute having a frequency spectrum spread across mid and high-frequency regions could be the reason for the ratings being similar for musicians between NAL-NL2 Tonal and Non-tonal formulae.

5.3 Mridangam

Non-musicians preferred NAL-NL2 Tonal formula compared to NAL-NL2 Non-tonal formula among four domains of the perceptual rating except on the loudness domain, where there was no significant difference. Also, there was no significant difference from the music perceived, between 9-channel and 3-channel HAs among the non-musicians.

Musicians preferred NAL-NL2 Tonal formula over NAL-NL2 Non-tonal formula, among the four domains of the perceptual rating, except on the sharpness domain, where there was no significant difference. In addition, 9-channel HA was preferred over 3-channel in the domains of loudness, fullness, and overall impression.

Acoustic analysis of the mridangam sample showed a frequency range of 160 – 9,420 Hz with a peak amplitude at 160 Hz. This lower frequency importance, which was enhanced through the NAL-NL2 Tonal formula, proved to be advantageous over the Non-tonal formula, as the DNR settings were kept on the prescribed levels. Also, musical training is associated with an enhancement of both temporal fine structure (TFS) cues encoding and F0 discrimination (Bianchi, Carney, Dau & Santurette, 2019). Hence having higher number of channels, with finer tuning across the frequency bands has proven to be beneficial for musicians.

5.4 Ghatam

Participants who were non-musicians preferred the NAL-NL2 Tonal formula compared to NAL-NL2 Non-tonal formula in loudness and pleasantness domains of perceptual rating. Also, there was no significant difference from the music perceived, between 9-channel and 3-channel HAs among the non-musicians.

Musicians preferred NAL-NL2 Tonal formula over NAL-NL2 Non-tonal formula, in the domains of fullness and overall impression of the perceptual rating. There was no preference between 3-channel and 9-channel HAs, as both were rated similarly.

Acoustic analysis of the ghatam sample showed a frequency range of 114 – 14,774 Hz with a peak amplitude at 1,709 Hz. Since the ghatam sample has a wide frequency spectrum, the emphasis of lower frequencies in the NAL-NL2 Tonal formula has improved the perception in terms of fullness, in agreement with Vaisberg, et al., (2017). No difference between 3- and 9-channel HAs, suggest that processing was similar and equally efficient in both conditions.

5.5 Male vocal

Participants who were non-musicians preferred NAL-NL2 Tonal formula compared to the NAL-NL2 Non-tonal formula on all five domains of perceptual rating. But no such preference was seen between 9-channel and 3-channel conditions. Musicians preferred NAL-NL2 Tonal formula over NAL-NL2 Non-tonal formula, in the domains of loudness and overall impression of the perceptual rating. There was no preference between 3-channel and 9-channel HAs, as both were rating similarly.

Acoustic analysis of the ghatam sample showed a frequency range of 231 – 13,647 Hz with a peak amplitude at 530 Hz. Perception of music requires a larger range of frequencies (harmonics) to be perceived, unlike speech, along with the F_0 (Rosner & Narmour, 1992), and NAL-NL2 Tonal has helped in achieving that goal, thus proving beneficial. Also, it can be noted that irrespective of the number of channels used, a similar perception is achieved. It is hence proving that both 3-channel and 9-channel HAs are equally efficient in processing ghatam music.

5.6 Female vocal

Non-musicians preferred NAL-NL2 Tonal formula compared to NAL-NL2 Non-tonal formula among all five domains of perceptual rating. But no such preference was seen between the different channels condition. Musicians preferred NAL-NL2 Tonal formula over NAL-NL2 Non-tonal formula, in the domains of fullness and pleasantness of the perceptual rating. There was no preference between 3-channel and 9-channel HAs, as both were rated similarly.

Acoustic analysis of the ghatam sample showed a frequency range of 295 – 11,547 Hz with a peak amplitude at 295 Hz. This lower frequency importance, which was enhanced through the NAL-NL2 Tonal formula, proved to be advantageous over the Non-tonal formula, as the DNR and feedback settings were set to first-fit. Thus, it can be inferred that, for all different music samples, the NAL-NL2 Tonal formula was preferred over the NAL-NL2 Non-tonal formula. Among the different channels, 9-channel HA was preferred over 3-channel under few domains of flute, violin, and mridangam sample. Rosner and Narmour (1992) showed that the initial five harmonics are important for perceiving music. Violing having energy from mid to high frequencies benefitted from 9-channels more as the higher harmonics are also processed better than in 3-channel condition, where the high frequencies are grouped together.

