2013

Quantitative Analyses Of Acceptable Noise Level For Air Conduction Listening

Bankole K. Fasanya
North Carolina Agricultural and Technical State University

Quantitative Analyses of Acceptable Noise Level for

Air Conduction Listening

Bankole K. Fasanya

North Carolina A&T State University

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department: Industrial & Systems Engineering

Major: Human Machine Systems

Major Professor: Dr. Celestine A. Ntuen

Greensboro, North Carolina

2013

School of Graduate Studies
North Carolina Agricultural and Technical State University
This is to certify that the Doctoral Dissertation of

Bankole K. Fasanya

has met the dissertation requirements of
North Carolina Agricultural and Technical State University

Greensboro, North Carolina
2013

Approved by:

Dr. Celestine A. Ntuen Major Professor	Dr. M. McBride Committee Member
Dr. S. Jiang Committee Member	Dr. D. Mountjoy Committee Member
Dr. T. Smith-Jackson Department Chair	Dr. Sanjiv Sarin Dean, The Graduate School

Biographical Sketch

Bankole Fasanya earned his Bachelor of Engineering degree in Mechanical Engineering from The Polytechnic Ibadan in Nigeria in 1999. He received his Master of Science degree in Industrial, Manufacturing, and Information Systems Engineering in 2008 from Morgan State University in Baltimore, Maryland. He worked with the State of Maryland Motor Vehicle Administration as a facilities engineer in 2008 and 2009. In August 2009 he joined the doctoral program at North Carolina Agricultural and Technical State University (NC A&T). Bankole Fasanya has been the recipient of numerous honors and awards including "Best Research of the Year, 2011" at NC A&T, the Minority Xerox Scholarship, and a Sloan Foundation Scholarship. He is a member of the Industrial and Systems Engineering Honor Society "Alpha Pi Mu." He is also a member of several organizations which include the Institute of Industrial Engineers (IIE), the Human Factors and Ergonomics Society (HFES), and the National Society of Black Engineers (NSBE).

Mr. Fasanya has published several papers in prestigious international journals and conference proceedings on Acceptable Noise Level (ANL) and multitasking activities, auditory perception, and gender differences for different tasks. He worked for Dr. Tucker at the University of North Carolina Greensboro (UNCG) in the summer of 2011 as a research assistant on brain mapping. He has led several not-for-profit organizations in the United States. His current research interests include ergonomics and human factors, industrial safety, noise assessment, and decision and judgment policy.

Dedication

I would like to dedicate this doctoral dissertation to my sister, the late Mrs. Yemisi Abolasere, for continually guiding and advising me with love, supporting all my efforts. Her love, interest, passion, and toughness have been the reasons for my success. I am everything I am today because of her. My parents, particularly my father, the late Pa, Isaiah Akinola Fasanya, indeed is a father.

Acknowledgements

My foremost appreciation goes to God Almighty for his unmerited favor and unlimited grace upon my life. It is important to note that from the cradle to the grave, we will always need people who help us succeed and fulfill our destiny.

My deep sense of respect and gratitude goes to my advisor Dr. Celestine Ntuen, who has been the guiding force behind the success of this work, and has always been there when needed. Thank you to all of the members of my dissertation committee for making my impossible dream a reality. I greatly appreciate all of the support and encouragement given to me throughout my entire program, especially during the tough times (Dr. S. Jiang, Dr. M. McBride, & Dr. D. Mountjoy).

My appreciation also goes to my mentor, Dr. Tom Letowski; I am greatly indebted to him for his constant encouragement, fatherly role, and invaluable advice in every aspect of my academic life. I consider it my good fortune to have gotten an opportunity to know such a wonderful person.

I cannot but thank my brother, Mr. Wale Fasanya, for his financial support during my high school and first degree, my sister, Florence Fasanya, and my friends (Festus Akinmade, Emeka Idoye, Mrs. Regina Popo-Ford, Joseph Akyeampong, Dr. Paul Akangah, Mr. Olusola Olaniyi, Hon. Suraju Adekunbi, Mr. Oluseun Omotoso, Dr. Ben Uzochukwu, and Dr. Rotimi Ojifinin).

What would I say about my wonderful and beautiful wife, Mrs. Olariyike Fasanya? I would like to clearly state that I appreciate you, your prayers, wisdom, understanding, and support at all times. May your destiny be fulfilling in Jesus name!

My lovely children, Precious and Victor Fasanya - I appreciate you guys. Dr. Musibua Shofoluwe, Dr. & Mrs. Adeyemi, Dr. & Mrs. Oguntimein, Pastor Dapo Oyewole and his wife, thank you for all the love and support.

Table of Contents

List of Figures xi

List of Tables xiii

Abbreviations xvi

Abstract 2

CHAPTER 1 Introduction 3

1.1 Background 3

1.2 Effect of Noise on Human Performance 5

1.3 Rationale for the Study 7

1.3.1 An examination of factors contributing to inter-subject variability in ANL. 7

1.3.2 An examination of the effects of loudspeaker locations on ANL. 7

1.4 Research Objectives and Methods 8

1.4.1 Statement of objectives. 8

1.4.2 Hypotheses 9

1.5 Intellectual Merits 9

1.6 Broad Impact 10

1.7 Chapter Review 10

CHAPTER 2 Related Thematic Concepts 11

2.1 Signal-to-Noise Ratio 11

2.2 Speech Intelligibility (SI) 12

2.3 Acceptable Noise Level 15

2.4 Speech Comprehension in Noise 17

2.5 Internal and External Noise 18

2.6 Justification for ANL Study from Psychophysical Models 20

2.7 Chapter Summary 22

CHAPTER 3 Methodology 23

3.1 Signal Detection Theory 23

3.2 Mathematical Derivation of ANL in Terms of SDT 25

3.3 Psychophysical model for ANL 30

3.4 Experimental Design 32

3.5 Instrumentation 32

3.6 Noise and Speech Recordings 35

3.7 Speech Recording 36

3.8 Chapter Summary 36

CHAPTER 4 Effects of Frequency Bandwidths on ANL 37

4.1 Background 37

4.2 Participants 39

4.3 Method 39

4.4. Materials 40

4.5 Procedure 40

4.6 Frequency Bandwidth 46

4.7 Results 47

4.7.1 Descriptive statistics. 47

4.8 Psychophysical Results 56

4.9 Discussion on the Effects of High Frequency Bandwidth on ANL 66

4.9.1 The effect of signal source on the ANL 66

4.9.2 The effect of frequency bandwidth on the ANL. 67

4.9.3 The effects of background noise type on ANL 67

4.9.4 The effect of the interaction between independent variables on ANL. 67

4.9.5 Meta-analysis with psychophysical parameters 68

4.10 Summary 69

CHAPTER 5 Effects of Listening Modalities and Loudspeaker Locations on ANL 71

5.1 Effects of Loudspeakers Location on ANL 71

5.2 Participants 72

5.3 Method 73

5.4 Materials 74

5.5 Procedure 75

5.6 Noise Stimulus 79

5.7 Results 80

5.8 Psychophysical Results for Air Conduction 86

5.9 Discussions on the Effects of Noise Loudspeaker Locations 91

5.9.1 Psychophysical ANL 91

5.9.2 Discussion on ANL 91

5.10 Summary 92

CHAPTER 6 Differences in Signal Comprehension in Noise Level (SCNL) and Acceptable Noise Level 94

6.1. Background 94

6.2 Participants 95

6.3 Method 95

6.4 Materials 96

6.5 Procedure 97

6.6 Results 100

6.7 Psychophysical Model 105

6.8 Discussion on the Effects of Noise on SCNL and ANL 108

6.9 Summary 109

CHAPTER 7 Summary, Discussions, Observations, Future Research and Conclusion 110

7.1 General Summary 110

7.2 Discussions and Observations 112

7.3 Limitations of the Current Study 114

7.4 Recommendations 115

7.5 Directions for Future Research 115

7.6 Conclusion 116

References 119

Appendix A 133

Appendix B 135

Appendix C 139

Appendix D 143

Appendix E 146

Appendix F 149

Appendix G 151

List of Figures

Figure 1. Psychophysics model for sound processing 20

Figure 2. Air conduction hearing pathway. 22

Figure 3. The signal detection model (Green & Sweets, 1988). 25

Figure 4. Audiometer and sound level meter. 33

Figure 5. Sound attenuating booth. 35

Figure 6. Omni-directional noise source of three loudspeakers. 40

Figure 7. White noise from Sound Forge software. 45

Figure 8. Babble background noise from Sound Forge software. 45

Figure 9. Spectrum plot using Hanning window at 6dB and High-pass filter for low frequency. 46

Figure 10. Spectrum plot using Hanning window at 6dB and low-pass filter for high frequency. 47

Figure 11. Mean ANLs for white noise under both conventional and earphone listening conditions and error bars with percentage. 49

Figure 12. Mean ANLs for babble noise under both conventional and earphone listening conditions. 50

Figure 13. Mean ANLs for both conditions across the four different background noise frequencies. Low ANL scores represent better tolerance to background noise than high ANL scores. 51

Figure 14. Interaction plots of frequency effects on ANL. 55

Figure 15. Relationship between listeners' discriminability bias toward noise intensity when the signal is presented through earphones 62

Figure 16. Relationship between listeners' discriminability bias toward noise intensity when the signal is presented via sound field. 62

Figure 17. Relationship between listeners' discriminability bias toward speech signal intensity when it was delivered through earphones under different background noise frequencies. 64

Figure 18. Relationship between listeners' discriminability bias toward speech signal intensity when it was delivered through sound field under different background noise frequencies.......... 64

Figure 19. Relationship between computed ANL and the computed sound discriminability 66

Figure 20. Spectrum plot using Hanning window at 6dB with cutoff frequency 1000 Hz. 73

Figure 21. Experimental set-up for experiment II 74

Figure 22. Babble background noise from Sound Forge software. 79

Figure 23. Mean ANL values for the 23 participants for each loudspeaker locations with error bars and standard errors. 81

