CHAPTER 6
SUMMARY AND CONCLUSIONS

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. 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.

To evaluate the above objectives, two digital RIC hearing aids with modulation based NRA were chosen. The output from the hearing aid was recorded using the KEMAR. Both acoustic and perceptual measures were obtained. Acoustic and perceptual measures were studied subjectively and objectively. Perceptual measures were obtained from both individuals with normal hearing and with hearing impairment.
The effect of NRA on different types of noise using acoustic measures was studied by analyzing the reduction of noise [overall LAeq (dB) & 90th percentile LA90 (dB)] at the output of the hearing aid with NR OFF and NR ON at three gradations (NR min, NR med, & NR max). The NR ON condition had more reduction in noise at the output of the hearing aid than the NR OFF condition, for all types of noise. In the NR ON condition, NR max had greatest reduction of noise followed by NR med and NR min gradation. The NR min was almost equivalent to NR OFF position. Among the types of noise, non-speech like noise had more reduction in noise (traffic noise had maximum reduction of 6.9 dB; white noise: 4.9), than highly modulated noise, which have more modulations like speech (speech babble had least reduction by 1.5 dB).

Likewise, the effect of NRA on the acoustic aspects of the hearing aid output in speech in noise condition was evaluated using objective and subjective methods. Among the objective measures, as documented in the literature, the output SNR was better (increased) with NR ON compared to NR OFF condition for all the types of noise. Among the three NR gradations, NR max position showed better output SNR than medium and minimum positions. The NR ON at minimum gradation was almost equivalent to NR OFF position. This was true for all the five types of noise. However, larger the difference between the speech and noise in their acoustic characteristics, more was the improvement in SNR. Thus, the improvement in SNR with NR max was decreased for speech babble compared to other types of noise in the study. The output SNR was increasing with corresponding increase with the input SNR. Though the output SNR was reducing with poor input SNR, it was noted that at -5 dB input SNR, at NR max gradation, the output SNR was improving for cafeteria noise, fan noise, traffic noise and white noise. The EDI values were lower with NR ON compared to
NR OFF condition for all the types of noise. The EDI values were increasing with poor SNR. However, at poor input SNR (-5 dB) with NR max gradation, the EDI values were lower than other NR gradations for all the types of noise except for speech babble. Thus, the NR max gradation would aid in preserving the temporal envelope of the speech even if the input SNRs are poor. The PESQ (MOS) did not show a trend with the NR gradations. However, among the input SNRs, +5 dB had better PESQ (MOS) scores than 0 dB and -5 dB. This may be due to the fact that speech inherently would have better quality at positive input SNR. The results from PESQ (MOS) show that NR could not bring about improvements in the quality of the speech in noise signal between gradations.

In the subjective analysis, the rating for noisiness and formant representation of the speech in noise spectrum showed that the SLPs rated the hearing aid output as less noisy as the WADA-SNR value increased, and they rated formant representation to be better at the output of the hearing aid as EDI values decreased across NR gradation. The SLP rating for noisiness of the speech in noise spectrum had very low inter-subject reliability. Since the number of SLPs who participated in analyzing the acoustic signal was less, the feasibility of this method in studying the acoustic changes could not be proven.

Further, the effect of NRA on different types of noise using perceptual measures was evaluated by loudness judgment for noise (LJN). Individuals with normal hearing had preferred NR max as less noisy, whenever it was compared with NR OFF, NR min and NR med; and NR med was chosen whenever it was compared with NR min. This was true for both HA 1 and HA 2 and the two types of noise (cafeteria noise & traffic noise). However, individuals with hearing impairment could differentiate the
reduction in loudness with NR ON only if the NR gradation was set to maximum position.

The effect of NRA on speech perception in the presence of different types of noise using perceptual measures was studied using speech perception measures and quality judgement task. In individuals with normal hearing, though there was a significant difference in the SIS (higher SIS scores with higher NR gradation), when raw scores were observed, the mean SIS improved negligibly within the NR gradations and between NR ON and NR OFF. This can be attributed to the ceiling effects in the performance of individuals with normal hearing. In the quality judgment task, when speech was presented with noise (either cafeteria noise or traffic noise) with NR at maximum gradation, the sample was clearer and less noisy than other conditions for individuals with normal hearing.

In individuals with hearing impairment, the SNR-50 was better with NR max than at NR OFF for both the types of noise and with the two hearing aids. Though this finding was disparate with most of the findings in the literature, most of the recent studies have shown improvement in speech perception with NRA ON. In the quality judgment task, NR ON condition was preferred as against NR OFF conditions for all the tasks with cafeteria noise and traffic noise. All the participants were naïve hearing aid users, and none of them preferred NR OFF. This may be due the fact that individuals with hearing impairment require better listening comfort and reduction in overall level of noise. Further, when speech was presented with noise (either cafeteria noise or traffic noise) with NR at maximum gradation, the sample was rated clearer and less noisy than other conditions.
To conclude, noise reduction algorithms do help in reducing the noise. The amount of reduction depends on the acoustic characteristics of the input noise and how different it is from the speech signal. The amount of noise reduction is relatively more for steady-state noise as against noise having similar features as that of speech. Likewise, larger the difference between the speech and noise in their acoustic characteristics, more was the improvement in SNR. The output SNR was increasing with corresponding increase with the input SNR. The NR when ON and at maximum gradation had greatest reduction in noise. Individuals with hearing impairment could differentiate the reduction in noise level with NR ON only if the NR gradation was set to maximum position. The speech perception did not improve within the NR gradations and between NR ON and NR OFF for individuals with normal hearing. However, speech perception scores were better with NR max than at NR OFF in individuals with hearing impairment and this finding was on par with the quality judgment. However, as each noise reduction accommodated in digital signal processing circuitry would vary, caution must be exercised while generalising the study to other algorithms.

6.1 Implications of the study

The following implications were drawn from the study:

- As there was different effect of NR on different types of noise, it provides insight about how noise reduction algorithms behave with different types of noise. This would aid in counselling the hearing aid users regarding the benefit that they would obtain from the hearing aid in different situations.
- The effect of NR gradation would aid in programming and fine tuning the hearing aid for a hearing aid user. This would help in personalizing the needs of the hearing aid users while fine tuning a hearing aid.
- The results of present study can give direction to Audiologist’s that the NR does not work the same way for different noises, SNRs, and gradations.
- It helps in counselling patients regarding the use of specific NR gradations in different situations.
- The results of the present study can give direction also to the hearing aid manufactures that NR does not work the same way for different noises, SNRs and gradation. This would support in development of more advanced technology and overcome the deficits in the present day technology.

6.2 Future directions

- It is important that a new hearing aid with NRA be evaluated through acoustic / perceptual measures before it is utilized clinically.
- Researchers can replicate the study using limited parameters and hence draw correlations between acoustic and perceptual measures.
- Acoustic analysis can be done with latest advanced measures which can be directly correlated with speech perception measures.
- Effect of noise reduction can be studied by varying the input noise levels.