THE ACOUSTICAL AND PERCEPTUAL ASSESSMENT OF BENEFIT OF DIRECTIONALITY AND NOISE REDUCTION ALGORITHM OF HEARING AIDS WITH EAR TO EAR SYNCHRONIZATION

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Dedicated to the

Living God's my Dear

Appa, Amma.

And also to my

Uncle & My Guide

CERTIFICATE

This is to certify that this dissertation entitled **"THE ACOUSTICAL AND PERCEPTUAL ASSESSMENT OF BENEFIT OF DIRECTIONALITY AND NOISE REDUCTION ALGORITHM OF HEARING AIDS WITH EAR TO EAR SYNCHRONIZATION"** is the bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) student with Registration Number 12AUD024. This has been carried out under the guidance of a faculty of this institution 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 dissertation entitled **“THE ACOUSTICAL AND PERCEPTUAL ASSESSMENT OF BENEFIT OF DIRECTIONALITY AND NOISE REDUCTION ALGORITHM OF HEARING AIDS WITH EAR TO EAR SYNCHRONIZATION”** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This dissertation entitled **"THE ACOUSTICAL AND PERCEPTUAL ASSESSMENT OF BENEFIT OF DIRECTIONALITY AND NOISE REDUCTION ALGORITHM OF HEARING AIDS WITH EAR TO EAR SYNCHRONIZATION"** is the result of my own study under the guidance of Mrs. Geetha C, Lecturer 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.

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TABLE OF CONTENTS

Chapter	Content	Page No.
1.	Introduction	1-6
2.	Review of Literature	7-15
3.	Method	16-24
4.	Results and Discussion	25-32
5.	Summary and Conclusion	33-35
	References	36-41

LIST OF TABLES

Table Number	Title	Page Number
4.1	Mean and SD of SNR-50 in all the conditions (N=15)	26
4.2	Results of Bonferroni pair-wise comparison	28
4.3	Mean and SD of SPL for all frequencies in all seven conditions (N=5)	30
4.4	Results of Wilcoxon Signed Rank test for pair-wise comparison	31

Chapter 1

Introduction

Sensorineural hearing loss is most often accompanied by a loss of spectral and temporal resolution in the auditory processing (Dillon, 2001; Plomp, 1978). As a result, difficulty in understanding speech in noisy backgrounds is the main complaint of individuals with sensorineural hearing loss. To reach the same amount of speech understanding as a normal hearing person, a hearing aid user requires a signal-to-noise ratio (SNR) increase of about 4–10 dB (Dillon, 2001; Hamacher et al., 2005).

The advances in hearing aid technology such as Digital Noise Reduction algorithms (DNR), adaptive directionality, and other advanced digital signal processing (DSP) techniques helps the hearing aid to work better in noisy situations and thus gives better SNR (Bretoli, Bodmer, & Probst, 2010). In addition, binaural hearing plays a main role in understanding speech in noise in individuals with normal hearing sensitivity due to several reasons such as head diffraction, binaural squelch and interaural time differences. The same applies to even hearing aid users if they are using binaural amplification (Wightman & Kistler, 1997).

Experiments have shown that hearing impaired listeners wearing two hearing aids (i.e. bilateral amplification) can extract benefits from binaural hearing (Boymans et al., 2009). Hence, the rate of bilateral fitting has increased in the past few years (Marketrak, 2009), and together with advances in digital signal processing (DSP) features such as adaptive directionality and digital noise reduction, bilateral amplification continues to contribute to hearing aid fitting success.

These advanced DSP features have been found to improve speech intelligibility (Boymans & Dreschler, 2000; Ricketts & Hornsby, 2003; Taufik et al., 2010; Valente & Mispagel, 2006). However, localization studies of binaural hearing aids with adaptive DSP features have shown that sound localization errors were lesser in the unaided condition when compare to the binaural aided conditions with active adaptive directionality (Kiedser et al., 2006; Van den Boegert et al., 2006). This is attributed to the reason that two hearing aids operating as separate units tend to distort the cues (Dirks & Wilson, 1969; Hirsh, 1950).

It has been reported that spatial characteristics of sound, such as time differences and level differences also play an integral role in helping the listener to understand speech in the complex listening world. Hence, preservation of binaural cues is said to be crucial for localization as well as speech understanding (Hawley, Litovsky, & Colburn, 1999; Wightman & Kistler, 1997). In order to achieve this, bilateral hearing aids that coordinate and synchronize their processing through wireless communication have been introduced (Kreisman et al., 2010).

Binaural wireless hearing aids use a wireless data connection to exchange data between the right and the left hearing aids, process that information, and adjust the settings to the specific auditory situation. This technology, reportedly, significantly improves speech comprehension, particularly in loud environments. The individual hearing systems in the left and the right ear exchange data wirelessly and coordinate their functions. If the volume is adjusted on one unit, for example, the other hearing aid automatically adjusts volume as well. This also applies to other functions, such as directionality of microphones (Hamacher et al., 2005).

Kreisman et al. in the year 2010 studied the speech intelligibility in noise using a new, binaural broadband hearing instrument system. Thirty six participants with symmetrical, sensorineural hearing loss were fitted with binaural wireless hearing instruments and advanced digital hearing instruments. Following an adjustment period with each device, participants underwent two speech-in-noise tests: the QuickSIN and the Hearing in Noise Test (HINT). Results showed a significant better performance on both the QuickSIN and the HINT measures with the binaural broadband hearing instruments with wireless synchronization, when compared with the advanced digital hearing instruments without it.