Figure 24. Male and female average ANLs in (dB) for different loudspeaker locations. 83

Figure 25. Experimental set-up for experiment III. 96

Figure 26. Mean and standard error bar chart for comparing SCNL and ANL under different background types. 103

Figure 27. Graphical representation of the relationship between SCNL and ANL under the two background noises (BN=Babble noise, SS=Speech spectrum). 104

Figure 28. Relationship in listeners' discriminability biases during SCNL and ANL at different background noise. 107

List of Tables

Table 1 2^k Factorial Design for the Experiment 38

Table 2 Research Design for Masking Noise and the Signal on Effect of Frequency Bandwidths 38

Table 3 Means, Standard Deviations, and Range of ANLs with Different Frequencies 48

Table 4 Average ANLs (dB) for each Participant for High and Low Frequencies for All Participants 49

Table 5 Percentage Differences of ANL across Frequency Level 52

Table 6 Output of ANOVA Test for Signal Source, Noise Type, and Noise Level ANOVA 54

Table 7 Noise Types and Noise Frequency Level Effect Sliced by Noise Type and Noise Frequency Level for ANL 55

Table 8 Noise Types and Noise Frequency Level Effect Sliced by Signal sources and Noise Frequency Level for ANL 56

Table 9 Noise Types and Noise Frequency Level Effect Sliced by Signal sources and Noise Type for ANL 56

Table 10 Parameter Estimates for MCLL, c_1, and β_1 under Earphone-High-White Condition.... 57

Table 11 Parameter Estimates for BNL c_2, and β_2 under Earphone-High-White Condition........ 58

Table 12 Psychophysical ANL Regression Equations, c-values, β-values and the Corresponding R-squared Values under Different Conditions Tested 59

Table 13 Standard Errors between the Predicted ANL and the Measured ANL 60

Table 14 Participants Discriminability Bias (β) toward Both Noise and Signal under ANL 60

Table 15 Participant Discriminability Bias (β) toward Signal Source in the Determination of the Intensity of Experienced ANL 61

Table 16 Predicted MANL Threshold under Experimental Conditions as a Function of d' 65

Table 17 Experimental Design for Loudspeaker Locations 72

Table 18 Research Design for Masking Noise and the Signal on Loudspeakers Position Effects on Human Tolerance to Noise 78

Table 19 Means and Standard Deviations of ANLs for the 23 Participants Based on the Loudspeaker Locations 80

Table 20 Mean ANLs for Each Participant from the Three Trials under Different Loudspeaker Locations 81

Table 21 Mean and Standard Deviation ANLs for Males and Females under Different Loudspeaker Location 83

Table 22 ANOVA Results for the ANLs at Different Loudspeaker Locations 85

Table 23 ANOVA Results for Contrast Analysis 85

Table 24 P-values of ANLs between Genders at Different Loudspeaker Locations 85

Table 25 ANLs Inter-subject Variability on Gender at Different Loudspeaker Locations 86

Table 26 Psychophysical ANL Regression Equations for Different Loudspeaker Locations under Air Conduction 87

Table 27 Standard Percentage Errors between the Predicted ANL and the Measured ANL 87

Table 28 Participants' ANL Biases, Predicted Discriminability, and MANL for Different Noise Loudspeaker Locations 88

Table 29 Psychophysical ANL Regression Equations for Male at Different Loudspeaker Locations 89

Table 30 Psychophysical ANL Regression Equations for Female at Different Loudspeaker Locations 89

Table 31 Gender Discriminability Biases toward Noise and Signal at Different Noise Background Locations 90

Table 32 Gender Differences in Listeners' Discriminability Bias toward Sound 91

Table 33 Means, Ranges, and Standard Deviations for Both SCNL and ANL under Both Babble and Speech Spectrum Noise........ 101

Table 34 Detail SCNLs and ANLs for All Participants and Their Demographics Information. 101

Table 35 ANOVA Results of the Differences on the Effects of Background Noise Types 105

Table 36 Psychophysical ANL Regression Equations for both SCN and ANL 106

Table 37 Listeners' Discriminability Biases and the Minimum ANL and SCNL Thresholds ... 107

Table 38 Standard Percentage Errors between the Predicted ANL and the Measured ANL 108

Table 39 Effects of Frequency Bandwidths on ANL........ 117

Table 40 Effects of Loudspeaker Locations under Normal Listening Conditions 117

Table 41 Gender Effects Based on Loudspeaker Locations 117

Table 42 Effects of Speech Comprehension in Noise Level and ANL 118

Abbreviations

β	Discriminability Bias
ψ	Frequency Bandwidth
δ	Internal Response
ADA	Americans with Disabilities Act
ABR	Auditory brainstem Response
AC	Air Conduction
ANL	Acceptable Noise Level
ANSI	American National Standards Institute
ALLR	Auditory late latency responses
ASP	Automatic Signal Processing
BNL	Background Noise Level
DNR	Digital Noise Reduction
dB SPL	Decibel(s). Sound pressure level
HL	Hearing level
IAC	Industrial Acoustic Chamber
IRC	Interdisciplinary Research Center
K	Sound Familiarity
MCLL	Most Comfortable Listening Level
MANL	Minimum Acceptable Noise Level
N	Noise
NC A&T	North Carolina Agricultural and Technical State University
OSHA	Occupational Safety and Health Administration

S	Signal
SLM	Sound Level Meter
SCNL	Speech Comprehension in Noise Level
SRTs	Speech Recognition Thresholds
SCCL	Speech Comprehension Comfort Level

Abstract

This study was conducted to develop quantitative models for Acceptable Noise Level (ANL) under air conduction (AC) listening conditions. Experimental results on the effects of frequency bandwidths on ANL under two listening conditions involving earphones and loudspeaker (sound field) with high and low frequencies and babble noise and white noise revealed: (a) there are statistically significant interactions among the background noise types, the background noise frequency bandwidths and signal source; (b) background noise and noise frequency bandwidths have effects on listener discriminability bias toward the noise and the signal intensity; (c) different listening conditions had different ANL thresholds; and (d) a significant difference existed between listeners' Minimum ANL threshold under earphone listening and air conduction listening. The findings revealed that ANLs at different loudspeaker locations were not significantly different statistically from one another. The psychophysical parameters revealed that males had a higher positive discriminability bias toward signal and noise intensities at all locations, except at the 315 degree azimuth; female listeners had higher discriminability biases (β) toward sound at the 315 degree azimuth. For example, the β value for males under signal alone was 0.2095 compared to females' value of 0.23 at the 315 degree location. Under noise only, male β values were all superior to those of females with values higher than 0.22 against less than 0.1 for females at the 180-, 225-, and 315-degree locations. The result showed that the minimum ANL threshold and the listeners' discriminability biases toward sound could be found at the 315-degree loudspeaker location. Finally, a study to determine the differences between ANL and Speech Comprehension in Noise Level (SCNL) was not significant. However, the sensitivity toward sound intensity was higher under ANL than SCNL. This is because ANL is the willingness to work in noisy conditions while SCNL seeks meaning out of signals.

CHAPTER 1

Introduction

1.1 Background

Humans communicate by three different methods: (a) oral, (b) non-verbal, and (c) written. Non-verbal communication involves only body movement or body language without the opening of the mouth. Written communication is in symbolic forms such as with the use of paper, email, fax, etcetera. Oral (verbal) communication involves a speaker opening his/her mouth to deliver a message in an environment and in the presence of a listener. When a message from the speaker is not clear to the listeners or causes the listeners to strain their ears before hearing the message, communication breakdown occurs. Several factors are responsible for such breakdowns. Some examples are hearing loss, interfering sound, distance, interest, and some physical factors (e.g., temperature, heat, etc.). The interfering sounds are commonly referred to in human factors literature as noise. However, the term noise has both a narrow meaning and a broad meaning.

Noise in its narrow meaning is a wideband sound consisting of an infinite number of components with constant amplitudes and random phases. Such noise is referred to as physical noise. One example of a physical noise is thermal noise. This occurs when all components have similar amplitudes. Thermal noise is the noise underscoring most physical processes, including spontaneous brain activity (Gilden, 2001). The idealized form of thermal noise in which all components have exactly the same amplitudes is called white noise. Another idealized form of noise is called pink noise (Gilden, 2001). Pink noise is defined as acoustical energy distributed uniformly by octave throughout the audio spectrum (the range of human hearing), approximately 20 Hz to 20 kHz (Rouse, 2006).

In its broad meaning, noise is any unwanted sound, including physical noise, regardless of its source. Various forms and levels of unwanted sounds are sometimes referred to as environmental noise (Schomer, 2001). Such noise has caused frequent complaints from people trying to communicate, work, listen to the radio or television, or relax outdoors. Noise does not need to be at a high level to be annoying. People serving in the military (e.g. soldiers), factory workers, construction workers, airport workers, and other similar workers are often exposed to high intensity noise, which is not only annoying, but can be detrimental to human physical health. High level noise, if not protected against, may result in temporary or/and permanent hearing loss, especially for high frequency sounds, as well as tinnitus (ringing in the ears), or both (Humes, Joellenbeck & Durch, 2005).

According to Nabelek (2005), the presence of background noise adversely affects speech perception by hearing aid users causing them to limit the use of their hearing aids. This observation led to the development of a procedure that quantifies the maximum amount of background noise that listeners are willing to accept while listening to speech (Nabelek, Tucker, & Letowski, 1991). In this procedure, listeners adjust the background noise level (BNL) to the highest level of intensity that they deem acceptable while listening to a recorded story at their most comfortable listening level (MCLL). The acceptable noise level (ANL) is calculated by subtracting the maximum acceptable BNL from MCLL (i.e. ANL = MCLL – BNL). For example, an individual with low ANLs (e.g., 7 dB) will accept larger amounts of background noise than those with high ANLs (e.g., 20dB). This concept has been extensively studied under air conduction hearing processes. However, no study has investigated the Minimum ANL (MANL) threshold under various listening conditions with air conduction. This gap in existing research is the focal theme of this research.

