OUTCOME OF EXPERIENCED USERS OF WIRELESS SYNCHRONIZATION DIGITAL HEARING AIDS USING SPEECH, SPATIAL AND QUALITIES QUESTIONNAIRE

Shiyaamsundar V B
Register Number: 16AUD027

This Dissertation is submitted as part fulfilment

For the Degree of Master of Science in Audiology

University of Mysuru, Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSURU-570006

APRIL 2018

CERTIFICATE

This is to certify that this dissertation entitled **"Outcome of experienced users of wireless synchronization digital hearing aids using Speech, Spatial and Qualities questionnaire"** is the bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 16AUD027. 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.

Mysuru
April, 2018

Prof. S. R. Savithri
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysuru-570006

CERTIFICATE

This is to certify that this dissertation entitled **"Outcome of experienced users of wireless synchronization digital hearing aids using Speech, Spatial and Qualities questionnaire"** 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.

Mysuru
April 2018

Dr. Geetha C
Guide
Reader in Audiology
All India Institute of Speech and Hearing
Manasagangothri,
Mysuru-570006

DECLARATION

This is to certify that this dissertation entitled **“Outcome of experienced users of wireless synchronization digital hearing aids using Speech, Spatial and Qualities questionnaire”** is the result of my own study under the guidance of Dr. Geetha C, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration No: 16AUD027**

April, 2018

Dedication

To God

To my Dad, mom, bro

Acknowledgements

I would like to thank Dr. S.R.Savithri, Director, All India Institute of Speech and Hearing, Mysuru, for permitting me to carry out my dissertation.

My heartful gratitude to my guide, Dr.C.Geetha, reader in audiology, Dept. of Audiology, AIISH, for the constant guidance and support. Madam, your patience and help have made this study possible. You have been a tremendous mentor for me. Thanks a lot mam.

I would like to express my thanks to vikas sir, sharath sir,Malar mam, Sumana mam, shanthala mam, rohith sir, pavan sir, prawin sir, vijayalakshmi mam, asha mam, akshay sir and also others for helping me in my data collection.

I express my sincere thanks to Dr.Vasanthalakshmi and Dr.Santhosha C.D. for guiding me in statistical analysis.

All the participants …without which this study would not have been completed. Thank you all for your patience and spending your valuable time with me….thanks a lot.

I would like to express my thanks to my friends --Decibels, Firebolt, sustainers and others for their timely and valuable help provided.

I would like to express my thanks to people who also directly and indirectly helped me to complete my dissertation.

Happy Reading…☺

ABSTRACT

The present study aimed at evaluating the subjective responses of speech, spatial and quality of hearing in elderly individuals who use binaural hearing aids with wireless synchronization feature and comparing it with elderly individuals with binaural hearing aids without wireless synchronization feature through Speech, spatial and Quality of hearing (SSQ) questionnaire. The data were collected from 20 elderly individuals with bilateral mild to moderate sensorineural hearing loss. They were divided into two groups based on the wireless synchronization feature as group I with wireless and group II without wireless synchronization feature. Routine audiological evaluation was done to check for the eligibility criteria to participate in the study. SSQ questionnaire which consisted of 50 questions divided into three categories as speech, spatial and quality was administered. Statistical analyses were performed to compare the subjective ratings in group-wise and pair-wise manner. The results revealed better performance in spatial and quality domains by wireless synchronization users which was not statistically significant and significantly better performance in speech domain by non-wireless synchronization hearing aid users. Hence, the present study suggests that hearing aids with wireless synchronization feature can help in better performance in spatial and quality aspects. However, other influencing factors have to be ruled out.

Keywords: Wireless synchronization, Speech, Spatial, Quality, hearing aids.

Table of Contents

List of Tables

List of Figures

CHAPTER 1

INTRODUCTION

World Health Organization (WHO) in 2013 had estimated that around 360 million people in the world suffer from disabling hearing loss. Hearing loss can lead to difficulties in exchanging information, thereby affecting daily life, causing loneliness, isolation from the society, dependence on others and frustration especially in elderly adults (Ciorba, Pelucchi & Pastore, 2012). Presbycusis is usually referred to as hearing loss associated with aging. Presbycusis is considered as a common cause of hearing loss in elderly individuals (Nelson & Hinojosa, 2006). The elderly individuals diagnosed with sensorineural type of hearing impairment are found to suffer a greater interference in communication irrespective of the cause of the hearing loss (Mulrow et al., 1990; Nelson & Hinojosa, 2006). Most of the individuals with sensorineural hearing loss suffer from reduced audibility, reduced dynamic range, reduced frequency selectivity (Moore & Glasberg, 1997) and impaired temporal resolution (Nelson & Thomas, 1997). This in turn causes reduced speech intelligibility and listening discomfort in quiet as well as adverse listening conditions. The primary management option for these individuals is fitting hearing aids.

Hearing aid helps in amplifying the sounds thereby making the signal audible and comfortable. New features in hearing aids are being developed day-to-day to improve the real life experience of hearing aid users. One such advanced feature is the binaural synchronization wherein the two hearing aids in both ears of an individual communicate with each other synchronously.

Geetha, Tanniru and Rajan (2017) found that there could be a reduction in localization errors and also improved speech perception in the presence of noise, because of the wireless connectivity between the two hearing aids. This possibly enables the directional microphones in the wireless synchronization hearing aids to preserve the binaural cues. There are a few more published research studies on speech perception and localization performance of wireless synchronization hearing aids.

One such study was conducted by Kreisman, Mazevski, Schum and Sockalingam (2010). They fitted binaural hearing aids with and without wireless synchronization in two different models of hearing aids on 36 individuals who had sensorineural hearing loss in both the ears. They studied speech perception in the presence of noise and found that there was a significant improvement in performance with the hearing aids with wireless synchronization when compared to hearing aids without it. They also reported that the newer model of hearing aid yielded better results when compared to the older one.

Sockalingam, Holmberg, Eneroth and Shulte (2009) studied the spatial and quality aspects in 30 bilateral sensorineural hearing impairment individuals who were fitted with wireless synchronization hearing aids. They subsequently studied with and without wireless synchronization between the two binaural hearing aids and found that the conditions with wireless synchronization scored better than without it.

Ibrahim, Parsa, Macpherson and Cheesman (2012) studied the localization ability and speech intelligibility in individuals with bilateral sensorineural hearing loss who were fitted with different brands of bilateral wirelessly connected wide dynamic range compression (WDRC) hearing aids. They found that there was a significant improvement in Front/Back localization in individuals with wireless synchronization hearing aids.

The above review highlights the studies done on speech perception and localization measures with wireless synchronization hearing aids. Smith et al. (2008) evaluated self assessment of benefit with the wireless synchronization feature found in advanced digital hearing aids. They included 30 listeners with hearing impairment and divided them into three groups. The researchers compared the performance of synchronized and non-synchronized bilateral hearing aids using the Speech, Spatial and Qualities of Hearing scale. The results revealed that self assessed benefit was more for hearing aids with synchronization.