A study done by Iman et al. (2013) evaluated the effect of binaural wireless technology in speech intelligibility and localization. They measured the speech intelligibility and localization of hearing impaired listeners using different brands of bilateral wirelessly connected hearing aids. Twenty subjects participated in their study. They were tested with Hearing in Noise test (HINT) and sound localization test with wireless synchronization on and wireless synchronization off. They had deactivated all the other DSP algorithms.

Their results of speech recognition data showed no statistically significant difference in both conditions. They also measured the errors in localization in both the Front/Back and Left/Right dimensions. They reported that activating the wireless synchronization significantly reduced the rate of Front/Back confusions by 10.5% among the hearing impaired group.

However, Iman et al's study showed no specific benefit from wireless WDRC synchronization for the HINT. The differences in the results between the above two studies have been attributed to the differences in the method. Kreisman et al. (2010) had conducted experiments with all DSP features activated whereas Iman et al. had deactivated all advance DSP features. This could have led to no specific benefit from wireless WDRC synchronization in Iman et al's study.

Need for the study

There are few studies evaluating the performance of the hearing aids with wireless communication (Kreisman et al., 2010; Iman et al., 2013; Smith et al., 2008; Sockalingam et al., 2009). These studies have evaluated the effect of either only the wireless WRDC synchronization on speech perception in noise (Iman et al., 2013) or effect of wireless synchronization with all the DSP features (Directionality and DNR) activated together (Kreisman et al., 2010).

Several hearing aid manufacturers have developed different models of hearing aids that co-ordinate their signal processing through wireless communication. They promise that this new era of hearing aid technology along with adaptive directionality and DNR will lead to better speech intelligibility in day to day noisy situations by preserving binaural cures when compared to the basic digital hearing aids without the above facilities.

It is, hence, important to present evidence to see that each of these features provide benefit. However, there are no published reports, to our knowledge, evaluating each of the advanced features, that is, the directionality and noise reduction algorithms in the WDRC binaural wireless hearing aids in comparison with non-wireless hearing aids. The assumption is that the directionality and DNR with the wireless synchronization provide improvement in speech perception in noise even when they are activated independently, when compared to binaural hearing aids without wireless synchronization.

Aim of the study

The current study aims to check the subjective and objective benefits of Directionality and Noise Reduction Algorithms of binaural WDRC wireless technology hearing aids.

Objectives of the study

The objectives of the current study are to:

1) Obtain SNR-50 in the following conditions using binaural wireless WDRC technology hearing aids:

- Unaided
- Aided- Directionality on with wireless synchronization on
- Aided- DNR on with wireless synchronization on
- Aided-Both algorithms activated with wireless synchronization on
- Aided- Directionality on with wireless synchronization off
- Aided- DNR on with wireless synchronization off
- Aided-Both algorithms activated with wireless synchronization off

2) Measure the output of the hearing aid in the above mentioned aided conditions.

Chapter - 2

Review of Literature

Persons with sensorineural hearing loss most often have difficulty in understanding speech in noise due to the loss of spectral and temporal resolution in the auditory processing (Dillion, 2001; Plomp, 1978). Hence, they require boost in the SNR to be able to perceive better. The amount of dB required for hearing aid user to understand speech like a normal person in noisy situation is approximately 4-10 dB (Dillion, 2001; Hamacher et al., 2005).

The advances in hearing aid technology such as Digital noise reduction algorithms, adaptive directionality and advanced digital signal processing have been found to help to understand better in noisy situations by providing better SNR (Bretoli et al., 2010).

Binaural hearing plays a main role in understanding speech in noise in normal individuals due to several reasons such as head diffraction, binaural squelch and interaural time differences. The same applies to hearing aid users as they can get these benefits if they are using binaural amplification (Dillon, 2001).

Even though binaural hearing aids provide better understanding, reports show that they may corrupt the binaural cues of perception when they work as separate units. These results have led to the invention of wireless hearing aids which communicate with each other. The present aims to evaluate these hearing aids which talk to each other, and the

DNR and directionality in these hearing aids. Hence, the literature has been reviewed under the following headings:

- Digital technology and noise reduction algorithm
- Digital technology and directionality
- Effect of both directionality and DNR technology in Digital hearing aids
- Wireless technology hearing aids

Digital technology and noise reduction algorithm

The main principle of digital noise reduction is to reduce the output of hearing aid when an unwanted signal is present. DNR algorithms have been found to improve the signal when the spectrum of noise is very different from speech. However, when it comes to a competing speaker situation and multi-source noise situation, the present technology was not found to show much improvement (Tawfik et al., 2010).

Bentler and Chiou (2006) reviewed different noise reduction algorithms in the hearing aid and also the development in the noise reduction algorithm. They concluded that the evidence for effectiveness of DNR is sparse when they looked into speech understanding using only the digital noise reduction algorithms. Further, studies have reported that the improvement in speech perception augments in binaural hearing aids condition when compared to monaural condition.

Rickets and Hornsby (2005) conducted a paired comparison study using binaural fitting approach in order to find out the effects of both directional and DNR features. The listener's task was to rate only the comfortness. The results indicated that there was a strong preference for DNR in both high level and low level noise even though the speech perception was not affected. Hence, DNR has a positive effect. However, the hearing aids that they used in their study did not have wireless synchronization. Hence, they worked as two separate equipments without getting feedback from each other.