1.2 Effect of Noise on Human Performance

Noise can not only lead to hearing loss/tinnitus, temporary threshold shift (TTS), or permanent threshold shift (PTS); it also affects communication and speech understanding in day-to-day human activities. Noise can prevent humans from hearing signals that are important to the performance of a task. For instance, a soldier's survival depends greatly on his auditory awareness of a context environment and the ability to hear and understand communicated speech clearly. For example, soldiers need to be able to hear what is going on around them, understand radio messages clearly, receive verbal orders, and communicate with other members of their squad (Rao & Letowski, 2003). Likewise, normal and hearing-impaired individuals working in factories, construction sites, or in any noisy environment should be able to hear danger signals and understand verbal instructions very clearly in order to avoid accidents. Since noise also consists of sounds useful to other people, it has been overlooked to the extent that medical practitioners ignore the effects of noise even in hospital environments (e.g., intensive care unit). To illustrate the level of disregard, Christensen (1997) demonstrated that the average noise level of 52 dBA was generated in a four-bed intensive care unit, and was attributed to staff conversation 55% of the time.

Noise can have an effect on mental and physical conditions. Maxwell and Evans (1999) documented the different effects of noise to include "physiological effects" such as increased blood pressure, "motivational effects" such as decreased academic performance, and "cognitive effects" such as memorization. Noise has been observed to induce temporary changes in a person's physiological state, including neurological, endocrinological, and cardiovascular changes (Kantowitz & Sorkin, 1983). These changes are temporary and apparently do not result in permanent damage to the human exposed (Kryter, 1970). Another study conducted by Evans and Maxwell (1997) identified a link between chronic noise exposure and reading skills. The noise source was a nearby airport where planes flew over the school at an average of one plane every six minutes, resulting in classroom decibel levels of 90 dBA. In the study, children in the noisy school had poorer reading skills when compared to children from similar schools with lower noise levels and were not good at distinguishing speech masked by “white” noise, but were able to distinguish specific sounds (e.g., cat meowing, baby crying).

In another study, Kryter (1976) defined noise as “acoustic signals, which can negatively affect the physiological or psychological well-being of an individual.” This means that noise can be regarded as a pollutant and a hazard to human health and hearing. Kryter (1976, 1980) stated that the net result of many human and animal studies so far does not support the presence of harmful autonomic nervous system reactions to noise, except when the noise is “psychologically meaningful” to the organism. He then suggested that it is the psychological annoyance resulting from the noise, rather than the body’s autonomic system response, that generates general negative effects on an organism’s health. Several studies have reported that certain types of noise exposure resulted in poorer performance on tasks, even after the noise exposure has been terminated (Percival & Loeb, 1980). Likewise, whenever speech understanding is affected, it makes it harder to determine what is being said and all aspects of life are affected (Fitzpatrick, 2008). Valla and Sweetow (2000) reported in their study that stress and fatigue increased as results of chain reactions that occur when a hearing-impaired individual strains to hear and understand speech during communication. During this period, the hormones and neurotransmitters released are increased and can lead to strong emotional reactions such as anger, paranoia sadness, and/or tension. It is no wonder that normal-hearing listeners get frustrated easily when they find it difficult to understand speech in background noise. Likewise, hearing impaired people with untreated hearing loss have reported frustration, anger with themselves, depression, loneliness, and embarrassment, which sometimes led to negative self-image and insecurity (Trychin, 1993).

1.3 Rationale for the Study

About two decades ago, Nabelek et al. (1991) developed ANL as a model to measure a person's ability to function in the presence of noise. This study was conducted to look into factors such as noise bandwidth frequency, sound discriminability, judgment bias, signal energy, noise power, and time duration that impact ANL outcomes. No quantitative relationship was established. This study will investigate the effects of the psychophysical factors on ANL.

1.3.1 An examination of factors contributing to inter-subject variability in ANL. Studies have shown that there are large inter-subject differences in the acceptance of background noise and rejection of hearing aids due to noise among listeners (Nabelek et al., 1991; Nabelek, Tampas, & Burchfield, 2004). This is the reason why factors affecting listening to speech and its comprehension are very critical areas of study for auditory researchers. Among factors tested, ANL has been shown to be dependent on hearing aid types and types of masking noise. However, there is still a need to fully determine all of the contributing factors to the differences in ANLs in order to understand how to improve on the design of hearing aids for users with varying ANLs. This research will expand the concept of the ANL to address the relationship between the various types of background noise and speech signals of normal-hearing listeners.

1.3.2 An examination of the effects of loudspeaker locations on ANL. In previous ANL studies performed in the sound field, such as those by Rogers, Harkrider, Burchfield, & Nabelek (2003), Franklin, Thelin, Nabelek, and Burchfield (2006), and Freyaldenhoven et al. (2010), the loudspeakers for signal and noise were positioned at zero degree (0^0) azimuths. In a small percentage of studies, the noise was presented from 180º azimuths (Freyaldenhoven et al., 2010). Kattel, Fasanya, Letowski, and Hargrove (2008) used monophonic and stereophonic signals to find the effects of background noise on ANL when noise loudspeakers were located at 90^o and 180^o azimuths and signal loudspeaker(s) were positioned at either ± 45º or 90^o (single channel monophonic reproduction). The results of the Kattel et al. (2008) study differed in some respects from the results of Nabelek et al. (1991), especially regarding the effect of the types of background noise. The Kattel et al. study was conducted on normal listeners while the Nabelek et al. study was conducted on hearing impaired and normal listeners. Nabelek et al. (1991) showed that background noise types have no significant effect on ANL, while the findings from Kattel et al. (2008) were contrary. It is unclear whether these differences were related to the different positions of the loudspeakers or the masking noise used in these studies.

No studies until now have examined the effect of loudspeakers' positions on ANL, except white noise was used in the study by Kattel et al. (2008). Likewise, no study has compared the effects of listening in the sound field with listening through earphones. Therefore, this study is intended to examine the effects of different listening modalities, namely, sound field, earphones, and loudspeaker positions on ANL.

1.4 Research Objectives and Methods

1.4.1 Statement of objectives. The main goal of this study was to develop quantitative models for ANL under AC listening conditions. The following objectives will be addressed:

a. Investigate the effects of noise types (differences in noise spectra) and speech signal types (e.g., such as speech by males or females) on the ANL for normal hearing listeners.
b. Investigate the effects of noise on speech comprehension as measured by acceptable signal to noise ratio (SNR) and compare speech comprehension in noise (SCN) with ANL for the same listeners.
c. Investigate the effects of loudspeakers configuration on ANL and speech comprehension under various listening conditions.

1.4.2 Hypotheses. In this study, the following hypotheses relevant to the objectives are investigated:

i. High frequency bandwidths will have no statistically significant effect on a listener's ability to accept background noise when simultaneously listening to a speech of interest.

ii. Loudspeaker positions will have no statistically significant effect on ANL measures.

iii. Effects of background noise on ANL will be significantly different from its effects on SCN.

1.5 Intellectual Merits

Measures of acceptable noise in normal hearing listeners and hearing aid users should have a combination of subjective and objective metrics. Harkrider and Smith (2005) reported in their study that the commonly-used psychophysical model for measuring listeners' ability to accept background noise is subjective. It is argued here that some quantitative models will give specificity to existing metrics. Furthermore, it is necessary to develop quantitative models that can measure the acceptance of noise using these air conduction hearing pathways.

In addition to the metric development, such metrics can be used to determine the thresholds for listening in background noise. The existing ANL models cannot address this issue. This contribution is expected to yield some positive results due to its robustness in considering many auditory parameters such as internal response, sound discrimination ability, and human discriminability bias. The consideration of signal detection theory (SDT), Webber formula, and Stevens power laws to ANL provide new ways to estimate factors affecting ANL.

1.6 Broad Impact

This study will help find the effect of noise type and bandwidth on ANL. In addition, the results of this study will help audiologists better understand the various factors that contribute to the effect of background noise on listeners, thereby helping to identify the right hearing aid devices for different patients.

1.7 Chapter Review

This chapter introduced the background of this study, the rationales for the study, the objectives, the hypotheses, and the intellectual contributions. Chapter 2 gives a summary of related past studies. Chapter 3 presents mathematical models for psychophysical ANL. Chapter 4 discusses the effects of frequency bandwidth on ANL. Chapter 5 discusses the effects of listening modalities and the effects of loudspeaker location on ANL. Chapter 6 discusses the differences between SCN and ANL. Chapter 7 discusses the general summary, discussion, limitation, recommendations, conclusions, and major quantitative psychophysical ANL values findings of the study.

CHAPTER 2

Related Thematic Concepts

2.1 Signal-to-Noise Ratio

From the physical point of view, the relationship between noise and signal reception can be represented by signal-to-noise ratio (SNR). SNR is a logarithm of ratio of sound (signal) to background noise energy expressed in decibels (dBs; Choma, Sarunic, Yang, & Izatt, 2003). The larger the ratio, the more the desirable sound (music, voice, affects) is separated from acoustical effects and background noise. For example, SNR of 70dB is much more desirable than SNR of 50dB, and SNR of 100dB is considered excellent for audio transmission (Robert Silver, About.com Guide to Home Theater 2000). Walden, Surr, Cord, and Dyrlund (2004) concluded that under most circumstances, the effect of SNR on human ability to hear may vary systematically with spatial locations of signal and noise sources. In most typical listening situations, the signal source (e.g., talker) is in front of the listener, and some spatial separation exists between the talker and noise source(s) in the listening environment. In addition, the signal will get less intense as the distance between the talker and listener increases. At this point, the SNR will get progressively worse. Hearing-impaired children require SNRs of at least +10 to +20 dB for effective classroom performance (Finitzo-Hieber & Tillman, 1978; Gengel, 1971). In 2002, the American National Standard Institutes (ANSI) recommended a minimum SNR of +15 dB at the child’s ear.