1.1 Need for the study

Binaural hearing helps in improving signal to noise ratio (SNR), auditory localization, loudness summation, reduction of head shadow effect and improved sound quality (Mueller & Hall, 1998). Hearing aids are implemented with a new array of technology and features every now and then. One such advanced and relatively newer feature includes wireless synchronization where the hearing aids communicate with each other and synchronizes the information on both the instruments simultaneously. There are a few studies on the efficacy of directional hearing aids and they consistently report better speech perception in noise (Geetha et al., 2017) and localization (Smith et al., 2008; Geetha et al., 2017) in the lab and clinical set ups.

1.1.1. Need to assess real-life benefit of wireless binaural hearing aids

Most research done on the wireless synchronization hearing aids have focused on lab based measures such as speech perception and localization. While these measures are important, consumer satisfaction is the major key and needs a comprehensive assessment (Metselaar et al., 2009). “Satisfaction is a subjective phenomenon that shows patients concept of structures, processes, and the outcomes of delivered services” (Uriarte, Denzin, Dunstan, Sellars & Hickson, 2005). More appropriate services can be delivered to hearing impaired population by studying the efficacy of rehabilitation services and also their satisfaction with hearing aids which are usually adjusted according to their needs (Angeli, Jot, Barba, Demengbi & Mello, 2009). Providing appropriate amplification has an effect on efficacy of aural rehabilitation. Moreover self reported questionnaires measures the real life outcomes and gives information even on specific categories of rehabilitation (Cox, 2003) which cannot be measured using laboratory settings. Hence, self-report questionnaires can be considered as appropriate instruments for assessing consequences of using hearing aids and also the user’s satisfaction (Uriarte et al., 2005).

Assessing any hearing aid fitting can be done using a simple, quick and effective procedure. Self-assessment questionnaire can be used to compare hearing aids and/or features within hearing aid and also validating the results in hearing aid selection and fitting process (Hush & Hosford-Dunn, 2000).

There is only one evidence of self perceived benefit and satisfaction of wireless hearing aids. Smith et al. (2008) had assessed self-perceived benefit of wireless over non-wireless hearing aids using Speech, Spatial and Qualities (SSQ) of Hearing Scale. The number of participants was only around 10 numbers in each group. In addition, they had included a very large age range (i.e., between 38 to 75 years) where age related changes in the auditory system might have influenced the results in their study. Further, results obtained from wide age range may be difficult to generalize (Faber & Fonseca, 2014). Therefore, there is a dearth of research on the real-world performance as perceived by the listeners with wireless synchronization hearing aids.

1.1.2. Need to use Speech, spatial and qualities Questionnaire

SSQ is a questionnaire developed by Gatehouse and Noble (2004). This focuses on measuring the aspects of hearing in three domains, i.e., speech, spatial and qualities. It includes various situations where there is a specific and typical speaking situation, as well as including distance, direction and movement of sound. It also includes questions on quality of sound, such as voice recognition and effort required to listen. Since wireless hearing aids result in a combine scene analysis and symmetrical steering of processing functions, SSQ will be an appropriate tool to be used.

1.2 Aim of the study

The aim of the present study was to evaluate the potential benefit of day-to-day life subjective outcome of digital hearing aids with wireless synchronization in comparison with hearing aids without wireless synchronization.

1.3 Objectives of the study

The objectives of the present study were -

- To compare daily life outcome between Group I (with wireless synchronization hearing aid users) and Group II (without wireless synchronization hearing aid users) on three domains viz., speech, spatial and quality.

- To compare daily life outcome across the three domains namely speech, spatial and qualities for each group.

CHAPTER 2

REVIEW OF LITERATURE

Individuals who are diagnosed as sensorineural hearing loss usually have poor understanding of information in noisy as well as reverberant situations (Helfer & Wilber, 1990; Plomp, 1986). In order to restore their audibility, hearing aids are fitted for these individuals. Though the hearing aid fitting may be successful in some cases, the satisfaction from the hearing aid may vary from one individual to other (Humes & Humes, 2004). The benefit from hearing aid mainly depends on the speech perception abilities of the individuals (Meister, Lausberg, Kiessling, Walger & Wedel, 2001, 2002). Kochkin in 2005 reported that only 59% of the individuals among 3000 people were satisfied with their hearing aids and the reason for reduced satisfaction in other individuals being difficulty in noisy environments. Moreover the satisfaction mainly depended on the naturality and the clarity of the sound. Signal to noise ratios (SNR) could be a factor to be considered for satisfaction (Walden & Walden, 2005). Therefore bilateral digital technology that helps in noise reduction and enhancing the speech perception can be suitable for these individuals.

Individuals with sensorineural hearing loss are likely to have disruption in spectral cue based localization (Byrne & Noble, 1998; Byrne, Noble & Lepage, 1992, 1994; Noble, Byrne & Ter-Horst, 1998; Rakerd, Velde & Hartmannt, 1998). Localization is an important aspect as it helps in improving speech perception in noise (Bronkhorst & Plomp, 1988, 1989). Byrne and Noble (1998) reported that localization difficulties in hearing aid users become evident only when asked about it. Therefore, speech, spatial and qualities of hearing questionnaire (SSQ) was developed which also includes questions related to spatial hearing. Though, bilateral fitting helps in improving localization for mild to severe hearing loss individuals (Byrne et al., 1992), hearing aids with wireless synchronization (designed in such a way that the two hearing aids work together as a single system using electromagnetic transmission), have been found to be better than those without wireless synchronization in terms of speech recognition in noise and localization (Powers & Burton, 2005). In the present study, the subjective real life performance of wireless hearing aids have been assessed using SSQ questionnaire and compared with that of hearing aids without wireless synchronization. The relevant literature is reviewed and presented below under the following headings:

2.1 Speech perception with binaural non-wireless synchronization technology

2.2 Speech perception with binaural synchronization technology

2.3 Spatial perception with binaural non-wireless synchronization technology

2.4 Spatial perception with binaural synchronization technology

2.5 Quality perception with binaural non-wireless synchronization technology

2.6 Quality perception with binaural synchronization technology

2.1 Speech perception with binaural non-wireless synchronization technology:

Digital hearing aids are implemented with new technologies, features or algorithms in order for the individuals with hearing impaired to perform better. Shanks, Wilson, Larson and Williams (2002) studied speech recognition in individuals with symmetrical sensorineural hearing loss for peak clipping, compression limiting and wide dynamic range compression (WDRC) in binaural hearing aids. Northwestern University Auditory test no.6 (NU-6) and Connected Speech test was used to measure speech recognition. They found that speech recognition was slightly better with significant difference in peak clipping and compression limiting compared to wide dynamic range compression hearing aids.