Digital technology and directionality

Directional hearing aids are designed in such a way that they provide attenuation to the sounds which are emerging from the sides of the listener and is concentrated only in the front of the listeners face (Kuk et al., 2006). Hence, they are reported to result in improved speech recognition when speech and noise are coming from different directions (Ricketts, 2005). Directionality also plays a main role in understanding speech in noise because it maintains the interaural cues.

Ricketts and Henry (2002) reported that, hearing aids with adaptive directional microphones are those that change their polar patterns in the directional mode only and they may be effective in ensuring a more favorable SNR than a fixed directional microphone with changing noise sources. Kuk et al. (2005) reported that fully adaptive directional microphones have the best speech intelligibility and audibility by enhancing the SNR of the listening environment by moving from an omnidirectional pattern to any directional pattern depending upon the listening condition. However, the performance may differ depending on whether the hearing aid fitting was unilateral or bilateral (Rickets, 2005).

Rickets (2005) evaluated speech perception in noise with both directional and omnidirectional modes on 20 participants, who were fitted with both monaural and binaural amplification. He used HINT test to assess the speech in noise performance of the participants. The sentences from the HINT test were presented using the cafeteria noise which was spatially separated into five backgrounds. Participants were given a task of repeating sentences with 50% accuracy. In this study, their primary focus was to examine the impact of head and body angle on directional benefit. Their results indicated better advantage for those who fitted with both directional and binaural amplification in noisy environments.

He also reported that directional benefit and the binaural advantage were relatively independent and binaural advantage was an average of 2.3 and 2.5 dB for directional and omnidirectional modes respectively. Hence, directional microphones in binaural fittings will be useful only in some listening environments (Rickets, 2005). However, according to Rickets and Henry (2002), the unaided condition yielded better localization performance when compared to aided conditions. This was attributed to the disruption of ILD cues induced by the hearing aids.

Effect of both directionality and DNR technology in Digital hearing aids

Digital hearing aids increase speech in noise performance by applying the noise reduction algorithms, where they tend to select speech and cancel noise depending upon the various acoustic parameters that are present in speech versus noise. Similarly directional microphones are introduced in hearing aids with the same aim as above to increase better SNR. They cancel out the surrounding signal which comes from the sides of the listener and concentrates only in the signal that comes from the 0 degree of the listener with the concept that mostly speech is spoken in front of the listeners face.

Tawfik et al., (2010) studied the efficacy of combined directional microphone and DNR. In their study, they took 20 adult participants who had bilateral symmetrical moderate to moderately severe hearing loss. They conducted aided assessments in two conditions one with DNR alone and the second condition with DNR and directional microphone. They assessed the speech discrimination scores in quiet and in noisy condition in different situations of noise. The subject had to answer a questionnaire developed by them and using this hearing aid performance was assessed.

They found that there were better speech discrimination scores in the condition, with both DNR and directional microphone ‘on’. They concluded that the hearing aid performed well in noisy conditions and resulted better speech in noise when the directional microphones were combined with DNR. They also found that when omnidirectional microphone was used the speech discrimination was less.

Studies have reported that directional microphones with DNR help in better SNR when the speech originates from front of the listener. However, when the speech arises from other sides in noisy condition, then, it does not show a good result. Ricketts et al. (2003) showed that participants indicated a lower satisfaction for a directional microphone when the desirable sounds originated from the sides or the back. When more than one noise reduction technique is activated, studies have reported that, the cues for localization and speech perception in noise may be affected when the two hearing aids in both ears process the incoming signal separately.

Keidser et al. (2006) summarized the potential effect of modern hearing aid signal processing features on sound localization cues when the two hearing aids in both the ears worked as separate units. They reported that independently acting multi-channel WDRC and DNR features affect the Interaural Latency Differences (ILDs) and spectral shape differences, with mismatched directional microphone configurations between left and right hearing aids additionally impacting the Interaural Time Differences (ITDs).

Hence, there was a need for technology that can facilitate one to one communication between hearing aids which helps to preserve these ILD and ITD cues. This led to the invention of hearing aids with ear to ear synchronization facilities.

Wireless technology hearing aids

The brain always relies on information supplied by both ears and always looks for relation between the two signals which are received by both the ears. Hence, it is important that hearing aids should be able to provide information to brain about the ear to ear differences in the signal arriving at both the ears (Kreisman et al., 2010). Wireless technology fulfills this need by connecting two hearing aids without the use of any wires.

The principle behind the wireless processing technology is near field magnetic induction (NFMI). It is a short range wireless transmission technique. NFMI in hearing aids are able to handle enough bandwidth (currently 120 Kbits) and also they can carry both high-quality audio signals and high content data signals because of the recent developments in the area of signal processing. Its size and power consumption are reportedly much lower than compared to the current FM or Bluetooth devices (Schum, 2008).

This high quality, short-range technology is perfect for connecting the two hearing aids in a binaural pair. Hence, these hearing aids should be providing better speech understanding in the presence of noise and better localization (Schum, 2008).

Kreisman et al. (2010) evaluated to find out whether speech intelligibility in noise can be improved using this wireless broadband hearing aids or not. They took 36 adult listeners with symmetrical moderate hearing loss. Eighteen of the listeners were experienced hearing aid users and the rest of them were naïve hearing aid users.