Gelfand (2009) notes that hearing-impaired persons need higher SNRs than normal individuals to achieve similar levels of performance while listening to speech in noisy conditions (Dubno, Dirks, & Morgan, 1984; Gelfand, Ross, & Miller, 1988). The study conducted by Summer and Leeks (1998) on speech intelligibility among hearing impaired people showed that deficits in fundamental frequency ($F0$) coding and pitch perception may be a possible cause for the lack of masking release in hearing-impaired individuals. The study by Kanekama (2009) on SNR using American and Indian participants revealed that American participants benefitted significantly more from speech reading at poorer SNRs than at favorable SNRs. They also concluded that Indian participants benefitted less from speech reading than the American participants at poorer SNRs, but benefitted more from speech reading than American participants at favorable SNRs. The levels of SNRs used in the study were +6, 0, -6, -12, or -18 dB.

2.2 Speech Intelligibility (SI)

Communication is the primary function of spoken language, so the intelligibility of speech is the primary concern; thus, SI is the main criterion for assessing the efficiency and effectiveness of human communication and communication systems (Blue, Ntuen, & Letowski, 2010). The measures of SI are sensitive to the accuracy with which a listener can comprehend speech (Jamieson, Parsa, Price, & Till, 2002). SI is defined as the percent of correctly produced, transmitted, and received units of speech; it is usually measured in the presence of noise and distortion. However, people can still comprehend a sentence without adequately recognizing each word from the sentence.

Oxenham and Simonson (2009) measured SI for sentences presented in the same spectrally-matched steady noise, single-talker interference, or speech-modulated noise for unfiltered, low- and high-pass filtered speech using normal hearing listeners. The study revealed that for both the high pass (HP) and the low pass (LP) filter conditions, masking release (the decrease in masked thresholds that occurs when the masker is amplitude-modulated) was roughly equal, but was much less than in unfiltered conditions. The results showed that pitch conveyed by the temporal fine structure of low-order harmonics played a crucial role in masking release. Most noted was that “masking release in normal-hearing listeners can be strictly reduced simply by limiting the available frequency spectrum, without any further degradation release" (Oxenham & Simonson, 2009).

Festen and Plomp (1990) compared speech intelligibility in steady noise with intelligibility in spectrally and/or temporally fluctuating maskers. Normal listeners were used for the study. The result showed that speech intelligibility improves intensely when temporal fluctuations are introduced into a noise masker, or when the noise masker is replaced by a single-talker and interferes with the same long-term power spectrum. They concluded that hearing-impaired listeners typically will show much less release from masking when the masker is changed from steady noise to a fluctuating noise or to a single-talker interferer.

Chermak, Vonhof, and Bendel (1989) showed that adults with learning disabilities had poorer word identification in background noise than adults without learning disabilities. The authors also found that adults with and without learning disabilities had greater difficulty when the target words were masked by speech spectrum noise than when they were masked by competing linguistic strings. This masker-dependent decline in performance was greater for the adults with learning disabilities than for those without disabilities.

Picheny, Durlach, and Braida (1985) reported that clearly spoken nonsense sentences were more intelligible than those spoken conversationally in a quiet condition for listeners with hearing impairments, and when presented in a noise background to listeners with normal hearing. Picheny et al. concluded that speech intelligibility under adverse conditions can be improved by modifying either the listener's speech perception or the acoustic properties of the speech signal, but not by modifying the talker's speech production. A similar study by Uchanski, Choi, Braida, Reed, and Durlach (1996) showed that key words excised from clear and conversational sentences have nearly the same intelligibility as the same words spoken in sentence contexts, suggesting that differences in pause structure do not necessarily account for differences in intelligibility. The study was conducted on intelligibility of two groups with different speaking "styles," namely, conventional and clear speech groups.

Adams and Moore (2009) found that the best speech intelligibility performance for listeners with normal hearing was achieved with the slowest rate of speech (130 wpm). The performances with the preferred rate of speech (170 wpm) slightly deteriorated; therefore, listeners required a slightly higher (better) SNR to achieve 50% accuracy on the experimental speech intelligibility measure. Adams and Moore's (2009) study revealed the effects of speech rate and background noise on speech rate judgment and on speech intelligibility for listeners with and without a simulated hearing loss. The speech rate judgment task and the speech intelligibility task were produced using sentences from the separated version of the Quick signal in noise (SIN) test (Etymotic Research, 2001). Picheny et al. (1989) observed that an extreme slowing of speech rate may cause deterioration in intelligibility in the presence of background noise. Krause and Braida (2002) suggested that the intelligibility of clear speech at some rate, say between 200 and 300 wpm, supplemented by varying amounts of training, should help determine the maximum cutoff rate for achieving sizeable clear speech benefits.

Deterioration in SI has been attributed to background noise. Summers, Pisoni, Bernacki, Pedlow, and Stokes (1988) confirmed that "people talk much louder in a noisy environment" (p. 917). Summers et al. (1988) found that in the presence of masking noise, speakers reduced their rate of speaking and increased the duration and intensity of their utterances.

Moore (1996) concluded that if the signal is limited due to background noise or temporal alteration, the listener had to compensate by depending on cognitive abilities to interpret and store information. According to Marchetto, Avanzini, and Flego (2009), speaker recognition is very significant and has potential applications to such areas as voiced internet applications, security, telephone banking, surveillance, and others.

SI is very important in any exchange of information - whether man-to-man, machine-to-man, or man-to-machine communication.

2.3 Acceptable Noise Level

Speaker identification systems work well within controlled environments that are relatively noise-free. To assess a listener's comfort with noise during a listening task, Nabelek et al. (1991) introduced the concept of ANL, which is defined as the difference between the listener's MCLL and the listener's maximum BNL. Nabelek et al. (2004) reported that there are two levels of noise assumed to be responsible for hearing aid dissatisfaction: loud noises, which may exceed an individual's loudness discomfort level (LDL), and moderate noises, which may interfere with speech understanding. Dillon (2001) found that LDL is accounted for in most hearing-aid fitting formulas to limit discomfort from excessive loudness. Nabelek (2005) reported that LDLs are unrelated to ANLs for listeners with normal hearing and impaired hearing. The findings from Nabelek et al. (1991) showed that the acceptance of background noise is a good predictor of successful use of a hearing aid. Research related to ANL has shown that listeners' reactions to background noise are not uniform. For example, Nabelek et al. (1991, 2004) reported large inter-subject differences in the acceptance of multi-talker speech (babble noise) while listening to speech. In light of this, investigations of ANL have attempted to identify the variables contributing to the wide range of differences exhibited among individuals in their acceptance of background noise.

Nabelek et al. (2004) and Nabelek, Freyaldenhaven, Tampas, Burchfield, & Muenchen, (2006) found no relationship between ANL and scores on the speech perception in noise (SPIN) test. Recent studies on reverberation, which is known to affect intelligibility, have also resulted in no significant changes in ANL with varying levels of reverberation (Adams, Gordon-Hickey, Moore, & Morlas, 2010). In some studies related to ANL, MCLL measures have been replaced by an investigator-prescribed speech-presentation level (Franklin et al., 2006; Freyaldenhoven, Plyer, Thelin, & Hedrick, 2007; Tampas & Harkrider, 2006), so that the ANL actually represents the difference between BNL and the Prescribed Speech Level (PSL). However, these substituted concepts are different from ANL and should be termed differently.

Nabelek et al. (1991) and Nabelek et al. (2006) have demonstrated that ANLs for normal-hearing elderly participants were not significantly different from the elderly participants with sensorineural hearing loss, but differed between successful and unsuccessful hearing aid users. These results suggest that ANL is related to hearing aid use, but not related to age or hearing loss. Lytle (1994) replicated the study conducted by Nabelek et al. (1991) with two groups of successful (n = 10) and unsuccessful (n = 10) hearing-aid users. The groups were matched for lifestyle activity, age, hearing sensitivity, and speech discrimination scores. The listeners were tested while wearing a single analog hearing aid and without the aid. The results of this study showed that successful users of hearing aids accepted more background noise than did unsuccessful users. Results for the aided and the unaided listening conditions were not different for either group of participants. These findings suggest that ANLs are capable of predicting hearing aid use before the hearing aids are actually fitted.

The study conducted by Mundorff (2011) on ANL used clear speech, conversational speech, and fast-rate speech as signal stimuli, and multi-talker speech (babble noise) as background noise. The result showed that ANL is affected by the intelligibility of the speech stimulus type. It was also revealed from the study that individuals were willing to accept a significantly higher level of background noise when presented with clear speech than when a fast-rate speech signal was presented. Mundorff concluded that older, hearing-impaired listeners can tolerate more background noise when listening to speech that is slow and clearly articulated than when listening to a very fast speaker with far less background noise.

Rogers et al. (2003) found that although males had higher comfortable listening levels and accepted higher levels of background noise than females, there was no difference in ANLs between genders. In their study, the listener's comfortable listening levels for speech and accepted levels of babble background noise were obtained binaurally via the sound field. Listeners were 50 (25 male, 25 female) young adults with normal hearing sensitivity. The results showed that cochlear responses, olivocochlear, bundle pathway, middle ear characteristics (Harkrider & Smith, 2005) or primary language of the listener (Von Hapsburg & Bahng, 2006) had no effect on ANL. However, research results are not consistent regarding the type of noise. Crowley and Nabelek (1996) showed that conventional ANLs are not related to speech-babble background noise. Likewise, the study conducted by Fasanya and Letowski (2009) concluded that there were different masking effects of white and pink noise on ANL.

Harkrider and Tampas (2006) reported that for listeners with normal hearing, brain responses to noise were different for people with low ANLs than people with high ANLs. The physiological finding of this study supported the concept that acceptance of background noise might be inherited and independent of the conditions in which a person lives. The study also showed that no difference could be found in the judgment of background noise exhibited by individuals due to differences in physiological activity in the auditory system. Meanwhile, Crowley and Nabelek (1996) found that the central nervous system contributed to the amount of background noise that an individual is willing to accept while listening to a continuous discourse.

