CHAPTER 1
INTRODUCTION

Noise degrades the perception of speech for individuals with normal hearing as well as those with hearing impairment (Alcántara, Dooley, Blamey, & Seligman, 1994). It has been reported in literature that there is a decrease in speech identification ability in the presence of noise compared to that in quiet (Wilson, Zizz, Shanks, & Causey, 1990). Dubno, Dirks, and Morgan (1984) have reported that individuals with even a mild hearing loss, whose speech discrimination in quiet is almost as good as that in listeners with normal hearing, may have difficulty in understanding speech in the presence of noise. It has also been reported that, hearing aid users have great difficulty in understanding speech in the presence of noise (Cox & Alexander, 1991; Duquesnoy & Plomp, 1983; Plomp, 1986).

During conversation, the presence of human speech in the background can itself become a competing noise and this is the most common type of interference encountered during conversation. In addition to this, the other environmental noises that interfere in normal conversation are traffic noise and wind noise (Plomp, 1978). In real life, the characteristics of the background noise differ from situation to situation. An individual can encounter many different types of noise with different spectral and temporal characteristics. Hence, it is necessary that a hearing aid be able to reduce the noise and enhance the speech perception in such a situation.

The Digital Signal Processing (DSP) was introduced in hearing aids in the year 1996 (Edwards, 2007). Since then, there have been many strategies such as noise reduction algorithms (NRA), in addition to the directional microphones, in hearing aids in order to reduce the effect of noise. It has been noted by Bray and Nilsson
(2000) that when noise and speech originated from the same direction, directional microphones provide limited benefits. Therefore, NRA have become a focal point in research. According to Jamieson, Brennan, and Cornelisse (1995), benefits of noise reduction (NR) include reduced upward spread of masking and reduced distortion. Other benefits include ease of listening, increased tolerance for noise, reduced effort in listening to speech and improved speech quality (Mueller, Weber, & Hornsby, 2006; Palmer, Bentler, Mueller, 2006; Sarampalis, Kalluri, Edwards, & Hafter, 2009; Zakis, Hau, & Blamey, 2009).

Several algorithms have attempted to improve speech recognition in noise. Bentler, Anderson, Niebuhr, and Getta (1993a, 1993b), and Walden, Surr, Cord, Edwards, and Olson (2000) have reported ease-of-listening with a variety of NRA but did not find improvement in speech intelligibility. Similar findings have been reported by Ricketts and Hornsby (2005). However, Alcántara, Moore, Kuhnel, and Launer (2003) did not report any reduction of noise at the output of the hearing aid nor ease-of-listening. This could be attributed to the differences in the NRA and the types of noise used in different studies.

Even with the advancements in technology, the hearing aid users continue to complain of difficulty in hearing to speech in noise (Kerckhoff, Listenberger, & Valente, 2008). According to the MarkeTrak VII data by Kochkin (2005), only 51% of the hearing aid users were satisfied while listening in noisy situations. The quality / technology of NR available in some models of hearing aids, impacts the ability of the user to benefit from NRA. When a comparison is made between different digital hearing aids with NRA, there are several factors that might influence the findings.
Digital hearing aids employ a number of different noise reduction strategies/algorithms to effectively separate speech from noise. In a multi-band hearing aid, speech and noise can be processed in different bands. According to Smriga (2000), the gain for a speech signal is reduced, when the speech is found in a band designated for noise, as the gain in a specific band is reduced. Problems arise when the noise resembles speech and the algorithms do not recognize it as noise. Theoretically, Summe (2003) stated that it would be easy for an algorithm to detect steady-state noises and separate them from speech since speech consists of peaks and valleys that make it clearly distinct from a broadband signal. However, not all unwanted noise signals are steady-state. Some noises have the same peaks and valleys in their spectrum as that of speech, thus mimicking the real world speech.

In order to study these effects, several investigators have considered different types of noise that mimic the real-life situation and different types of hearing aid which have different NR strategies (Bray & Nilsson, 2000; Cord, Leek, & Walden, 2000; Shields & Campbell, 2001; Summe, 2003; Ricketts & Hornsby, 2005; Bentler, Wu, Kettel, & Hurtig, 2008; Zakis et al., 2009; Chung, 2012; Brons, 2013). The results show that there was an improvement while using some strategies and for a few types of noise.