Kuk, Lau, Korhonen and Crose (2015) studied speech intelligibility in adults with symmetrical moderate to severe hearing losses across different input levels. They found that there was a decrease in speech intelligibility scores for increased input levels. Therefore, it can be inferred that binaural hearing aids can provide speech in noise benefit at very high noise inputs.

Quintino, Mondelli and Ferrari (2010) studied the speech perception in presence of noise in ITE, CIC and BTE monaural digital hearing aid users where directivity and noise reduction was activated and found that speech perception scores improved and also the benefits in daily life situations showed improvement. However, they did not compare the scores in binaural condition.

Santos and Costa (2016) studied the speech perception in noise in elderly individuals who had mild to moderately severe sensorineural hearing loss with different microphones and noise reduction strategies in the hearing aids which were fitted binaurally. Better scores where found when both the features were activated. Directional microphones seemed to provide better scores when sound was from behind.

Simpson, Hersbach and McDermott (2005) studied the monosyllabic word recognition in binaurally fitted digital hearing aids on 17 experienced hearing aid users out of which eight subjects showed increased scores and one subject showed poor scores. This variability could be due to the audibility provided in the high frequency region.

From the above studies, it can be concluded that even though there are strategies and noise reduction algorithms used, the hearing aids fitted without wireless synchronization doesn’t give significant improvement in speech perception in all the individuals. Moreover there are binaural cues reaching both the ears separately unlike wireless synchronization feature which can help in better speech perception.

2.2 Speech perception in binaural wireless synchronization technology:

Wireless synchronization is a feature wherein the two instruments communicate with each other simultaneously providing real time binaural cues to both ears thereby improving the listener’s performance. Some of the studies with wireless synchronization feature are discussed below.

Smith et al. (2008) studied the speech perception in individuals with wireless linked and unlinked conditions using speech spatial and quality questionnaire (SSQ). They found that individuals with linked hearing aids showed better speech perception scores compared to unlinked hearing aid users.

Geetha et al. (2017) studied the speech perception in noise in adults with wireless synchronization hearing aids where directional microphones were activated. They found improved speech perception scores in that condition. Ibrahim et al. (2012) also studied the speech intelligibility in wireless synchronization hearing aids with wide dynamic range compression (WDRC). Hearing in noise test (HINT) was performed on these individuals and found no specific benefit in speech intelligibility scores.

Kreisman et al. (2010) studied speech intelligibility in 36 symmetrical SNHL individuals using speech in noise tests which included the Quick SIN and Hearing in noise test. The participants were fitted with wireless binaural broad band hearing aids and advanced digital hearing aids. Results showed better speech intelligibility scores for wireless binaural broadband hearing aids in all conditions.

Picou and Ricketts (2011) studied speech perception in wireless routing conditions. They took 20 participants in whom six had wireless routing transmission and one participant with acoustic telephone condition. The speech signal which was the stimulus was delivered to both the ears in the presence of background noise and saw the effect of noise. They found that there was no effect of presence of noise and concluded that bilateral fitting of wireless hearing aids showed good performance compared to unilateral fitting. Most of the above research studies showed a positive change in speech perception scores when binaural hearing aids with wireless technology are used.

2.3 Spatial perception with binaural non-wireless synchronization technology:

Binaurally fitted hearing aids help in providing better performance in individuals with bilateral symmetrical hearing losses. Hearing aids in both the ears provide cues from all the directions thereby playing a role in localization when compared to monaural hearing aids.

Köbler and Rosenhall (2002) studied the horizontal localization in individuals with unilateral and bilateral fitting and found that bilateral users showed good performance than unilateral users in horizontal localization. Bogaert, Klasen, Moonen, Deun and Wouters (2006) studied frontal horizontal localization in bilateral hearing aids in bilateral hearing aid users and compared it with normal hearing individuals. They found that in localization task normal hearing individuals performed better than bilateral hearing aid users. Moreover both normal and bilateral hearing aid users showed poor performance when the acoustic environment was complex. Bogaert, Carette and Wouters (2011) studied the localization in front-back dimension in commercial hearing aids and compared with normally hearing individuals and found that no significant increase on performance in localization was seen.

The above studies are done in lab settings. There are a few reports on subjective rating of binaural hearing aid benefit. Best et al. (2010) used the Speech, Spatial and Qualities of Hearing Scale (Gatehouse & Noble, 2004) in unilateral and bilateral hearing aid users and found that the individuals with unilateral fitting showed some benefit in directional hearing and bilaterally fitted individuals showed benefit in distance and movement discrimination in the spatial domain.

As mentioned earlier, binaural digital hearing aids seemed to show slight improvement in various phases of localization but the cues reach each sides differently whereas wireless synchronization hearing aids through its real time synchronization can help in better preservation of binaural cues thereby can improve localization in all phases.

2.4 Spatial perception with binaural wireless synchronization technology:

Wireless synchronization hearing aids communicate with each other thereby providing real time information about the signal in both the hearing aids simultaneously. There are few studies measuring the spatial aspects in this technology. There a few published studies conducted in lab show that wireless hearing aids perform better in localization.

Sockalingam et al. (2009) studied localization in 30 wireless synchronization hearing aids users and compared with binaural off condition in some individuals. They found that binaural synchronization hearing aids could provide better localization even in the presence of multiple speakers. Geetha et al. (2017) studied the spatial perception in individuals with wireless synchronization hearing aids where directional microphones were activated. They reported an improvement in localization abilities in that condition.

Ibrahim et al. (2012) studied localization in 20 individuals out of which 12 had wireless synchronization hearing aids and remaining were normal hearing individuals which acted as reference group. They found that individuals with binaural wireless synchronization hearing aids had good localization abilities.

Smith et al. (2008) studied the spatial perception in individuals with wireless linked and unlinked conditions using SSQ. They found that individuals when fitted with linked hearing aids showed better spatial perception compared to the unlinked condition.

From the above studies, it can be inferred that wireless hearing aids result in better localization in a test set up. There are a very few reports on real-life localization benefit of hearing aids. Hence, there is a need to study localization in individuals with wireless synchronization feature because of its preserved binaural cues through its simultaneous synchronized information to both ears.

2.5 Quality perception with binaural non-wireless synchronization technology:

Quality assessment is also an important part of hearing aid outcome assessment. It plays a good role in satisfaction measures. Kochkin in 2005 through a survey of around 1500 hearing aid users found that the satisfaction was 71% and 78 % for individuals with 0-5 year’s old instruments and 1 year old instruments respectively. However, the satisfaction reduced tremendously for severe to profound loss individuals. The satisfaction was 90 % and 59 % for one-on-one and cell phone respectively.