2.4 Speech Comprehension in Noise

Speech comprehension measures the listener's ability to understand speech in everyday challenging conditions. This includes speech perceived in noisy conditions, speech understanding in distracting conditions, and speech containing reduced pronunciation variants, hesitations, and disfluencies. Several research studies have shown that speech comprehension is age dependent (Schneider, Daneman, Murphy, & Kwong-See, 2000; Schneider, Daneman, & Pichora-Fuller, 2002; Wingfield, 1996). Speech comprehension is also the ability of listeners to follow a conversation in a non-conducive environment. The study conducted by Nabelek et al. (2004) on speech perception in background noise (SPIN) and acceptance of background noise showed that SPIN scores improved with amplification, but could not be used to predict who will be a successful user of hearing aids. Research has revealed that speech comprehension depends on the integrity of the spectral content and temporal envelope of the speech signal (Ahissar et al., 2001). It has been reported that across a low-frequency modulation range, speech comprehension does not usually depend on the exact frequencies of the temporal envelopes of incoming speech since the temporal envelope of normal speech can be compressed in time down to 0.5 of its original duration before comprehension is significantly affected (Beasley, Bratt, & Rintelmann, 1980). Speech comprehension has been a serious issue among children and the elderly. Fuller, Fuller, Fuller, and Levitt (2012) concluded that brain plasticity from auditory and cognitive neuroscience provides new insights into how to facilitate speech perceptual re-learning by older adults.

2.5 Internal and External Noise

From hearing and audiometric studies, noise is a combination of noise from internal and external sources. Noise from an internal source is known as internal noise and is generated by the neural responses (Heeger, 1997). The neural responses determine the individual internal judgments toward external noise. Iindividual internal noise level is controlled by noise familiarization. Apparently, when there is no noise in the surrounding environment, there will still be some internal noise in the individual’s mind, since every signal carries some level of noise. Therefore, the chance of detecting a signal in the presence of noise depends on the neural activities of an individual. The determination of response to noise by an individual is best studied by neural activities in the brain (Heeger, 1997).

Schomer (2001) defines external noise as an environmental noise, that is, noise emitted from all sources except internally. The major sources of environmental noise are road, air traffic, rail, industries, construction, public works, and neighborhood noise. This phenomenon is best explained by psychophysics.

Figure 1 illustrates the development of ANL from psychophysics principles. This figure shows that sound waves from either air conduction hearing processes go through some steps before the ANL can be determined. Initially, the human senses the sound. Based on neural activities, they can decide on the preferred sound levels. Concurrently, they can discriminate between sound levels and select the most comfortable listening level (MCLL). Similarly, the human ear can filter background noise in order to determine the maximum BNL, the MCLL, and the BNL is used to define ANL.

In the course of hearing, sound waves enter human ears through the air-conduction hearing process and strike the eardrum, causing it to vibrate. In AC, the sound waves are concentrated by passing from a relatively large area (the eardrum) via the ossicles to a relatively small opening leading to the inner ear (National Institutes on Deafness and other Communication Disorders-NIDCD, 2003). The alternating changes in pressure agitate the basilar membrane on which the Organ of Corti rests, moving the hair cells. This movement stimulates the sensory hair cells to send electrical impulses along the auditory nerve to the brain. The brain is the part of the human body which is responsible for auditory signal processes. Auditory signal processes such as sound discrimination, association, memory, figure ground, closure, sound bleeding, attention, and organization take place in the Central Auditory Processor (CAP) in the brain.

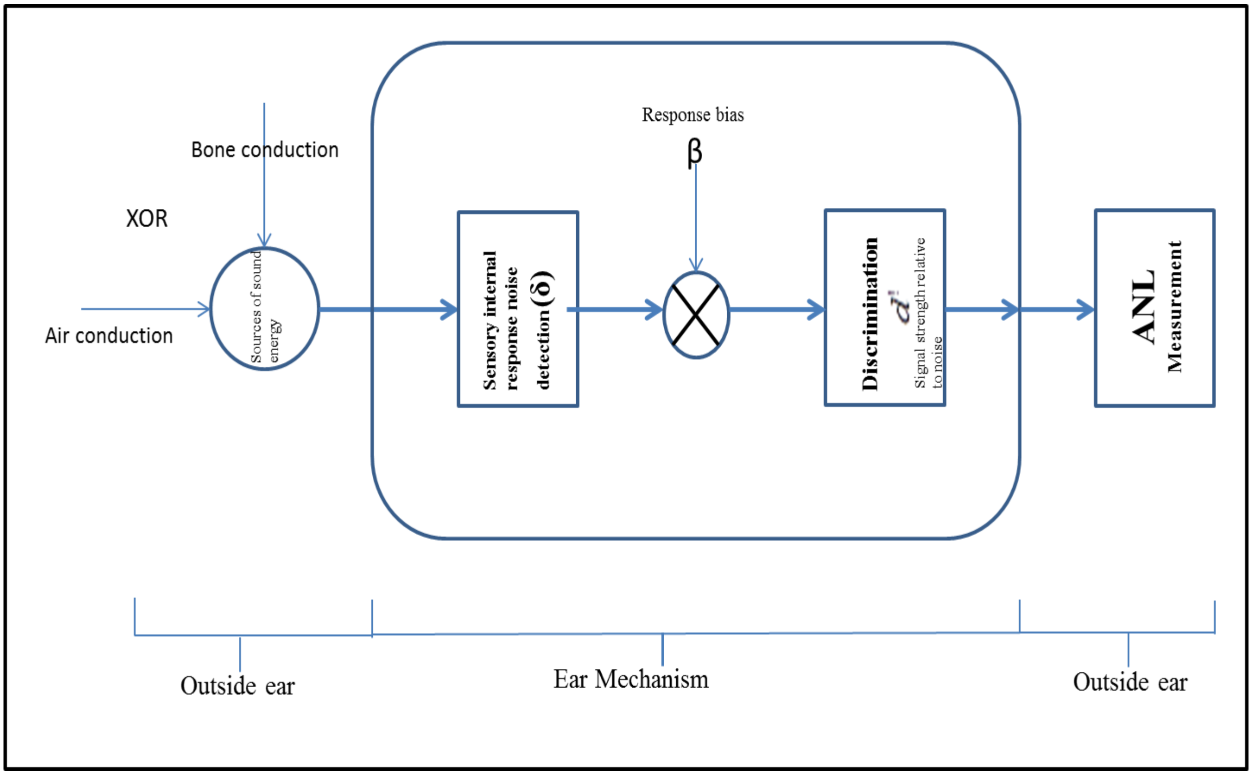


Figure 1. Psychophysics model for sound processing

2.6 Justification for ANL Study from Psychophysical Models

The entire processes of the ANL metric are a result of the brain's interpretation of the signal and the noise. Listening by means of air conduction is bilateral as well as unilateral; conversely, from the reception of sound signals (mechanical energy) in the cochlear to the auditory cortex for interpretation, the hearing process under any conditions is the same when it goes through Central Auditory Processing (CAP).

Freyaldenhoven et al. (2005) suggest that the acceptance of noise may be mediated in central regions of the nervous system of listeners with normal hearing. For example, stimulant mediation reduced ANLs significantly, but showed no effect on MCLL in listeners with normal hearing. Freyaldenhoven et al. (2005) observed that ANL reduction stimulant mediation was not a result of peripheral auditory phenomena, but occurred because of changes in auditory processing due to central, non-auditory processes. Harkrider and Smith (2005) discovered a correlation between monotic ANLs and dichotic ANLs in listeners with normal hearing. The authors discovered that monotic ANLs do not correlate with levels of activity in the acoustic reflex pathway or the medial olivocochlear bundle pathway. Monotic ANLs indicated that background noise acceptance may be mediated, in part, beyond the level of the superior olivary complex, where binaural processing initially occurs within the central auditory nervous system (Harkrider & Smith, 2005). Harkrider and Smith (2005) describe ANL in terms of human auditory discriminability, decision criterion, and noise familiarity; all these are components of auditory processing that occur at the CAP in the brain (Tucker, 2009).

The parts of the hearing process controlled by physiological components are shown in Figure 2. For air conduction, the outer ear receives sound energy in the form of waves and channels it to the middle ear where the sound energy is converted to mechanical energy by the tympanic membrane (Savaliya, Rakholiya and Marar, 2008). The mechanical energy moves to the inner ear where it is converted to electrical impulse before arriving at the auditory cortex for interpretation.

The activities that occur between hearing pathways can best be modeled by psychophysical models. Psychophysics relates noticeable changes in stimuli to internal factors such as impulse response and human degree of sensitivity; also, internal responses during discrimination tasks can best be explained by psychophysical models (Green & Swets, 1966).

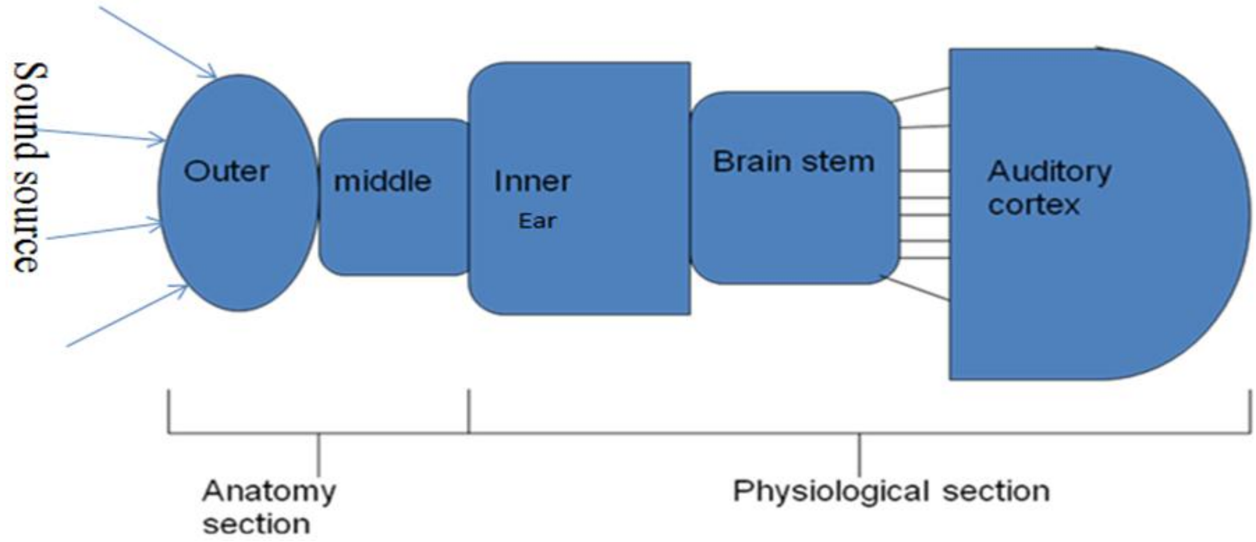


Figure 2. Air conduction hearing pathway.