All the participants were tested with Quick SIN test and Hearing in Noise test HINT (HINT) test. The first condition was speech babble presented at ±135° azimuths, and the second condition was speech babble presented at ±45°and ±135° azimuth. Their results suggested that there was a significant better performance in the Quick SIN test and HINT test when the participants were fitted with binaural wireless technology and they performed well in all noise conditions. Their results demonstrated a 3.1 to 3.5 dB difference between the HINT and QuickSIN scores, with the HINT scores having a lower SNR indicating better performance.

Iman et al. (2013) evaluated the effect of binaural wireless technology in speech intelligibility and localization with different brands of bilateral wirelessly connected hearing aids. Twenty listeners had participated in their study. Speech intelligibility was assessed using the HINT procedure under three test conditions: i) noise was presented to the right of the participant (90° azimuth); ii) noise was presented to the left of the participant (270° azimuth); and iii) noise was presented simultaneously from 90° and 270° azimuths.

Their results showed no statistically significant difference between the conditions when wireless on and wireless off. They also measured the errors present in localization in both the Front/Back and Left/Right dimensions. They reported that activating the wireless synchronization significantly reduced the rate of Front/Back confusions by 10.5% among the hearing impaired group when the sound source was broadband.

Ciorba et al. (2014) evaluated the benefit offered by these wireless binaural synchronization hearing aids on nine participants who had normal hearing using speech in noise test. The speech signal consisted of 13 lists, which contained 20 Italian meaningful sentences. It was given from the speaker which was located at 0°. The noise consisted of cocktail party noise and was delivered from 0°, 90°, 180°, and 270° angles. The stimuli were presented in three conditions: 1) wireless synchronization mode on with directionality off; 2) wireless synchronization mode off with directionality on; and 3) wireless on and directionality on. The results revealed that the wireless on and directionality off condition resulted in the best performance followed by Wireless on with Microphone on then by Wireless off /Microphone on mode. They concluded that, in the extremely noisy conditions, the condition where wireless is on and directionality is off can be recommended.

Hence, all the reports on hearing aids that is equipped with wireless synchronization report superior performance by these hearing aids at least in some of the tasks. However, these studies have either disabled all advanced digital signal processing techniques or enabled all of them or studied only directionality. Hence, the effect of each of the advanced digital signal processing techniques such as DNR and directionality in wirelessly connected hearing aids are not known. Studies have shown that fully adaptive directional microphones and also the noise reduction algorithm play a significant role in better understanding of speech in noise (Kuk et al., 2005).

Keidser et al. (2006) reported that these DSP features can disrupt important cues for localization and speech in noise when the two hearing aids cannot communicate with each other. The cues that are disrupted otherwise may be expected to be preserved and hence, may result in speech perception in noise and localization ability when wireless hearing aids are used. Hence, the present study aimed to evaluate the benefit of binaural wireless technology hearing aids on speech intelligibility in noise in individuals with hearing impairment.

Chapter 3

Method

The present study aimed to check the benefit of binaural wireless technology hearing aids on speech intelligibility in noise in individuals with hearing impairment. The method consisted of the following steps:

Step 1: Selection of participants

Step 2: Hearing aid programming and routine hearing aid evaluation

Step 3: Experiment to assess the benefit of binaural wireless technology on speech intelligibility in noise

Step 4: Objective Measurement of the Output of Hearing aid

Step 1: Selection of Participants

Fifteen hearing impaired participants, with an age range of 18-55 years (Mean Age = 40.2, SD = 11.12; Males = 11 and Females = 4) had been included in the study. The participants who fulfilled the following criteria were selected for the study:

Inclusion criteria

- Participants with bilateral post-lingual mild to moderate flat sensorineural hearing loss were selected for the study. The configuration was considered flat if the difference was not more than 10 dB HL at every octave from 250 Hz to 8000 Hz (Kennedy, Levitt, Neuman, & Weiss, 1998).

- The difference between right ear and left ear thresholds had not exceeded 15 dB HL (Gatehouse, Naylor, & Elberling, 2006).
- Speech identification scores was not less than 70%,
- ‘A’ or ‘As’ type of tympanogram with acoustic reflex thresholds were appropriate to the degree of hearing loss at 500 Hz to 4000 Hz,
- No past experience with any hearing aid, and
- Had mother tongue as Kannada Language.

Exclusion criteria

Participants with middle ear disorders, neurological involvement and psychological related problems were excluded from the study. The details on the above aspects were obtained through detailed case history.

Instrument Used

- A dual channel diagnostic audiometer, Piano Inventis, was calibrated and was used for routine audiological evaluation and for the actual experiment. The tests were carried out using this audiometer with TDH 39 head phones which was housed in MX-41 AR cushion and Radio Ear B-71 bone vibrator and also two loud speakers located at 1 meter distance at 45° angle for routine evaluation and at 90° azimuth for the actual experiment.
- To check the functioning of the middle ear, tympanometry and acoustic reflex assessment had been carried out with a GSI-Tympstar middle ear analyzer.