Chapter 6

Summary and Conclusions

Music perception through hearing aids has not been achieved as satisfactorily as speech perception. With the advancement in technology, there is a need to assess and understand the efficiency of the hearing device. Hence in this study, music perception was assessed using all types of individual music sources such as instruments (violin, flute, mridangam, and ghatam), and vocal (male and female), using perceptual rating on a 10-point rating scale and acoustical analysis.

Hearing aid's music processing was assessed in different programs (simulation). The different settings in the hearing aid were as follows:

- 3-channel mode with the prescriptive formula NAL-NL2 (Tonal).
- 3-channel mode with the prescriptive formula NAL-NL2 (Non-tonal).
- 9-channel mode with the prescriptive formula NAL-NL2 (Tonal).
- 9-channel mode with the prescriptive formula NAL-NL2 (Non-tonal).

All other aspects in the programming were set to first-fit, such as noise reduction algorithms, feedback cancellation, and microphone directionality for a moderate degree sensorineural type of hearing loss.

Initially, the HA was programmed to each of those settings, placed on KEMAR with a microphone, and the output was recorded through SLM. Original music sample was also recorded through KEMAR, to make the unprocessed music sample equivalent to the music sample processed through hearing aids.

The results of perceptual and acoustical analysis implied the following settings of hearing aid for better music perception. These conclusions are made with respect to the music samples, hearing aids, and the settings that were used in this study.

- NAL-NL2 Tonal formula was preferred more than NAL-NL2 Non-tonal formula, among the two prescriptive formulae tested.
- Among the number of channels, both 3-channels and 9-channels had similar ratings. However, in a few aspects, 9-channel outperformed 3-channel hearing aid.

6.1. Limitations of the study

- The hearing aid programming was done for a hypothetical moderate degree flat sensorineural type of hearing loss. This was done to eliminate the variability in compression and make all the parameters similar across the entire frequency range. But this does not reflect the real-life situation, as such hypothetical cases are rare.
- The simulation was used, where the processed music samples were obtained from hearing aids was programmed and connected to KEMAR and output recorded through SLM. These were perceptually rated by normal individuals (musicians and non-musicians), to avoid individualistic variations such as the slope of the audiogram, preferred settings in HA such as compression, gain settings, feedback settings, however, these ratings might not entirely reflect how the music would be perceived by individuals having a hearing impairment, using hearing aids.
- A 10-point rating scale was used, which assessed music perception across five domains to account for minor variability, which might not get reflected through the

use of 5-point scales. However, individualistic variations in terms of rating could be present to some extent.

- Hearing loss could manifest in various ways across individuals despite having a similar degree and type of loss in terms of frequency resolution, temporal resolution, loudness perception, supra-threshold performance. These aspects may affect music perception differently. But since this study was conducted through simulation on individuals with normal hearing, such variations are not accounted. Hence, the results of the study should be interpreted thoughtfully upon addressing individuals with hearing loss.

6.2. Future directions

- Future research can be conducted for hypothetical loss with different slopes (configuration) of hearing loss such as raising, sloping, steeply sloping, across different degrees of hearing loss.
- A similar study can be conducted on individuals having a hearing impairment, by programming their own hearing aid, to assess music perception.
- With the improvement in technology, the efficiency of music perception with the use of Bluetooth sharing, using remote microphone technology, radio-frequency sharing, needs to be assessed.
- Variations in the perception of music due to source and environment, such as live vs recorded in quiet vs noisy situations, room vs auditorium, can also be assessed.
- Improvements needed in technology to achieve comparable music perception between simulated and natural condition needs to be studied. This can help to

bridge the gap, perception-wise, thus enabling precise and quality music percept with minimal manipulations through programming.

In conclusion, music, being one of man's best friends, is often compromised on account of one's hearing impairment. This needs to be addressed and worked upon to improve the individual's overall quality of life. Music perception can be enhanced by doing appropriate changes in the settings of the different hearing aid parameters, and it was found that the use of a Tonal version of NAL-NL2 formula and use of 9-channel HA helps in achieving this in most conditions tested in this study.

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