Ricketts and Hornsby (2005) studied the quality measures of bilaterally fitted hearing aids through speech in noise test by implementing digital noise reduction (DNR) technology in 14 individuals and found that even a single implementation of DNR strategy can provide an improvement in sound quality.

Dillon, Birtles and Lovegrove (1999) studied the outcome from hearing aid users in 4421 individuals using Hearing Aid User's Questionnaire (HAUQ) and Client Oriented Scale of Improvement (COSI) to study their needs, benefits, problems, satisfaction, hearing aid use, and change in listening ability and also in various other situations.

Broca and Scharlach (2014) used the International Outcome Inventory for Hearing Aids questionnaire to validate the results in hearing aid selection and fitting and found that the questionnaire was helpful in assessing benefit and satisfaction in the individuals.

Cox, Gilmore and Alexander (1991) studied the benefit from hearing aids by comparing two questionnaires namely the Profile of Hearing Aid Benefit (PHAB) and the

Intelligibility Rating Improvement Scale (IRIS). These were administered in 42 individuals and found PHAB showed significantly reduced benefit from hearing aids.

2.6 Quality perception with binaural wireless synchronization technology:

Wireless synchronization hearing aids through its real time amplification and communication between hearing aids help to provide cues in real time playing a role in quality of hearing. There are very few studies which assess quality one of which is discussed below.

Sockalingam et al. (2009) studied sound quality in 30 wireless synchronization hearing aids users and compared with binaural off condition in same individuals. They found that binaural synchronization hearing aids could provide a more natural sound quality. Similarly, Smith et al. (2008) studied quality in binaural linked and unlinked hearing aids and found improvement in quality with linked hearing aid individuals.

To summarize, there are studies which reported the perception of speech, spatial and quality aspects of hearing aids through laboratory setups and subjective measures. However, a self reported questionnaire is the only subjective measure which can provide information about their speech, spatial and quality of perception in real world situations. From the above studies, it is clear that self report questionnaires are useful in determining the effectiveness in terms of acceptance, benefit and satisfaction from hearing aid users. Moreover there is a need to study about the satisfaction in a broad and detailed aspect in wireless synchronization and also non-wireless synchronization digital hearing aids.

CHAPTER 3

METHOD

The present study evaluated the real-life outcome of hearing aids with wireless synchronization using a questionnaire for which standard group comparison research design was used. The participants who passed the inclusion and exclusion criteria were administered with a questionnaire and compared within the two groups.

3.1 Participants

A total of 20 participants in the age range between 59 to 84 years with mild to moderate sensorineural hearing loss in both the ears with flat or gradual sloping pattern participated in the study. Out of these, ten individuals were experienced users of digital hearing aids with wireless synchronization in both ears. These individuals were assigned in Group I. The mean age of participants in this group was 70.3 and SD was 8.9. The remaining ten individuals were experienced users of digital hearing aids without wireless synchronization in both ears and served as controls. These individuals were assigned in Group II. The mean age of participants in this group was 70.8 and SD was 6.2.

Group I had mean PTA of 51.62 dB HL (SD = 3.12) in the right ear and 51.87 (SD = 2.71) in the left ear and Group II had mean PTA of 50.75 dB HL (SD = 3.59) in the right ear and 50.75 (SD = 3.34) in the left ear. There were other selection criteria used and they are given below.

3.2 Inclusion criteria

- Individuals who had degree of hearing loss within mild to moderate sensorineural hearing loss participated.
- Immittance findings of “A” type or “As” type.
- Unaided speech identification scores greater than 70% (Narne & vanaja, 2008)
- Participants who were a native speaker of Kannada language (a Dravidian language spoken in the state of Karnataka, India).
- Individuals in group I had experience with binaural wireless hearing aids for at least 3 months (Wu et al., 2016)
- Individuals in group II had experience with binaural non-wireless hearing aids for at least 3 months (Wu et al., 2016)
- An attempt was made to match age, listening environment and hearing aid processing between the two groups.

3.3 Exclusion criteria

- Participants with middle ear pathologies were excluded from the study.
- Individuals with unilateral hearing loss were also excluded.
- Individuals with any neurological or psychological disorders identified through detailed case history and previous examination reports were eliminated from this study.

All the participants were selected through the above selection criteria. The demographic and the audiological details of all the participants are given in the Table 3.1.

Table 3.1 *The demographic and audiological details of the participants*

Groups	Sl. No.	Age (yrs) / Gender	PTA (dB HL)		SIS (%)		Hearing aid usage	Hearing aid style
			Right ear	Right ear	Right ear	Left ear		
Group I	1	68/F	52.5	50	88	84	2 years	RITE
	2	61/F	56.25	55	84	84	14 years	RITE
	3	84/M	48.75	51.25	92	88	5 years	RITE
	4	79/F	52.5	52.5	88	88	5 years	RITE
	5	68/M	50	48.75	92	92	3 years	RITE
	6	77/M	46.25	48.75	92	92	2 years	RITE
	7	59/M	52.5	55	84	80	1 years	RITE
	8	68/M	56.25	55	76	80	4 months	BTE
	9	79/M	50	48.75	84	84	5 years	RITE
	10	60/F	51.25	53.75	80	76	9 years	BTE
Group II	1	76/F	46.25	50	84	88	7 months	RITE
	2	71/M	55	53.75	76	76	2 years	RITE
	3	60/F	45	43.75	96	92	3 months	CIC
	4	72/M	51.25	51.25	80	80	8 years	RITE
	5	67/M	48.75	46.25	88	92	3 years	RITE
	6	69/M	53.75	51.25	80	80	10 months	RITE
	7	75/F	50	52.5	76	76	4 years	RITE
	8	74/M	55	53.75	72	76	2 years	RITE
	9	81/F	48.75	51.25	80	80	3 years	RITE
	10	63/M	53.75	53.75	88	88	6 months	RITE

Note: RITE-Receiver in the ear; CIC-Completely in the canal; BTE-Behind the ear; Group I- Individuals with wireless synchronization hearing aids; Group II- Individuals without wireless synchronization hearing aids; PTA- pure tone average of hearing thresholds at 500 Hz, 1 kHz, 2 kHz and 4 kHz.

The participants in this study used hearing aids that varied in models, type, experience and also company. Though, most of the participants used Receiver in the ear (RITE) hearing aids where there were also very few with Behind the ear (BTE) and CIC (Completely in the canal) hearing aids. Most hearing aids had similar fitting range, signal processing options and number of channels.

3.4 Instrumentation

- Calibrated GSI-61, dual channel diagnostic audiometer with TDH-39 supra aural headphone housed in MX-41 AR cushion, B-71 bone vibrator and loudspeakers was used for the routine audiological evaluation.
- GSI-Tympstar middle ear analyser was used to assess the functioning of middle ear using tympanometry and acoustic reflex testing.