- Two digital WDRC hearing aids of same model with the following features were selected:
    - With the facility of Near field magnetic induction (NFMI) facilitating wireless transmission,
    - With the fitting range of mild to moderately severe degree,
    - With adaptive directionality microphone and DNR options,
    - With the option of disabling/enabling the above features, and
    - With the facility to turn on and off the wireless synchronization between the two hearing aids.
- The computer with an Intel Core 2 Duo processor with windows 7 configuration was used to program the hearing aids which were connected to Hi-PRO using the NOAH-3 software. Appropriate cable for programming and specific program software given by that particular hearing aid company had been used to program the hearing aid.
- A personal laptop with Intel Core i3 processor with windows 7 configuration was connected to the audiometer auxiliary input to present the stimuli for carrying out the experiments.

Test Environment

A sound treated air conditioned double room set-up was used to administer all the above mentioned tests. The noise level in the testing room was maintained within the permissible limits (ANSI, 1999).

Stimuli

- SRT testing was carried out using the Kannada paired words developed at the Department of Audiology, All India Institute of Speech and Hearing, Mysore.
- SIS was obtained using the PB word lists which were developed in Kannada language by Yathiraj and Vijayalakshmi (2005) for routine hearing evaluation. This test has four lists of 25 phonemically balanced words.
- Speech intelligibility in noise was assessed using the QuickSIN test in Kannada language developed by Avinash, Raksha and Ajithkumar (2010). This test has seven equivalent lists with seven sentences each.

Procedure for Routine audiological evaluation

Routine audiological evaluation included Pure-tone Audiometry, Speech audiometry and Immittance evaluation. In the pure-tone audiometry, the pure tone thresholds were traced by using the modified Hughson and Westlake procedure (Carhart & Jerger, 1959). This testing was done for air conduction thresholds for frequencies from 250 Hz to 8000 Hz and for obtaining the bone conduction thresholds from 250 Hz to 4000 Hz. The air conduction threshold at 500 Hz, 1 kHz and 2 kHz was used to calculate the Pure Tone Average (PTA).

Speech Identification Scores (SIS) were obtained at 40 dB SL (re: SRT) using the PB word lists which was developed in Kannada language by Yathiraj and Vijayalakshmi (2005). UCL for speech was also obtained. SIS was used to correlate with the obtained PTA using Kannada paired words.

In order to check the middle ear function, Immittance Evaluation was done on all the participants. Tympanometry and Acoustic reflex assessments had been carried out using GSI-Tympstar middle ear analyzer instrument using the normal standard procedures. Based on the results of the above tests, participants who fulfilled the selection criteria underwent further evaluations.

Step 2: Hearing aid programming and routine hearing aid evaluation

- The participants were fitted with the selected digital BTE hearing aid, using the computer with the NOAH-3 software which was connected to Hi-PRO.
- Hearing aid was programmed based on NAL–NL1 Prescriptive formula using the audiometric thresholds of the individual and First fit was applied.
- Ling’s six sounds were presented at a distance of 1 meter and the participant was instructed to identify these sounds. The hearing aid gain setting was modified till the participant could identify the sounds.
- A routine hearing aid evaluation using the audiometer was carried out by asking five questions and finding out SIS at 40 dB HL. This was done for individual ears as well as for binaural fitting.

Step 3: Experiment to assess the benefit of binaural wireless technology on speech intelligibility in noise

Participants were seated in the sound-treated room which contained a speaker located at 90° degree azimuth, and the center of the head of each participant was 1 meter away from each loudspeaker. The sentences from QuickSIN test was presented at 70 dB SPL (Avinash, Raksha and Ajith Kumar, 2010) through the computer which was connected to a calibrated dual channel diagnostic audiometer in the following conditions.

- Unaided
- Aided- Directionality on with wireless synchronization on
- Aided-Only DNR on with wireless synchronization on
- Aided-Both algorithms activated with wireless synchronization on
- Aided- Directionality with wireless synchronization off
- Aided- DNR on with wireless synchronization off
- Aided-Both algorithms activated wireless synchronization off

The WDRC settings were as prescribed by NAL-NL1 prescriptive formula. The QuickSIN test consists of seven equivalent lists with seven sentences each. These sentences are embedded in eight talker speech babble. In each list, the first sentence was presented at +8 dB SNR and SNR reduced in 3 dB steps till -10 dB SNR for the subsequent sentences.

The participants were instructed that ‘you will hear sentences in Kannada in the presence of noise in the background and you need to repeat what you hear using the talk back system’. The tester took down the responses and each correctly repeated key word was awarded one point. Each list in the QuickSIN test had five key words and each key point was awarded one point. Each sentence had a maximum score of five and each list had maximum score of 35. Before the actual test, a practice session was given.

The equation for arriving at SNR-50 was Spearman-Karber equation given by Finney (1952). The equation is as follows:

$$\text{SNR-50} = i + \tfrac{1}{2}(d) - (d)\,(\#\ \text{correct}) / (w)$$

Where,

I = the initial presentation level (dB S/B)

d = the attenuation step size (decrement)

w = the number of key words per decrement

Correct = total number of correct key words

Test conditions were randomized and counterbalanced to reduce order effects. Each sentence lists were used only once in order to avoid practice effect.

Step 4: Objective Measurement of the Output of the hearing aid

The SPL at the ear drum in the seven conditions mentioned in step 3 were measured using Fonix 7000 system. The SPL was recorded on another five participants age range of 18-25 (Mean age = 22 and SD = 1.30; four females and one male). The inclusion criteria used for selecting these subjects was that the participants had to have normal middle ear and ear canal free of debris. This was assessed using otoscopic examination and Immittance testing.