The acoustic measures of NRA have been investigated by some investigators (Hickson, Thyer, & Bates, 1999; Summe, 2003; Nilsson & Bray, 2004; Rout, Hanline, & Halling, 2007; Chong & Jenstad, 2010; Chong & Jenstad, 2011; Chung, 2012) while others have investigated the perceptual measures (Boymans, Dreschler, Schoneveld, & Verschuure, 1999; Bray & Nilsson, 2000; Alcántara et al., 2003; Ricketts & Hornsby, 2005; Mueller et al., 2006; de Oliveira, Lopes, & Alves, 2010; Brons, Houben, & Dreschler, 2013). There are a few studies comparing the acoustic
and perceptual measures with different types of noise (Zakis & Wise, 2007; Miller, 2013; Neher, Wagener, & Fischer, 2016; Miller, Bentler, Wu, Lewis, & Tremblay, 2017). The studies evaluating NR with acoustic measures have shown a decrease in noise and improvement in SNR at the output of the hearing aid. However, the effects of NRA on perceptual measures have shown equivocal results across the studies. Some studies have shown that participants preferred NR (Boymans & Dreschler, 2000; Ricketts & Hornsby, 2005), whereas others have shown that participants did not find any difference in listening comfort or sound quality due to NR (Alcántara et al., 2003; Bentler et al., 2008). Thus, the present study is being undertaken to address some of these important issues.

1.1 Need for the study

There are a lot of advancements in hearing aid technology in the recent years. One of the signal enhancing strategies in hearing aids include use of NRAs. Even though there are advancements in technology, it is very difficult to meet the satisfaction of the hearing aid user to the fullest extent. Hence, it’s necessary to study the effects of NRA on different types of noise across different SNRs and with different NR gradation.

1.1.1 Need to select different types of noise

Noise reduction algorithms (NRA) have a variety of processing strategies, some of which include modulation detection, spectral subtraction, Wiener filtering, synchrony detection, etc. The idea behind these strategies is that it should reduce the unwanted noise while enhancing the speech signal of interest. According to Boymans and Dreschler (2000) and Summe (2003), it is easy for an algorithm to detect steady-state noises and separate them from speech. Since speech consists of peaks and
valleys, it is makes it clearly different from the steady, non-varying noise. For instance, the spectral subtraction method, presumes that the speech is always varying, and that the noise is steady. However, the noise in the environment may not always be steady over time (Levitt, 2001). Some noises even have similar peaks and valleys as that of speech. It is known that, if competing noises are speech shaped noise or speech signal itself, then they significantly degrade the primary desired speech signal. If the NRA can attenuate speech-weighted noise effectively, then there will be improved speech perception in noise (Summe, 2003). It is also hypothesized by Plomp (1978) that speech babble is considered as one of the most commonly encountered background noises. It is also known that an individual can encounter many situations in daily life. Each situation can be challenging because as the environment changes, the type of noise in the environment also changes. Thus, the most frequently encountered noises in the Indian context are selected in the study for evaluating the effectiveness of NR in hearing aids.

Thus, the objective of the present study was to evaluate the effect of NRA in hearing aids on the acoustic measures. This was done with five different types of noise such as cafeteria noise, fan noise, speech babble, traffic noise and white noise. Further, the effectiveness of NRA on perceptual measures was also evaluated. This was done in presence of cafeteria noise and traffic noise.

1.1.2 Need to study effect of NRA using acoustic measures

With the introduction of digital hearing aids, its performance was assessed using coupler and/or probe microphone measurements to represent its gain and output characteristics. In the early years of digital signal processing, Cox and Studebaker (1979) have evaluated the hearing aid processed speech during hearing aid fitting.
However, this was found to be inappropriate, as each individual will have different gain requirements. Bentler and Chiou (2006) have stated that verification of the way the NR scheme actually works for a given individual is an important process in hearing aid fitting. Bentler and Chiou (2006) found that modulation based digital noise reduction in hearing aids would identify speech and reduce noise in the frequencies other than the speech frequency. This is done without reducing gain in the speech frequencies. However, the algorithm also identified International Collegium for Rehabilitative Audiology (ICRA) noise as speech and provided no gain reduction. This could be due to the assumption of the NRA which may not be effective in attenuating the noise that has speech-like features.