3.5 Ambient noise and environment

Entire testing was carried out in a sound treated double room set up. It was ensured that the ambient noise level within the test room was within the permissible limits (ANSI S3. 1999).

3.6 Stimuli / Material

- SRT testing was carried out using the Kannada spondee word list developed by the Department of Audiology, All India Institute of Speech and Hearing, Mysuru.
- SIS was obtained using the PB word lists (4 lists of 25 words) which was developed in Kannada language by Yathiraj and Vijayalakshmi (2005).

- SSQ in Kannada was used as the outcome measure. It included three categories and they are speech, spatial and quality. Speech domain had questions related to perception of speech in various situations and spatial had questions relating to distance, direction and motion of an object/ individual and also quality which included questions regarding the naturality, voice quality etc. There were a total of 50 questions: 14 in the Speech domain, 17 in the Spatial domain and 19 in the Quality domain.

3.7 Routine hearing evaluation

Participants in the current study were experienced hearing aid users. All the participants were re-evaluated with routine audiological testing in order to cross check for any elevation or deterioration of the thresholds. Routine hearing evaluation included pure tone audiometry, speech audiometry and immittance audiometry. In case of any changes or deteriorations in terms of pure tone average or speech identification scores then adequate changes in their hearing aids was done using NOAH software.

Immittance evaluation was carried out on all the participants in order to check the middle ear function. Tympanometry and acoustic reflex measurements were carried out using GSI-Tympstar middle ear analyzer. The participants who fulfilled the inclusion and exclusion criteria were included for further testing after obtaining informed consent.

3.8 Hearing aid evaluation

A routine hearing aid evaluation was carried out using the GSI-61, dual channel diagnostic audiometer by testing five questions and also their SIS at 40 dB HL to ensure that the gain settings used by the listeners' were adequate. It was ensured that all the hearing aids had all the DSP algorithms activated in both the groups and the wireless synchronization has been activated in all the participants in Group I.

3.9 Administration of SSQ

The participants in this study were given SSQ in Kannada language which consisted of 50 questions and the participants were asked to rate the questions. For each of the 50 questions, the patient responded based on an 11-point continuum were 0 represented “Not At All” and 10 represented “Perfectly” (or a term with an equivalent meaning). The questionnaire was scored for each of the three domains, or individual questions were viewed independently. Based on their experience with the hearing aids in different situations they rated their satisfaction. These ratings from rating scale were then compared between two groups on three different domains. Split half coefficient test was done to check the reliability for the subjective responses to questionnaire.

3.10 Statistical Analysis

Statistical package for the social sciences (SPSS) V17.0 was used for analyzing the data statistically. Test of normality was done followed by Mann-whiney U test for between group comparison, and Friedman’s test and Wilcoxson signed rank test for within group comparison.

CHAPTER 4

RESULTS

The main aim of the present study was to evaluate the potential benefit of day-to-day life subjective outcome of digital synchronizing wireless hearing aids and compare this with the individuals using hearing aids without wireless synchronization.

The subjective ratings on speech, spatial and qualities of hearing (SSQ) questionnaire from ten individuals with bilateral wireless synchronization hearing aids (Group I) and ten individuals without wireless synchronization hearing aids (Group II) were analyzed using SPSS for Windows (version 17) software. Split half coefficient test indicated moderate to good reliability for the subjective responses to questionnaire.

4.1 Comparison of real life outcomes between the two groups

Descriptive analysis of mean, median and SD of two groups revealed that Group I (wireless synchronization hearing aid) had higher ratings on spatial and quality domains and lower ratings on speech domain when compared to Group II. Inferential statistics to check for significant differences were carried out and are explained below. The mean, median and SD for the two groups are given in Table 4.1.

Table 4.1 *Mean, median and Standard deviation (SD) of subjective ratings on speech, spatial and quality domains in Group I and Group II*

Domain	Mean (raw scores)	Median (raw scores)	SD (raw)	Mean (%)	Median (%)	SD (%)
			Group I (wireless synchronization)			
Speech	3.37	3.21	1.24	33.7100	32.1400	12.45037
Spatial	5.51	6.29	2.48	55.1130	62.9400	24.89656
Quality	6.69	7.52	1.97	66.9400	75.2750	19.72452
			Group II (non-wireless synchronization)			
Speech	5.42	5.75	1.25	54.2820	57.4950	12.58686
Spatial	5.35	5.05	1.74	53.5850	50.5850	17.45854
Quality	5.73	5.41	1.83	57.3290	54.1600	18.37068

Note: Maximum possible average scores (raw) for all the domains was 10.

The scores on speech, spatial and quality domains between two groups were analyzed. As a part of statistical analysis, Mann-Whitney U test was performed to find out if any difference existed in speech, spatial and quality domains between wireless and non-wireless hearing aid users. The medians were compared instead of mean as non-parametric test was carried out. The results of this are given in Table 4.2.

Table 4.2 *Comparison of subjective rating between the two groups using Mann-Whitney U test*

Domain	|Z|	*P* value
Speech	2.695	.007*
Spatial	.454	.650
Quality	1.022	.307

Note: * $p < 0.01$.

The results revealed that the subjective rating in speech domain was significantly different [$|Z|=2.695$, $p < 0.05$] between the two groups. There was no significant difference between the two groups on spatial and quality domains of SSQ, though the Group I obtained higher rating on both spatial and quality domains.

4.2 Comparison of real life outcomes in speech, spatial and quality domains within group

The real life outcomes were compared between the domains within each group. The mean and SD of the same are given in Figure 4.1.