Procedure:

The hearing aid was programmed for a moderate degree of hearing loss. The gain and frequency response settings where same as that was used in one of the 15 participants tested in the previous step. The hearing aid was programmed in all the seven conditions.

The audiogram was loaded in the Fonix 7000 system. Real ear SPL measurement option was chosen in order to find the SPL in the ear canal. The participant was seated at one meter distance from the loudspeaker of an audiometer which was kept at 90^{o} degree azimuth. Otoscopic examination was done to ensure clear ear canal. The probe microphone of the Fonix 7000 system was inserted into the ear canal of the participant using the ‘composite’ method (Hawkins & Muller, 1992). The marker was used to mark the appropriate depth that can be inserted inside the participant’s ear canal. Levelling was done once the probe was inserted into the ear canal. Then, the source in the Fonix 7000 system was switched off.

A sentence from the QuickSIN test in Kannada language developed by Avinash, Raksha and Ajithkumar (2010) was presented through the calibrated audiometer using a personal computer. The sentence was presented at 65 dB SPL. Recording of the SPL was done in all the conditions using Fonix 7000 system.

Statistical analysis

The following data were subjected to statistical analysis using the SPSS (Statistical package for social science) software version 20. Repeated Measures ANOVA and Friedman test were carried out.

Chapter 4

Results and Discussion

The current study aimed to check the subjective and objective benefits of Directionality and Noise Reduction Algorithms of binaural WDRC wireless technology hearing aids in the following seven conditions:

- Unaided
- Aided- Directionality on with wireless synchronization on
- Aided- DNR on with wireless synchronization on
- Aided-Both algorithms activated with wireless synchronization on (In the table given as *All on Synchronization on*).
- Aided- Directionality on with wireless synchronization off
- Aided- DNR on with wireless synchronization off
- Aided-Both algorithms activated with wireless synchronization off (In the table given as *All off Synchronization off*)

The results are discussed under the following headings:

- o Experiment to assess the benefit of binaural wireless technology on speech intelligibility in noise
- o Objective Measurement of the Output of Hearing aid.

Experiment to assess the benefit of binaural wireless technology on speech intelligibility in noise

SNR-50 was obtained using the QuickSIN test in all the seven conditions which were mentioned above. The mean and standard deviation (SD) of SNR-50 in all the seven conditions are given in Table 4.1.

Table 4.1

Mean and SD of SNR-50 in all the conditions (N = 15).

Conditions	Mean	SD
Unaided	6.02	0.46
Directionality on Synchronization on	-1.62	0.38
DNR on Synchronization on	-1.26	0.35
All on	-2.18	0.30
Directionality on Synchronization off	0.51	0.35
DNR on Synchronization off	0.82	0.30
All on Synchronization off	0.30	0.29

The SNR-50 is defined as a SNR that is required to achieve 50% correct identification (Killion, 1997). A negative SNR-50 indicates better performance and a positive SNR-50 indicates poorer performance. From the Table 4.1, it can be observed that the aided conditions have yielded better SNR-50 when compared to the unaided condition. Among the aided conditions, the conditions with the wireless synchronization on resulted in better scores compared to that of without wireless synchronization. The condition with both DNR and directionality on and wireless communication on yielded the best score.

In order to see, if these differences in SNR-50 were significantly different or not, Repeated measure ANOVA was done. The results of this showed that there was a significant difference among the conditions tested [$F (6, 84) = 1177.90$, $p<0.001$). In order to find out which of the conditions differed from each other, Bonferroni pair-wise comparisons were done. The results of this are presented in Table 4.2.

Table 4.2

Results of Bonferroni pair-wise comparison (N =15).

Conditions	Compared condition	Mean Difference (I-J)
Unaided	2	7.6 **
	3	7.2
	4	8.2
	5	5.5
	6	5.2
	7	5.7
Directionality On Synchronization On	1	-7.6 **
	3	-0.3**
	4	-0.5 *
	5	-2.1 **
	6	-2.4 **
	7	-1.9 **
DNR On Synchronization On	1	-7.2 **
	2	0.3
	4	-0.9 **
	5	-1.7 **
	6	-2.0 **
	7	-1.5 **
All on Synchronization on	1	-8.2 **
	2	-0.5 *
	3	-0.9 **
	5	-2.6 **
	6	-3.0 **
	7	-2.4 **
Directionality On Synchronization Off	1	-5.5 **
	2	2.1 **
	3	1.7 **
	4	2.6 **
	6	-0.3
	7	-0.2
DNR On Synchronization Off	1	-5.2 **
	2	2.4 **
	3	2.0 **
	4	3.0 **
	5	0.3
	7	0.5 *
All On Synchronization Off	1	-5.7 **
	2	1.9 **
	3	1.5 **
	4	2.4 **
	5	-0.2
	6	-0.5 *

***p<0.001; *p<0.05. 1-Unaided, 2-Directionality on synchronization on, 3-DNR on synchronization on, 4-All on synchronization on, 5- Directionality on synchronization off, 6- DNR on synchronization off, 7- All on synchronization off*

As it can be viewed in the Table 4.2, the unaided condition and the All on synchronization on condition were significantly different from all the other conditions [$p<0.001$], unaided condition yielding lowest performance and All on synchronization on condition yielding the best performance. Among the conditions where synchronization was on, directionality and DNR were not significantly different from each other indicating similar performance in these two conditions. However, these two conditions were significantly different from all on condition and all the conditions with synchronization off.