Summe (2003) analyzed the speech spectrum of phonemes in words before and after the noise reduction. It was concluded that NRA did not attenuate the environmental sounds such as ocean waves, rain noise, subway noise and jet noise. Further, they reportedly attenuated speech-weighted babble, in three of the four hearing aids tested. Only one hearing aid effectively attenuated the environmental sounds in a desired manner. However, the differences in the hearing aid NR processing might have led to ineffectiveness of hearing aids in reducing different types of noise.

The above two studies have shown that studying acoustic measures provide a good understanding on the effect of NR to find out if the NR is efficiently reducing the noise or not. In order to ascertain the effect of various NRA on different types of noise and to quantify the reduction in terms of signal-to-noise ratio (SNR), acoustic analysis of the hearing aid output has been employed in recent years. This will help us
to understand the processing used by noise reduction algorithms according to Rout et al. (2007).

Further, the ineffectiveness of some algorithms in reducing noise may be due to the selection of smaller segments of speech such as phoneme or words (Galster & Pisa, 2010). Some of the recent NRA analyze the noise in between the segments or pauses of a speech signal and consider this in reducing the noise across the entire signal. Hence, in the present study, sentences were used to study the effect of NR in hearing aids on acoustic aspects of speech in the presence of noise using acoustic measures.

In addition, the SNR changes observed in the acoustic analysis can be associated with the speech perception. This can be a clinically useful measurement for predicting the outcomes from the hearing aid (Miller, 2013). Hence, it is essential to evaluate if the hearing aid with NR results in appropriate changes in the SNR at the hearing aid output and verify if the changes in SNR is bringing about similar changes in the speech perception. Thus, Waveform Amplitude Detection Analysis- SNR (WADA-SNR) measure was chosen to estimate the relative SNR in the hearing aid output.

Rohdenburg (2008) opines that subjective tests are time consuming and depend on participant factors like degree of hearing loss, experience with the hearing aid, practice effect, and their ability to comprehend the instructions. Hence, objective measures that quantify the subjective quality judgments may be utilized to understand the speech perception. Thus in the present study, Perceptual Evaluation of Speech Quality mean opinion scores (PESQ MOS) was utilized to objectively evaluate the perceived speech quality.
Literature shows that Envelope Detection Index (EDI) is often being measured to evaluate the temporal distortions in the hearing aid output after applying compression and digital noise reduction (DNR) algorithm (Jenstad & Souza, 2005; Jenstad & Souza, 2007; Walaszek, 2008; Chong & Jenstad, 2011; Souza, Hoover & Gallun, 2012; Geetha & Manjula, 2014). Hence, to study the temporal distortions in speech in noise condition that may arise from the NRA, the EDI analysis was utilized to check on the temporal changes that the NRA can bring about in the hearing aid output.

1.1.3 Need to study effect of NRA using perceptual measures

It is known that the recent digital processing approaches are providing new NRA to enhance speech perception in noise. It is important to assess whether the new noise reduction algorithms are helpful in enhancing the speech perception in noisy conditions. Though the acoustic parameters show that these algorithms are performing well, it can be validated only when there is patient satisfaction. In the recent years, there are many studies which have assessed the effectiveness of NRA by analyzing the output of the hearing aid perceptually. Walden et al. (2000) studied the effect of omni-directional microphone, dual-microphone directionality, and a combination of noise reduction circuit with dual-microphone directionality on speech perception. They assessed the performance using the connected speech test (CST). Further, subjective ratings of speech understanding, listening comfort, and sound quality/naturalness were also obtained using eleven-point interval scales. It was found that the dual microphones had more advantage in speech recognition test over the omni-directional microphone in noise. However, participants generally did not perceive these large advantages in everyday listening. The noise reduction with
directionality provided improved listening comfort but little changes in speech understanding.

Ricketts and Hornsby (2005) used a paired-comparison approach to determine preference for both directional microphone and DNR features. The subjects were also made to rate their preference. Even though speech perception measure did not show any improvement with DNR, a significant and strong preference for the DNR was indicated, in both low and high noise levels. The authors suggest that because the instructions were to choose the (directional vs. DNR) of preference, the subjects were responding to listening comfort rather than quality.