2.7 Chapter Summary

This chapter reviewed past studies and observed the gaps that are related to this study. As explained in the body of the literature, factors responsible for ANL inter-subject variability need to be understood before a reasonable conclusion can be made on ANL application. It was noted that results found in the factors responsible for differences in ANL by different authors were context specific.

CHAPTER 3

Methodology

This study has two parts; the first part develops mathematical models of acceptable noise level, and the second part conducts experiments to validate the hypotheses formulated for the study.

3.1 Signal Detection Theory

SDT is a signal-in-noise analysis technique widely applied in psychophysics (Wickens, 2001). SDT in hearing studies has the ability to discern between detection threshold and listener criterion. SDT has its origin in psychophysics, a domain of study that investigates the relationship between a physical stimulus and its subjective or psychological effects. The relevance of the theory to psychophysical studies of detection, recognition, and discrimination was recognized early by Tanner and Swets (1954) and Green and Swets (1966). SDT has been extensively used in the analysis of decision-making performance in a wide range of applications including aviation, military command and control, weather prediction, medicine, and personnel decisions (Swets & Pickett, 1982). SDT provides independent measures of the discriminability bias and the accuracy of decision outcomes, and can be used to analyze human, machine, or joint human-machine performance (Sheridan & Ferrell, 1974; Swets, 1996). It also helps to understand the functions and limitations of auditory and visual senses (Kantowitz & Sorkin, 1983).

According to Green and Swets (1966), the accuracy of SDT in signal detection is reflected in both the hit rate and the false-alarm rate. Wickens (2001) associates SDT performance to two phenomena known as recognition memory (RM) and classical signal detection (CSD). Theoretically, a threshold is a property of the detection model’s sensory process. Recognition memory is illustrated by Wickens (2001) as the ability of an observer to remember and recognize objects that s/he has seen before without any clue of identification. Wickens (2001) noted that CSD deals with the observer’s ability to detect changes in a white noise tone when he/she is distracted by another signal. Tuzlukov (2001) used a Gaussian model to describe CSD.

One of the major aims of classical psychophysical approaches was the determination of a stimulus threshold (Harvey, 2012). Harvey listed the types of thresholds which included detection, discrimination, recognition, and identification. The concept of threshold was defined in empirical and theoretical terms. Empirically, a threshold is the stimulus level that allows the observer to correctly perform a task. Tuzlukov (2001) concluded that CSD allows for the design of optimal systems with automatic turning of frequency and phase from the viewpoint of noise immunity. Verghese (2001) used a signal detection approach to investigate human visual search and attention. The study revealed that performance in a search task is largely determined by the discriminability of the target from the distractors. Attention helps to enhance the response to the attended stimulus by restricting the range and number of units responding to the distractors. Lovelace, Stein, and Wallace (2003) studied how an irrelevant light enhances auditory discrimination in humans using the signal detection approach. Results of the study revealed an improvement in stimulus detectability in the absence of any change in response bias, and the irrelevant light was found to enhance the detectability of the sound.

Unlike traditional psychophysical approaches which treat observers as sensors, SDT recognizes that observers are sensors and decision makers. SDT estimates two main parameters from the experimental data. The first parameter is called the Discriminability Index (d'), which is defined as the differences between two Gaussian distributions: the noise distribution (N) on the left, and the signal (S) distribution on the right. This is shown in Figure 3. d' also indicates the strength of the signal relative to the noise. The second parameter called beta (β) indicates the strategy adopted by the observer and is known as response bias or criterion. Response bias is the influence on the answer a respondent gives of what he or she believes the questioner wants to hear. The criterion does not change when the signal distribution changes its position along the internal responses (x-axis) as denoted by δ. Shifting the noise distribution relative to the signal changes the sensitivity, but does not change the response bias of the observer.

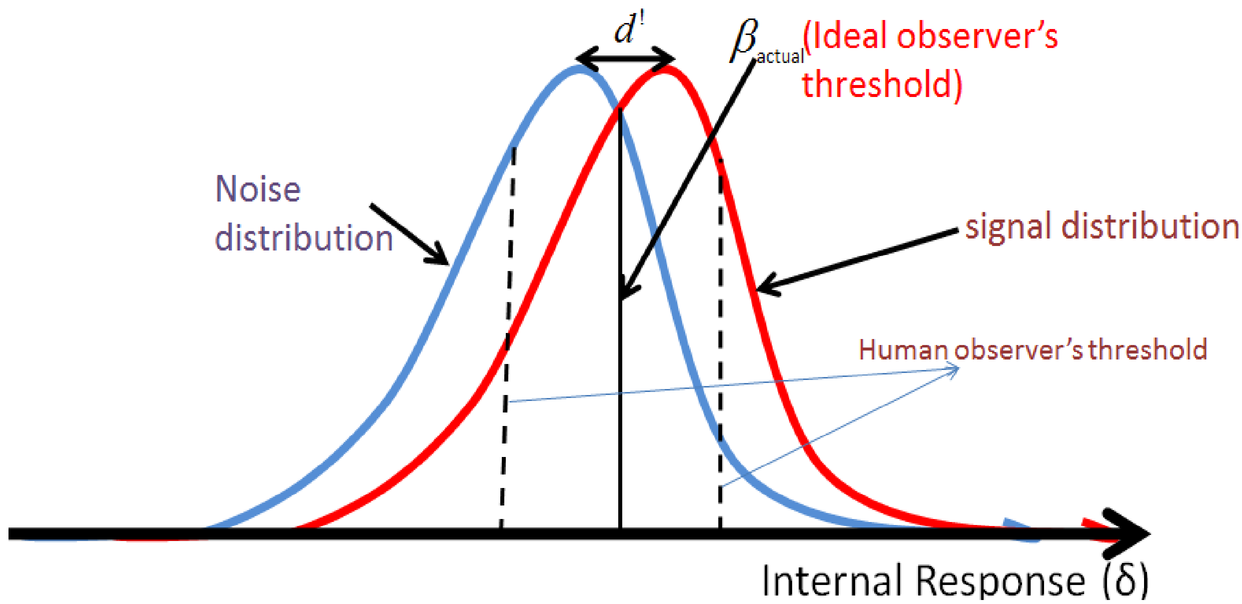


Figure 3. The signal detection model (Green & Sweets, 1988).

3.2 Mathematical Derivation of ANL in Terms of SDT

According to the SDT (Green & Swets, 1966), the accuracy of good identification is reflected in both the hit rate and the false-alarm rate. In the context of the current study, a hit rate is the probability of hearing a signal and responding to the signal; this is denoted by p (hit). False-alarm rate is the probability of hearing noise and responding to the signal; this is denoted by p (fa).

The SDT model assumes that the listener's response depends upon the intensity of a hidden variable (e.g., familiarity of noise type used or noise exposure ability). Participants might have larger or smaller ANLs because of this familiarity or because the ability of each listener to accept more or less background noise depends solely on the hidden variable. The respective measures are known as d' and response bias or the criterion score (β). Both measures can be derived mathematically from the hit rate and the false-alarm rate as showed in Equation (1):

$$d' = z(fa) - z(hit)\,, \tag{1}$$

where z(fa) and z(hit) are the corresponding readings of individual hit and false alarm output from the normal distribution table. The discriminability index of an ideal observer is defined by Kantowitz and Sorkin (1983) in Equation 2a and 3a.

$$d'_{ideal} = \sqrt{\frac{2E}{N_O}}\,, \tag{2a}$$

where E is the signal energy (signal power x signal duration) and N_o is the noise power per cycle;

$$L_{spectrum} = 10 \log N_o \tag{2b}$$

$L_{spectrum}$ is the noise spectrum level. According to Kantowitz and Sorkin (1983), the discriminability of brief tonal signals (less than 250 msec duration) by human observers follows Equation 2a, but is degraded by various factors such as noise within the auditory nervous system, and observer uncertainty about the signal and noise characteristics. Kantowitz and Sorkin (1983) modified Equation 2a to reflect the individual experience to signal as

$$d'_{human} = \sqrt{\frac{kE}{N_o}}\,, \tag{3a}$$

Therefore, from equations 2a and 3a, equation 3b can be deduced as:

$$d'_{human} = d'_{ideal}\sqrt{\frac{k}{2}}\,, \tag{3b}$$

where k is a constant for a particular individual which can be interpreted to represent the individual noise familiarity or noise exposure. Individual noise exposure can be measured with a questionnaire designed to capture the participant's past job experience, nationality, childhood environment, and usage of auditory equipment such as earphones, or listening to loud sounds, among others. Modified equation 2a to account for noise, equation 4 is used to define $L_{spectrum}$.

$$L_{spectrum} = L_{noise} - 10\log(\Psi), \tag{4}$$

where Ψ is the frequency bandwidth of the noise measured in cycles per second and defined as hertz (one cycle per second equals one hertz, abbreviated Hz). L_{noise} is the overall noise level produced by the noise bandwidth (Ψ). All logarithms are base ten. From equation 2b,

$$N_o = 10^{\left(\frac{L_{spectrum}}{10}\right)}. \tag{5}$$

By substituting Equation 4, Equation 5 reduces to Equation 6:

$$N_o = 10^{\left[\frac{(L_{noise} - 10\log(\Psi))}{10}\right]} \tag{6}$$

The signal energy is defined by Kantowitz & Sorkin (1983) as

$$E = 10^{\left[\frac{L_{signal} + 10\log t}{10}\right]} \tag{7}$$

$$S_P = \left[\frac{E}{t}\right], \tag{8}$$

where "t" is the time duration, S_p is the signal power, E is signal energy, and L_{signal} is the signal level expressed in dB.