All the conditions where synchronization was off were significantly different from all the conditions where synchronization was on and the unaided condition. Among the conditions where synchronization was off, directionality on was significantly different from all the conditions except DNR and all on synchronization off conditions.

To summarize, the DNR and directionality algorithms resulted in equal performance. Activation of both the algorithms resulted in better performance. Further, activation of ear-ear synchronization resulted in significantly better performance (approximately 2 dB) when compared to deactivation of ear-ear synchronization. These results are in concurrence with the results of the study done by Ciorba et al. (2014). They reported that when wireless mode and microphone mode was switched on there was a better performance in speech in noise test. They reasoned that it is due to the combined effect of attenuation of the external noise that disturbs the signal and the additional gain that it gives. However, they had not evaluated DNR algorithm.

Kreisman et al. (2010) also reported that they found a significantly higher performance in wireless synchronization on condition when tested with QuickSIN test and HINT test. In their study the test was done using the latest hearing aid which implements new DSP platform which is true with the present study as well.

However, Iman et al. (2013) found no significant difference in QuickSIN test even though binaural wireless synchronization is supposed to be preserving binaural cues and provide better SNR. The reason for this could be that, in Iman et al's study, DNR and Directionality algorithms had been deactivated in all the test conditions. The hearing aid that they used in their study did not have a wider bandwidth. They also reported that the participants included in their study were older population and age related cognitive deficits may also have influenced their results.

Objective Measurement of the Output of Hearing aid

The SPL obtained using Real ear aided measurements (REAM) in the frequencies 250, 500, 1 kHz, 2 kHz, 4 kHz and 6 kHz in all the seven conditions were subjected to statistical analysis. The mean and SD of this is given in the Table 4.3. The table shows that the SPL in the unaided conditions is lower compared to all the aided conditions. However, among the aided conditions, the mean SPL varied between the synchronization on condition and synchronization off condition. The Friedman test was used in order to find out if there are any differences statistically among the conditions tested.

Table 4.3

Mean and SD of SPL for all frequencies in all seven conditions (N=5).

Conditions	**250 Hz**		**500 Hz**		**1 kHz**		**2 kHz**		**4 kHz**		**6 kHz**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Unaided	51.1	4.2	51.9	4.5	43.2	9.9	38.5	7.5	34.5	2.9	31.4	4.6
Directionality On with Synchronization On	55.1	4.2	62.8	8.6	68.1	4.7	80.9	4.4	69.3	4.7	48.1	7.2
DNR On with Synchronization On	58.0	5.3	67.1	4.6	68.9	4.9	72.1	5.9	62.8	7.1	45.6	5.3
All On with Synchronization On	57.6	1.9	65.3	2.0	73.2	5.1	79.1	3.7	69.2	5.4	43.8	5.9
Directionality On with Synchronization Off	55.1	3.1	63.1	4.1	69.5	6.2	71.1	6.3	59.3	2.0	42.6	5.4
DNR On with Synchronization Off	55.6	3.9	66.7	4.0	74.6	2.4	79.1	5.8	63.9	6.8	44.5	4.7
All On with Synchronization Off	50.7	1.9	62.0	2.9	72.9	3.8	74.4	4.3	64.2	6.6	45.6	4.5

The results of Friedman test revealed that there was a significant difference (χ^2 (41) = 183.94, $p<0.01$) among the conditions. In order to see which conditions statistically differed, Wilcoxon Signed Rank test was administered and the results of this are given in Table 4.4.

Table 4.4

Results of Wilcoxon Signed Rank Test for pair-wise comparison (N = 5).