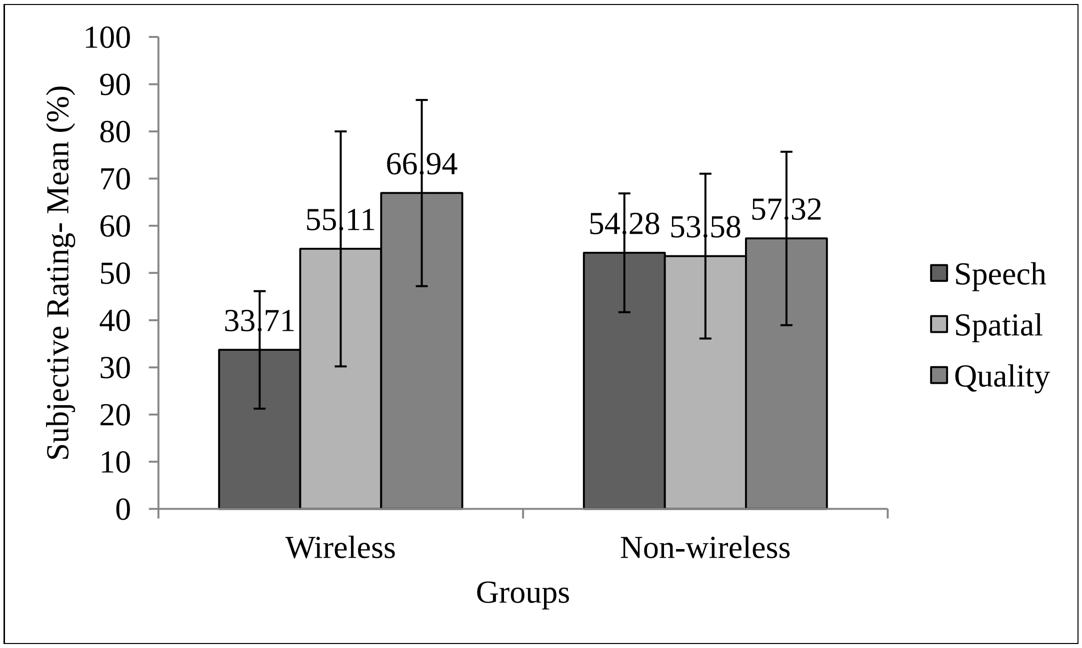

Figure 4.1 Mean (percentage) and SD of subjective ratings on speech, spatial and quality domains for two groups

It can be observed that the ratings between speech, spatial and quality domains differed in Group I and were similar in Group II. Friedman's test was carried out to see if there was any difference in the speech, spatial and quality domains in each group. The results revealed that there was a difference in speech, spatial and quality domain in Group I [χ^2 (2) = 13.400, $p < 0.05$] and no difference in speech, spatial and quality domain in non-wireless synchronization hearing aid user group [χ^2 (2) = 2.923, $p > 0.05$]

In order to check for pair-wise differences within the group, Wilcoxon signed rank test was performed. The results revealed that there was a difference subjective rating between speech and spatial [$|Z| = 1.988$, $p < 0.05$], between speech and quality [$|Z| = 2.803$, $p < 0.05$] and between comparison of Spatial and quality [$|Z| = 2.701$, $p < 0.05$].

Pair-wise comparison was not performed in Group II as they showed no differences in Friedman test.

CHAPTER 5

DISCUSSION

The daily life outcomes were measured in two groups of individuals, one who have been using binaural hearing aids with wireless synchronization and the other group had individuals who have been using hearing aids without wireless synchronization, using Speech spatial and quality of hearing (SSQ) questionnaire. The present study compared the SSQ scores between the two groups and between three domains within each group.

5.1 Comparison of real life outcomes between the two groups

The results of subjective rating on real-life speech perception in individuals with wireless and without wireless synchronization hearing aids revealed a significant difference between the two groups. The individuals using hearing aids without wireless synchronization scored better in speech domain when compared to wireless synchronization group. A similar study by Smith et al. (2008) found the opposite results in the speech domain. That is, the individuals using hearing aids with wireless synchronization provided higher rating on speech domain than the individuals without wireless synchronization.

In order to probe into the reason for the poorer rating on speech by individuals with wireless hearing aids in the present study, individual data was analyzed. Among ten in Group I, three of them had given poorer rating in SSQ. This may be due to the age related factors other than peripheral hearing loss might have contributed to diminished speech recognition (Salant & Fitzgibbons, 1993; Tremblay., 2002). We cannot be sure of the above reason unless the auditory processing is tested in all of them as even Group II had elderly individuals in similar age range. In addition, Smith et al. (2008) had included only participants who had an active life style i.e. who experience a variety of listening conditions in their everyday life where the present study didn't have such a criteria.

In the present study, the subjective rating of spatial perception by participants using hearing aids with wireless synchronization was higher than that of the individuals without wireless synchronization though there was no statistical significant difference. Similar findings were shown by Smith et al. (2008) where they reported that wireless synchronization group localize better in real world situations. The reason for this being real time amplification and synchronization between the hearing aids provides binaural cues to reach both the ears simultaneously in real time. The results of lab setting also revealed better performance with wireless synchronization in localization tasks. Sockalingam et al. (2009) studied localizations in lab setup in individuals with wireless synchronization activated and deactivated. They found that individuals performed better in localization tasks when wireless synchronization was activated. Similar results were also found by Ibrahim et al. (2012) and Geetha et al. (2017). Hence, it can be said that the directionality and DSP algorithms in wireless synchronization hearing aids can lead to better spatial perception even in real-life situation.

The result of self-rating on quality was similar to that of spatial perception. That is, the rating of quality by participants using hearing aids with wireless synchronization was not significantly different from that of the individuals without wireless synchronization, though the mean rating of quality was higher in wireless group compared to non-wireless group. These findings were supported by Smith et al. (2008)

where the quality of the sound was better in wireless group compared to non-wireless group in subjective measures. Sockalingam et al. (2009) studied the quality of sound through rating scale and found that wireless synchronization can improve the naturality of the sound in different situations when appropriate noise reduction settings, directionality synchronization and compression settings are optimized between ears. Powers and Burton (2005) stated that wireless synchronization feature improves the overall comfort in hearing aid because of synchronized decision making and also setting appropriate digital signal processing in them can improve the overall quality in various listening environments.

5.2 Comparison of real life outcomes in speech, spatial and quality domains within each group

The results of comparing speech, spatial and quality domains within individuals using wireless synchronization hearing aids showed differences between different permutations and combinations of three domains. The highest rating was for quality followed by spatial perception and the least scoring was for speech. There are no published reports, to our knowledge comparing these domains in wireless synchronization hearing aid users. The possible reason for such outcome could be exposure to environment, listening situations, communication needs etc.., which differs from person to person particularly in this elderly age group. Moreover the results of comparing speech, spatial and quality domains within individuals using non-wireless synchronization hearing aids showed no differences in all the domains.

From the present study, it can be inferred that participants with wireless synchronization hearing aids performed better in spatial and quality aspects of hearing and reduced performance in speech perception for wireless synchronization group compared to non-wireless hearing aid users. The possible reasons for reduced speech perception scores may be age related changes in the higher auditory system of participants and life style.

CHAPTER 6

SUMMARY AND CONCLUSION

The present study aimed to compare the performance of individuals with binaural wireless synchronization hearing aids (Group I) in elderly individuals with binaural non-wireless synchronization hearing aids (Group II). Ten participants in each group subjectively rated 50 questions in three domains in Speech, Spatial and Quality of hearing questionnaire (SSQ). Routine audiological evaluations were performed to ensure fulfillment of participant's selection criteria. The measures from SSQ questionnaire were tabulated for each domain. Descriptive and inferential statistics were carried out using SPSS software (v 17 for windows). The findings are summarized in the following sections.

- The median scores in percentage were significantly less compared to non-wireless synchronization hearing aid group.
- The median scores in percentage was slightly higher (not significant) compared to non-wireless synchronization hearing aid group.
- The median scores in percentage was slightly higher (not significant) compared to non-wireless synchronization hearing aid group.
- There was a difference in all the domains when a pair-wise comparison was done within this group.
- There was no difference in all the domains when a pair-wise comparison was done within this group.