Equation 2a is the ideal equation for detecting single tone signals of less than 250msec duration by the human observer. This could be affected by the noise within the auditory nervous system and the individual familiarization/exposure to noise type. Therefore, at a higher duration, and when considering human familiarity, Equation 3a is appropriate. If the human subscript from Equation 3a is dropped and the relationship is rearranged, Equation 9 will be obtained:

$$\sqrt{\frac{E}{N_o}} = \frac{d^{'}}{\sqrt{k}} . \tag{9}$$

To express the $\sqrt{E/N_O}$ ratio in dB terms, take log to base ten of Equation 9;

$$10\log\frac{E}{N_O} = 20\log\sqrt{\frac{E}{N_O}} = 10\log\left(\frac{d'}{\sqrt{k}}\right)^2 \tag{10}$$

Since N_o is noise power, “E” must also be expressed as signal power. According to Choma et al. (2003), SNRs are often expressed using the logarithm decibel scale. In decibels, the SNR is defined as the product of 10 and logarithm of ratio of power of signal to power of noise.

From equation 8 and the right side of equation 10,

$$10\log\left(\frac{d^{'}}{\sqrt{k}}\right)^2 = 20\log\sqrt{\frac{tS_p}{N_o}} \qquad (E = tS_P) \tag{11}$$

$$10\log\left(\frac{d'}{\sqrt{k}}\right)^2 = 20\log\sqrt{\frac{S_p}{N_o}} + 20\log\sqrt{t}$$

$$10\log\left(\frac{d'}{\sqrt{k}}\right)^2 - 20\log\sqrt{t} = 10\log\frac{S_p}{N_o}$$

By definition, SNR = 10log $\frac{S_p}{N_o}$

Therefore,

$$10\log\left(\frac{d^{'}}{\sqrt{k}}\right)^2 - 20\log\sqrt{t} = SNR \tag{12}$$

where d' is the human sound discrimination sensitivity.

Simplifying equation 10,

$$\log\frac{d'}{\sqrt{k}}=\frac{1}{2}\log\frac{E}{N_o} \tag{13}$$

Conventionally, ANL is expressed in dB, and is defined as the difference between the most comfortable listening level (MCLL) for speech and the highest background noise level (BNL) that is acceptable when listening to and following a speech sample. Kantowitz and Sorkin (1983) noted that for signal durations greater than 200msec, signal detectability depended on signal power rather than energy. Likewise, according to Penner and Shiffrin (1980), human detectability depended on signal power because the auditory system could not integrate energy for long durations. Therefore, by substituting Equations 6 and 7 into Equation 13, Equation 14 and 15 are obtained:

$$\log\frac{d'}{\sqrt{k}}=\frac{1}{2}\log\left[\frac{10^{\left(\frac{L_{signal}+10\log t}{10}\right)}}{10^{\left(\frac{L_{noise}-10\log\psi}{10}\right)}}\right] \tag{14}$$

$$\log\frac{d'}{\sqrt{k}}=\frac{1}{2}\left[\log 10^{\left(\frac{L_{signal}+10\log t}{10}\right)}-\log 10^{\left(\frac{L_{noise}-10\log\psi}{10}\right)}\right]$$

$$\log\frac{d'}{\sqrt{k}}=\frac{1}{2}\left[\frac{L_{signal}+10\log t-L_{noise}+10\log\psi}{10}\right] \tag{15}$$

But, $\Psi = 1/t$; hence Equation 13 reduced to Equation 14

$$\log\frac{d'}{\sqrt{k}}=\frac{1}{2}\left[\frac{L_{signal}+10\log t-L_{noise}+10\log 1/t}{10}\right] \tag{16}$$

$$\log\frac{d'}{\sqrt{k}}=\frac{1}{2}\left[\frac{L_{signal}+10\log t-L_{noise}+10\log 1-10\log t}{10}\right]$$

$$\log\frac{d'}{\sqrt{k}}=\frac{1}{2}\left[\frac{L_{signal}+10\log t-L_{noise}-10\log t}{10}\right] \tag{17}$$

$$d' = \sqrt{k} * 10^{\frac{1}{20}\left[L_{signal} - L_{noise}\right]} \tag{18}$$

$$d' = \sqrt{k} * 10^{\frac{(MCLL - BNL)}{20}};$$

by definition, $L_{signal} = MCLL; L_{noise} = BNL; ANL = MCLL - BNL,$ hence,

$$d' = \sqrt{k} * 10^{\frac{ANL}{20}} \tag{19}$$

d' is the index of sound discriminability of steady-state sound in wideband continuous noise.

3.3 Psychophysical model for ANL

ANL is an approximation of a psychophysical model of human auditory performance. Psychophysics is the study of perception, examining the relationship between observed stimuli and their responses and the reasons for those relationships. Weber (1878) formulated a law of psychophysics which states that to perceive a difference between a background noise level *x* and the background noise level plus some stimulation *x* + d*x*, the size of the difference must be proportional to the background noise level; that is, d*x* = *kx* where *k* is a constant. Weber's law can be stated in its general form as this is considered local psychophysics, where stimuli are discriminated only with a certain probability as shown in Equation 20:

$$\Delta R = z \frac{\Delta x}{x} \tag{20}$$

ΔR is the just noticeable change in psychological response, z is a constant of proportionality, and $\Delta x / x$ is Weber's ratio, which is constant for constant conditions (e.g., frequency) but varying for stimulus frequency level.

In 1957, Stevens proposed a new law to relate sensation magnitude to stimulus intensity. The new law has come to be known as "Stevens' power law" which is expressed as

$$S = QI^{\theta} \tag{21}$$

Q is a constant (arbitrary constant determining the scale unit). The exponent, θ, is a characteristic that indicates how fast the magnitude of the sensation grows as the stimulus intensity increases. S is the sensation magnitude and I is the magnitude of the actual stimulus. Equation 21 can be used to quantify ANL because Stevens's law is considered as the most accepted psychophysics law (Luce & Krumhansl, 1988).

Therefore, using Stevens's power law as shown in Equation 19, the psychophysical models for both the MCLL and the BNL for sound processing can be expressed as

$$MCLL = f_1(\beta, d') = c_1 d'^{\beta_1}_1 \tag{22}$$

$$BNL = f_1(\beta, d') = c_2 d'^{\beta_2}_2 \tag{23}$$

where β_i (i = 1, 2 . . .) represent listener discriminability bias toward the sound intensity experienced, d' is the sound magnitude to be discriminated, and c_i (i = 1, 2 . . .) is the constant of proportionality which can amplify or attenuate the magnitude of sound stimulus. Noting that ANL = MCLL – BNL, Equations 24 and 25 were obtained;

$$ANL(\beta, d') = f_1(\beta, d') - f_2(\beta, d') \tag{24}$$

$$ANL(\beta, d') = c_1 d'^{\beta_1}_1 - c_2 d'^{\beta_2}_2 , \tag{25}$$

assuming that $d_1' = d_2'$, meaning that listeners have the same tendency to discriminate the noise and the signal level in a particular condition. When the signal is considered as MCLL and noise as BNL, Equation 25 and 26 may be stated as

$$ANL(\beta, d') = c_1 d'^{\beta_1} - c_2 d'^{\beta_2} \tag{26}$$

Taking the log to base ten of both sides of equation 26

$$\log(ANL) = \log c_1 + \beta_1 \log d' - \log c_2 - \beta_2 \log d'$$

$$\log(ANL) = (\log c_1 - \log c_2) + (\beta_1 - \beta_2)\log d' \tag{27a}$$

$$\log(ANL) = C + \Delta\beta \log d',$$

where $\log c_1 - \log c_2 = C$ and $\Delta\beta = \beta_1 - \beta_2$

$$ANL(d',\beta) = 10^{[C+\Delta\beta \log d']} \quad (27b)$$

The application of Equation 27 is used in data analyses in Chapters 4 through 6.

3.4 Experimental Design

The experimental design is described in this section. All participants were students currently enrolled in different departments across North Carolina A&T State University. The participants' ages ranged from 18 to 45 years old. The average age of selected subjects was 27 years and the standard deviation was 6.57 years.

Academic level, cumulative grade point average, and department were not criteria for subject participation. Only hearing sensitivity played a vital role in the selection. All subjects had normal hearing in both ears as defined by hearing thresholds of 25 dB or below for octave band frequencies between 250 and 4000 Hz. Ninety two subjects were recruited for data collection, of which only 83 subjects met the criteria.

All participants read and signed a Statement of Informed Consent approved by North Carolina Agricultural and Technical State University Institutional Research Board (IRB). All participants also read and filled out a participant hearing screening form approved by the North Carolina Agricultural and Technical State University Institutional Research Board. Appendix A contains the Participant Hearing screening form, and Appendix B contains the Statement of Informed Consent.

3.5 Instrumentation

The apparatus and testing materials used in the study were a sound attenuating booth model RE-143MC as shown in Figure 5 (Larson Davis System 824 sound level meter, Fonix audiometer model FA-6, SONY earphones Figure 4), two desktop computers(Cooler Master

Glite desktop computer, model WHOL, and Lenovo desktop), five loud speakers (Logitech model Z 506), and SANUS (vuepoint) adjustable speaker stand model HTBS. All these instruments are located in the Center for Human-Machine Studies Laboratory at North Carolina Agricultural and Technical State University (NC A&T). The testing facility for this study is located at the NC A&T's Interdisciplinary Research Center (IRC) room 222 (67'6" x 49'8") that is designed for conducting human factors experiments.