Conditions	Compared condition	250 Hz Z	500 Hz Z	1 kHz Z	2 kHz Z	4 kHz Z	6 kHz Z
Unaided	2	-1.2	-1.7	-2.0 *	-2.0 *	-2.0 *	-2.0 *
	3	-1.7	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *
	4	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-1.7
	5	-1.7	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-1.7
	6	-1.7	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *
	7	-0.6	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *
Directionality On Sync On	1	-1.2	-1.7	-2.0	-2.0 *	-2.0 *	-2.0 *
	3	-1.4	-0.9	-1.7	-2.0 *	-1.7	-0.8
	4	-1.2	-0.9	-1.2	-0.1	-0.4 *	-1.7
	5	-0.4	-0.6	-0.1	-1.7	-2.0	-1.7
	6	-0.4	-0.6	-2.0 *	-0.7	-1.4	-1.2
	7	-1.7	-0.1	-1.4	-1.7	-1.2	-1.3
DNR On Synchronization On	1	-1.7	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *
	2	-1.4	-0.9	-1.7	-2.0 *	-1.7	-1.7
	4	-0.6	-0.6	-1.2	-1.4	-1.4	-0.1
	5	-0.9	-2.0 *	-0.1	-0.6	-0.9	-1.2
	6	-0.9	-0.1	-2.0 *	-2.0 *	-0.4	-0.6
	7	-2.0 *	-1.4	-1.2	-0.4	-0.1	-1.7 *
All on Synchronization on	1	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-1.7
	2	-1.2	-0.9	-1.2	-0.1	-0.4	-1.7
	3	-0.6	-0.6	-1.2	-1.4	-1.4	-1.4
	5	-1.2	-0.9	-0.8	-1.7	-2.0 *	-0.1
	6	-0.6	-0.4	-0.6	-0.1	-1.4	-0.6
	7	-2.0 *	-1.4	-0.1	-1.2	-1.2	-0.9
Directionality On Synchronization Off	1	-1.7	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-1.7
	2	-0.4	-0.6	-0.1	-1.7	-0.9	-1.7
	3	-0.9	-2.0 *	-0.1	-0.6	-2.0 *	-1.7
	4	-1.2	-0.9	-0.8	-1.7	-1.4	-0.3
	6	-1.3	-1.7	-1.2	-1.7	-1.4	-0.9
	7	-2.0 *	-0.6	-1.2	-1.2	-1.7	-0.9
DNR On Synchronization Off	1	-1.7	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *
	2	-0.4	-0.6	-2.0 *	-0.7	-1.4	-1.2
	3	-0.9	-0.1	-2.0 *	-2.0 *	-0.4	-0.1
	4	-0.6	-0.4	-0.6	-0.1	-1.4	-0.6
	5	-0.1	-1.7	-1.2	-1.7	-1.4	-0.9
	7	-2.0 *	-1.7	-0.1	-2.0 *	-0.1	-0.1
All On SynchronizationOff	1	-0.6	-2.0 *	-2.0 *	-2.0 *	-2.0 *	-2.0 *
	2	-1.7	-0.1	-1.4	-1.7	-1.2	-1.3
	3	-2.0 *	-1.4	-1.2	-0.4	-0.1	-0.2
	4	-2.0 *	-1.4	-0.1	-1.2	-1.2	-0.9
	5	-2.0 *	-0.6	-1.2	-1.2	-1.4	-0.9
	6	-2.0 *	-1.7	-0.1	-2.0 *	-0.3	-0.1

**p<0.05. 1-Unaided, 2-Directionality on synchronization on, 3-DNR on synchronization on, 4-All on synchronization on, 5- Directionality on synchronization off, 6- DNR on synchronization off, 7- All on synchronization off*

Results of the Wilcoxon pair-wise comparison revealed that the unaided condition was significantly different from all the other conditions in all the frequencies [$p<0.05$] except at 250 Hz. The finding of no significant difference at 250 Hz can be attributed to the lower gain settings of the hearing aid at 250 Hz.

However, among the aided conditions, there was no specific trend in terms of activation of synchronization, the type of algorithm or in terms of frequency. This may be because of the smaller sample size or may be because of the stimulus condition. In the present study, the stimulus used was a speech sentence embedded in speech babble. Hence, both speech and noise were presented through the same speaker, which is a very complex condition for the DNR and directionality algorithms to process. However, the conditions in which synchronization was on resulted in an average of 2 dB (Range = 0 to 10 dB) more output than that was observed in the conditions in which synchronization was off in many off the frequencies.

Chapter 5

Summary and conclusion

The new technology hearing aids with wireless technology communicate and transmit their signal processing between the hearing aids and this in turn is said to improve SNR by preserving the binaural cues (Kreisman et al., 2010). However, there are no published reports, to our knowledge, evaluating each of the advanced features, that is, the directionality and noise reduction algorithms in the WDRC binaural wireless hearing aids in comparison with non-wireless hearing aids.

Hence, the aim of the present study was to check the subjective and objective benefits of Directionality and Noise Reduction Algorithms of binaural WDRC wireless technology hearing aids. Fifteen hearing impaired participants, with an age range of 18-55 years had been included in the study. They were evaluated with QuickSIN test developed by Avinash, Raksha and Ajith Kumar (2010) and SNR-50 was traced. Objective measurement of the SPL in the ear canal was also done on another five participants. These measurements were carried out in the following conditions:

- Unaided
- Aided- Directionality on with wireless synchronization mode on
- Aided- DNR on with wireless synchronization mode on
- Aided-Both algorithms activated with wireless synchronization mode on
- Aided- Directionality on with wireless synchronization mode off
- Aided- DNR on with wireless synchronization mode off
- Aided-Both algorithms activated wireless synchronization mode off

Results showed that there was a significant improvement in understanding speech in noise using the wireless synchronization hearing aids when compared to deactivation of ear-ear synchronization. However, the DNR and directionality algorithms resulted in equal performance when tested alone, nevertheless, activation of both the algorithms resulted in better performance. Though the results of the objective measurement of SPL did not show a significantly superior performance of wireless hearing aids, the SPL recorded was slightly higher at many frequencies.

It can be concluded that wireless hearing aids do benefit the individuals with mild to moderate degree of hearing loss in speech in noise perception and activation of the DSP algorithms is beneficial. However, the results may be specific to the stimulus conditions. The speech in noise condition used in the present study is a very complex condition. Hence, similar studies are required to support the results of the present study in varying noise conditions.

Implications

- The results of this study present an evidence for the benefit provided by wireless hearing aids in better understanding of speech in noise.
- These results can be used to counsel the individuals who need to be fitted with hearing aids, during the selection of hearing aids, on the advantage that the wireless hearing aids provide and to counsel about the algorithms that will be suitable for the individual with mild to moderate sensorineural hearing loss.

Future Directions

- Further studies can be done using moving noise for speech in noise assessments and also localization tasks can be used.
- Assessment of real life performance of the wireless hearing aids would be helpful.

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