The above two studies support the fact that the NRA are more effective in improving the listening comfort when compared to the primitive noise reduction methods such as directional microphone and dual microphones. Alcántara et al. (2003) concluded that their participants found no preference for DNR ON or OFF condition. They attribute this to the reduction of speech information in the bands where the noise reduction is acted on. This finding is incongruent with that of previous studies.

The performance of adult individuals with sensorineural hearing loss was assessed by de Oliveira et al. (2010), with a NRA called Speech Sensitive Processing, in the presence of noise. Sentence recognition threshold in noise were obtained with and without the algorithm being enabled. The results revealed that the algorithm provided a benefit in SNR for most individuals with hearing impairment. The results pointed to a statistically significant difference when the algorithm was ON, compared to when the algorithm was OFF. These findings are also in agreement with those reported by Boymans and Dreschler (2000) and Galster and Pisa (2010).
The results are equivocal across the studies on the perceptual effects of hearing aid noise reduction. Some studies showed that the listeners preferred noise reduction over no noise reduction (Boymans & Dreschler 2000; Ricketts & Hornsby 2005; Sang et al., 2015); whereas others found no difference in listening comfort or sound quality due to noise reduction (Alcántara et al., 2003; Walden et al., 2000). In addition, it is seen that individuals usually report increased tolerance for noise, decreased listening effort and stronger preference for noise reduction enabled than when the noise reduction was disabled (Mueller et al., 2006; Palmer et al., 2006; Sarampalis et al., 2009; Zakis et al., 2009; Brons, Houben, & Dreschler, 2014; Brons, Houben, & Dreschler, 2015).

Hence, studying the acoustic changes at the hearing aid output along with the speech perception measurements could provide clues about what changes are perceptible to listeners. This may help to resolve the conflicting reports between speech perception and subjective benefits with NRA (Miller, 2013). And to date, studies have independently evaluated the effectiveness of NR feature in reducing background noise using either the acoustic or perceptual measures, and very few studies have evaluated both. Furthermore, studies have evaluated NR along with either directionality or Wide Dynamic Range Compression (WDRC). A small number of authors have evaluated only NR by excluding the effects of all other digital signal processing. Thus, there is a need to evaluate the independent effect of NR feature on sentences in reducing background noise, using both the acoustic and perceptual measures, in a hearing aid. In addition, the acoustic and perceptual findings need to be verified for better understanding of signal processing through hearing aids.
Moreover, Quackenbush, Barnwell, and Clements (1988) opine that only one objective measure will not be able to predict the subjective quality rating of hearing aid output. Houben, Dijkstra, and Dreschler (2011) suggested that to evaluate the overall effectiveness of a noise reduction system, researchers should consider broader range of speech, different noise types and a range of input SNRs. Similarly, the present study focused on evaluating the effectiveness of NR with different types of noise, at different input SNRs (+5, 0, & -5 dB), and with varied NR gradations.

1.2 Aim of the study

The aim of the study was to evaluate the effectiveness of Noise Reduction Algorithms (NRA) in two different hearing aids on acoustic and perceptual measures.

1.3 Objectives of the study

The specific objectives of the study included:

1. To evaluate the effect of NRA on acoustic measures in different types of noise and across different NR conditions, in noise only condition.

2. To evaluate the effect of NRA on acoustic measures in different types of noise at three input SNRs (+5, 0, & -5 dB) across different NR conditions, in speech in noise condition.

3. To evaluate the effect of NRA on perceptual measures in different types of noise and across different NR conditions, in noise only condition, in participants with normal hearing and hearing impairment.

4. To evaluate the effect of NRA on perceptual measures in different types of noise at three input SNRs (+5, 0, & -5 dB) across different NR conditions, in
speech in noise condition, in participants with normal hearing and hearing impairment.

1.4 Null Hypotheses

The null hypotheses have been stated for each objective of the study:

1. There is no effect of NRA on the acoustic measures in different types of noise, across different NR conditions, in noise only condition.

2. There is no effect of NRA on acoustic measures in different types of noise at three input SNRs (+5, 0, & -5 dB) across different NR conditions, in speech in noise condition.

3. There is no effect of NRA on perceptual measures in different types of noise and across different NR conditions, in noise only condition, in participants with normal hearing and hearing impairment.

4. There is no effect of NRA on perceptual measures in different types of noise at three input SNRs (+5, 0 & -5 dB) across different NR conditions, in speech in noise condition, in participants with normal hearing and hearing impairment.