To conclude wireless synchronization hearing aid group performed better (not significant) in spatial and quality domains while non-wireless synchronization hearing aid group performed better (significant) in speech domain. Wireless synchronization between the two hearing aids might have resulted in better scores on SSQ. However, the influence of other factors such as auditory processing, cognition, life style etc. have to be ruled out.

6.6 Clinical implications

- Wireless synchronization hearing aids can be recommended to individuals with bilateral symmetrical mild to moderate sensorineural hearing losses for improved performance in spatial and quality aspects of hearing.
- This study can be used to counsel individuals in selecting the appropriate amplification devices.

6.7 Future directions

- The sample size taken was less. Further, more participants can be chosen to improve the validity of the study.
- Objective measures can also be done and correlated with the subjective measures to provide more valuable results.

REFERENCES

Angeli, R. D., Jotz, G. P., Barba, M. C., Demengbi, P. G. M., & Mello, C. H. P. (2009). Effectiveness of a program of auditory prothetization in elders through the application of HHIE-S questionnaire. *Int Arch Otorhinolaryngol*, *13*(3), 277-80.

Best, V., Kalluri, S., McLachlan, S., Valentine, S., Edwards, B., & Carlile, S. (2010). A comparison of CIC and BTE hearing aids for three-dimensional localization of speech. *International Journal of Audiology*, *49*(10), 723–732. https://doi.org/10.3109/14992027.2010.484827

Bronkhorst, A. W., & Plomp, R. (1988). The effect of head-induced interaural time and level differences on speech intelligibility in noise. *The Journal of the Acoustical Society of America*, *83*(4), 1508–16. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3372866

Bronkhorst, A. W., & Plomp, R. (1989). Binaural speech intelligibility in noise for hearing-impaired listeners. *The Journal of the Acoustical Society of America*, *86*(4), 1374–83. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2808911

Byrne, D., & Noble, W. (1998). Optimizing Sound Localization with Hearing Aids. *Trends in Amplification*, *3*(2), 51–73. https://doi.org/10.1177/108471389800300202

Byrne, D., Noble ', W., & Lepaget, B. (1992). Effects of Long-Term Bilateral and Unilateral Fitting of Different Hearing Aid Types on the Ability to Locate Sounds. *Journal of American Academy of Audiology*, *3*, 369–382. Retrieved from https://www.audiology.org/sites/default/files/journal/JAAA_03_06_01.pdf

Ciorba, A., Pelucchi, S., & Pastore, A. (2012). The impact of hearing loss on the quality of life in adults. *Srpski Arhiv Za Celokupno Lekarstvo*, *139*(5–6), 286–290. https://doi.org/10.2147/cia.s26059

Cox, R. M. (2003). Assessment of subjective outcome of hearing aid fitting: getting the client's point of view. *International Journal of Audiology*, *42 Suppl 1*, S90-6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12918615

Cox, R. M., Gilmore, C., & Alexander, G. C. (1991). Comparison of two questionnaires for patient-assessed hearing aid benefit. *Journal of the American Academy of Audiology*, *2*(3), 134–45. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1768881

Dillon, H., Birtles, G., & Lovegrove, R. (1999). Measuring the Outcomes of a National Rehabilitation Program : Normative Data for the Client Oriented Scale of Improvement (COSI) and the Hearing Aid User's Questionnaire (HAUQ). *Journal of American Academy of Audiology, 10*, 67–79. Retrieved from https://www.audiology.org/sites/default/files/journal/JAAA_10_02_02.pdf

Faber, J., & Fonseca, L. M. (2014). How sample size influences research outcomes. *Dental press journal of orthodontics*, *19*(4), 27-29.

Gatehouse, S., & Noble, W. (2004). The speech, spatial and qualities of hearing scale (SSQ). *International journal of audiology, 43*(2), 85-99.

Geetha, C., Tanniru, K., & Rajan, R. R. (2017). Efficacy of Directional Microphones in

Hearing Aids Equipped with Wireless Synchronization Technology. *The Journal of International Advanced Otology*, *13*(1), 113–117. https://doi.org/10.5152/iao.2017.2820

Gordon-Salant, S., & Fitzgibbons, P. J. (1993). Temporal factors and speech recognition performance in young and elderly listeners. *Journal of Speech, Language, and Hearing Research*, *36*(6), 1276-1285.

Helfer, K. S., & Wilber, L. A. (1990). Hearing loss, aging, and speech perception in reverberation and noise. *Journal of Speech and Hearing Research, 33*(1), 149–55. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2314073

HOSFORD-DUNN, H. O. L. L. Y. (2000). Hearing Aid User Attitudes. *Textbook of Hearing Aid Amplification*, 467.

Humes, L., & Humes, L. (2004). Factors Affecting Long-Term Hearing Aid Success. *Seminars in Hearing*, *25*(1), 63–72. https://doi.org/10.1055/s-2004-823048

Ibrahim, I., Parsa, V., Macpherson, E., & Cheesman, M. (2012). Evaluation of speech intelligibility and sound localization abilities with hearing aids using binaural wireless technology. *Audiology Research*, *3*(1), 1. https://doi.org/10.4081/audiores.2013.e1

Köbler, S., & Rosenhall, U. (2002). Horizontal localization and speech intelligibility with bilateral and unilateral hearing aid amplification. *International Journal of Audiology*, *41*(7), 395–400. https://doi.org/10.3109/14992020309101320

Kochkin, S. (2005). MarkeTrak VII: Customer satisfaction with hearing instruments in the digital age. *The Hearing Journal*, *58*(9), 30-32.

Kreisman, B. M., Mazevski, A. G., Schum, D. J., & Sockalingam, R. (2010). Improvements in Speech Understanding With Wireless Binaural Broadband Digital Hearing Instruments in Adults With Sensorineural Hearing Loss. https://doi.org/10.1177/1084713810364396

Kuk, F., Lau, C. C., Korhonen, P., & Crose, B. (2015). Speech intelligibility benefits of hearing aids at various input levels. *Journal of the American Academy of Audiology*, *26*(3), 275-288.

Kumar Narne, V., & Vanaja, C. S. (2008). Speech identification and cortical potentials in individuals with auditory neuropathy. *Behavioral and Brain Functions*, *4*(1), 15.

Meister, H., Lausberg, I., Walger, M., & von Wedel, H. (2001). Using conjoint analysis to examine the importance of hearing aid attributes. *Ear and hearing*, *22*(2), 142-150.

Meister, H., Lausberg, I., Kiessling, J., Walger, M., & von Wedel, H. (2002). Determining the importance of fundamental hearing aid attributes. *Otology & Neurotology*, *23*(4), 457-462.

Metselaar, M., Maat, B., Krijnen, P., Verschuure, H., Dreschler, W. A., & Feenstra, L. (2009). Self-reported disability and handicap after hearing-aid fitting and benefit of hearing aids: Comparison of fitting procedures, degree of hearing loss, experience with hearing aids and uni- and bilateral fittings. *European Archives of Oto-Rhino-Laryngology*, *266*(6), 907–917. https://doi.org/10.1007/s00405-008-0847-x

Moore, B. C. J., & Glasberg, B. R. (n.d.). A Model of Loudness Perception Applied to Cochlear Hearing Loss. Retrieved from http://mechanicsofhearing.org/mohdl/pdfs/AN/Moore-Glasberg-AudNeurosci-1997.pdf

Mueller, H. G., & Hall, J. W. (1998). Audiologists' Desk Reference. Vol. II.

Mulrow, C. D., Aguilar, C., Endicott, J. E., Tuley, M. R., Velez, R., Charlip, W. S., … DeNino, L. A. (1990). Quality-of-life changes and hearing impairment. A randomized trial. *Annals of Internal Medicine, 113*(3), 188–94. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2197909

Nelson, P. B., & Thomas, S. D. (1997). Gap detection as a function of stimulus loudness for listeners with and without hearing loss. *Journal of Speech, Language, and Hearing Research, 40*(6), 1387-1394.

Nelson, E. G., & Hinojosa, R. (2006). Presbycusis: A human temporal bone study of individuals with downward sloping audiometric patterns of hearing loss and review of the literature. *Laryngoscope*, *116*(9 SUPPL. 3), 1–12. https://doi.org/10.1097/01.mlg.0000236089.44566.62

Noble, W., Byrne, D., & Lepage, B. (1994). Effects on sound localization of configuration and type of hearing impairment. *The Journal of the Acoustical Society of America*, *95*(2), 992–1005. https://doi.org/10.1121/1.408404

Noble, W., Byrne, D., & Ter-Horst, K. (1998). Auditory localization, detection of spatial separateness, and speech hearing in noise by hearing impaired listeners. *The Journal* *of the Acoustical Society of America*, *102*(4), 2343. https://doi.org/10.1121/1.419618

Organization, W. H. (2013). *WHO expert consultation on rabies: second report*. World Health Organization.

Picou, E. M., & Ricketts, T. A. (2011). Comparison of wireless and acoustic hearing aid-based telephone listening strategies. *Ear and Hearing*, *32*(2), 209–220. https://doi.org/10.1097/AUD.0b013e3181f53737

Plomp, R. (1986). A signal-to-noise ratio model for the speech-reception threshold of the hearing impaired. *Journal of Speech and Hearing Research*, *29*(2), 146–54. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3724108

Powers, B. T. A., & Burton, P. (2005). Wireless technology designed to provide true binaural amplification, *58*(1).

Quintino, C. A., Mondelli, M. F. C. G., & Ferrari, D. V. (2010). Directivity and noise reduction in hearing aids: speech perception and benefit. *Brazilian journal of otorhinolaryngology*, *76*(5), 630-638.

Rakerd, B., Velde, T. J. Vander, & Hartmannt, W. M. (1998). Sound Localization in the Median Sagittal Plane by Listeners with Presbyacusis. *J Am Acad Audiol*, *9*, 466–479. Retrieved from https://www.audiology.org/sites/default/files/journal/JAAA_09_06_08.pdf

Ricketts, T. A., & Hornsby, B. W. Y. (2005). Sound quality measures for speech in noise through a commercial hearing aid implementing digital noise reduction. *Journal of the American Academy of Audiology*, *16*(5), 270–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16119254

Santos, S. N. D., & Costa, M. J. (2016). Speech perception in noise in elderly hearing aids users with different microphones and noise reduction algorithm. *Audiology-Communication Research, 21*.

Schneider Broca, V., & Coelho Scharlach, R. (2014). THE USE OF SELF-ASSESSMENT QUESTIONNAIRES FOR VALIDATION OF THE RESULTS IN HEARING AID SELECTION AND FITTING PROCESS O uso de questionário de autoavaliaçâo na validação dos resultados do processo de seleção e adaptação de dispositivos eletrônicos de ampli. *Nov-Dez, 16*(6), 1808–1818. Retrieved from http://www.scielo.br/pdf/rcefac/v16n6/en_1982-0216-rcefac-16-06-01808.pdf

Shanks, J. E., Wilson, R. H., Larson, V., & Williams, D. (2002). Speech recognition performance of patients with sensorineural hearing loss under unaided and aided conditions using linear and compression hearing aids. *Ear and Hearing*, *23*(4), 280-290.

Simpson, A., Hersbach, A. A., & McDermott, H. J. (2005). Improvements in speech perception with an experimental nonlinear frequency compression hearing device. *International Journal of Audiology*, *44*(5), 281–292. https://doi.org/10.1080/14992020500060636

Smith, P., Davis, A., Day, J., Unwin, S., Day, G., & Chalupper, J. (2008). Real-world preferences for linked bilateral processing. *The Hearing Journal*, *61*(7), 33-34.

Sockalingam, B. R., Holmberg, M., Eneroth, K., & Shulte, M. (2009). Binaural hearing aid communication shown to improve sound quality and localization, *62*(10), 46–47.

Tremblay, K. L., Piskosz, M., & Souza, P. (2002). Aging alters the neural representation of speech cues. *Neuroreport*, *13*(15), 1865-1870.

Uriarte, M., Denzin, L., Dunstan, A., Sellars, J., & Hickson, L. (2005). Measuring Hearing Aid Outcomes Using the Satisfaction with Amplification in Daily Life (SADL) Questionnaire: Australian Data. *Journal of the American Academy of Audiology*, *16*(6), 383–402. https://doi.org/10.3766/jaaa.16.6.6

Van den Bogaert, T., Klasen, T. J., Moonen, M., Van Deun, L., & Wouters, J. (2006). Horizontal localization with bilateral hearing aids: Without is better than with. *The Journal of the Acoustical Society of America*, *119*(1), 515–526. https://doi.org/10.1121/1.2139653

Walden, T. C., & Walden, B. E. (2005). Unilateral versus bilateral amplification for adults with impaired hearing. *Journal of the American Academy of Audiology*, *16*(8), 574-584.

World Health Organization. (2013). *WHO expert consultation on rabies: second report* (No. 982). World Health Organization.

Wu, Y. H., Ho, H. C., Hsiao, S. H., Brummet, R. B., & Chipara, O. (2016). Predicting three-month and 12-month post-fitting real-world hearing-aid outcome using pre-fitting acceptable noise level (ANL). *International journal of audiology*, *55*(5), 285-294.

Yathiraj, A., & Vijayalakshmi, C. S. (2005). Phonemically balanced wordlist in Kannada. *University of Mysuru*.