Figure 4. Audiometer and sound level meter.

All the different types of equipment were calibrated according to ANSI specification standard (1996). Both speech and noise were played using the Sony Sound Forge version 10.0 software (1,001 sound effects), and channeled through an M-audio sound card on the desktop computer with the help of WINAMP software for signal looping. The positions of all volume controls except that of M-audio were fixed. A Sony stereo earphone MDR-J10, driver unit of

13.5 mm, dome type with a power handling capacity of 50mW of impedance 16 Ω at 1 kHz, frequency response: 18-22,000 Hz and sensitivity 104 dB/Mw was used for the study.

Logitech surround sound speaker system model Z506, 75watts (RMS) of power, 3.5mm, RCA & six-channel direct input 3D stereo for surround sound from two-channel sources, ported, with down-firing subwoofer 27 watts were used for this study. Custom amplifier tuning enhanced the integration between the high and low frequencies, delivering refined spectral balance and a smoother response.

Adjustable speaker stands made of heavy cast iron bases that provided stability and reduced acoustic vibration were used. They were equipped with adapter brackets included to fit most small speakers. Each weighed 3.5 pounds.

An acoustic chamber is a specialized environment that assists in acoustical measurements. It serves two main purposes:

1. To create an environment in which reflected sounds are negligible and do not interfere with listening to the direct sounds emitted from the sound sources.
2. To reduce or eliminate interference from external intruding noises, including but not limited to environmental noises, operation of support equipment, mechanical equipment, automobile, truck, aircraft, and rail traffic noise.

The size of the sound attenuating booth used for the study was 7’ 3” x 7’ x 6’ 6” and is shown in Figure 5.

Figure 5. Sound attenuating booth.

3.6 Noise and Speech Recordings

Three types of background noise were used in this study: white, speech multi-talker babble, and speech spectrum. White noise is an audio noise that has equal energy per frequency and generalized mean-square that are derivative of the Wiener process or Brownian motion (Wikipedia-Stolfi, 2013). This means that the energy frequency spectrum is mainly flat. Human hearing responds in a logarithmic manner. To the human, white noise sounds loudest at high frequencies (Rosu, 2011). Babble noise is the type of noise experienced when multiple talkers are speaking at the same time, such as the noise experienced at sport centers during games or at cocktail parties. Krishnamurthy and Hansen (2009) described babble noise as a tough noise and a hindrance in all speech systems. The proposed babble noise for this study is the speech babble of 12 voices by Frank and Craig (1984). Speech spectrum is an example of babble noise, but occurs as a result of a single speaker speaking in the background of signal processing. The energy and frequency are lower when compared to babble noise.

3.7 Speech Recording

Four signals were proposed as the speech signals for this study. They are “Bar Jokes,” “Complimentary Peanuts,” “Mad Cows and Udders,” and “Are There Golf Courses in Heaven?” All signals are excerpted from “Delight yourself and be the enemy of others” (comedian speech) CD by Garrison Keillor, Prairie Home Companion (2004).

Speech signals consist of variations in sound pressure, typically measured directly in front of the mouth, as a function of time. The amplitude variations of such signals correspond to deviations from atmospheric pressure caused by traveling waves. The signal is non-stationary and constantly changes as the muscles of the vocal tract contract and relax.

3.8 Chapter Summary

This chapter discussed the processes involved in developing a psychophysical ANL model from a signal detection theory perspective and Stevens’s power law. New formulas were developed for SNR and ANL. The psychophysical parameters in the new models include sound discriminability (d’), listeners’ bias to sound intensity (β), sound familiarity (k), frequency bandwidth (ψ), listeners’ most comfortable listening level (MCLL), and the maximum background noise level (BNL). Equipment used in the study was discussed, and a detailed explanation of each piece of equipment was documented. Procedures for the experiment were explained. Criteria for participation in the experiment were also documented.

CHAPTER 4

Effects of Frequency Bandwidths on ANL (Study I)

4.1 Background

As demonstrated in Pascoe (1975), high frequency information improved speech recognition for high frequency hearing loss listeners. Sullivan, Allsman, Nielsen, and Mobley (1992) reported in their study that the addition of supra-threshold, high-frequency information (i.e., increasing signal bandwidth) resulted in an improvement in recognition performance for the high-frequency hearing-impaired listeners used in their study. The experiment addressed in this chapter notes that changes in noise frequency bandwidths will not pose any significant effect on a listener's ability to accept more background noise when simultaneously listening to a speech of interest in a quiet condition. The alternative hypothesis is that high frequency bandwidths will have significant effects on ANL.

Freed and Soli (2006) showed that high-frequency bandwidth extensions have recently been made available in several hearing aid models. However, there have been many conflicts in research findings on the effects of high frequency bandwidth on speech recognitions in background noise. Studies, conducted by Hogan and Turner (1998) and Ching, Dillon, Katsch, and Byrne (2001) on human listeners with more severe hearing losses, reported negative effects on speech understanding performance with extended audible high-frequency bandwidth. Turner and Henry's (2002) and Horwitz, Ahlstrom, and Dubno's (2008) studies suggested that high frequencies can have a positive effect on speech recognition when listening with background noise.

The dependent variable in this study was the ANL, and the independent variables were the background noise frequency levels (high and low), and the signal sources (sound field and earphones).

Table 1 shows the experimental setup as a 2*2*2 experimental design, and Table 2 shows the research design for masking noise and the signal sources used.

Table 1

2^k Factorial Design for the Experiment

Signal Source	Background noise	Noise frequency level	Trial 1	Trial 2	Trial 3
Sound field	White	Low			
Earphone	White	Low			
Sound field	White	High			
Earphone	White	High			
Sound field	Babble	Low			
Earphone	Babble	Low			
Sound field	Babble	High			
Earphone	Babble	High			

Table 2

Research Design for Masking Noise and the Signal on Effect of Frequency Bandwidths

			Signal			
Masker			SF 1	SF 2	SF3	Earphone
SF	Front	white Noise				
		Speech spectrum				
		babble Noise				
	Rear	white Noise				
		Speech spectrum				
		babble Noise				
	Omni	white Noise	X			X
		Speech spectrum				
		babble Noise	X			X
Earphone		Speech spectrum				
		Babble Noise				

*SF1, SF2, SF3 represent sound-field (Signal Loudspeaker)

4.2 Participants

Participants were chosen based on the outcome of the hearing screening conducted prior to the beginning of the experiment. The experiment was designed to have 80% power of a test. The participant populations of twenty eight (28) students were determined by the two-tailed test in Equation 28 as documented in Engineering Statistic Handbook by the U.S. Department of Commerce (2010). Participants' age ranged from 18 - 41 years, with mean age $\mu = 26.46$ years and standard deviation $\sigma = 6.58$ years.

$$n = \left(Z_{\alpha/2} + Z_{\beta} \right)^2 \left(\frac{\sigma}{d} \right)^2 \qquad (28)$$

From Equation 28, β denotes type II error that a listener is willing to accept to determine the power of the test. Power is the probability that one rejects the null hypothesis when it is appropriate to reject (and thus avoid a Type II error). It is generally accepted that power should be 0.8 or greater. That is, there should be an 80% or greater chance of finding a statistically significant difference when there is one. Alpha (α) is type I error, usually set at 0.05. Effect size (d) is determined from a sample pilot study. Therefore, with $\alpha = 0.05$, $\beta = 0.8$, $d = 7.5$, $\sigma = 8$; from past studies, gives $n = 28$.

4.3 Method

The speech was delivered to each participant through two different sources: (1) Through a loudspeaker placed three feet away in front of the listener and (2) through earphones placed at the opening to the ear canal of the listener. The three foot distance is the typical distance used in ANL tests (Fasanya & Letowski, 2009). For sound field noise conditions, noise was simultaneously delivered through three loudspeakers positioned at 45, 180, and 270 degrees azimuth as shown in Figure 6. The ANLs were measured in two ways: (1) both signal and noise were delivered through air conduction in the sound field with ears open; and (2) signal through earphones and noise through loudspeakers located around the listener.

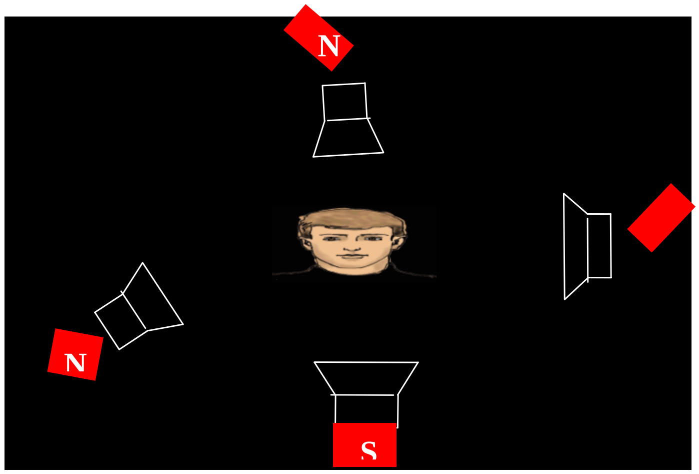


Figure 6. Omni-directional noise source of three loudspeakers.

4.4. Materials

Four loudspeakers were used; three loudspeakers simultaneously delivered noise and one loudspeaker delivered the signal. An earphone described in chapter 3 was also used to deliver signal. A Fonix audiometer was used for the hearing screening, a sound level meter for intensity calibration, a magazine, push button cord, two background noises (multi-talker babble and white noise, two levels each) and four comedian speeches (“Bar Jokes,” “Complimentary Peanuts,” “Mad Cows & Udder,” and “Are There Golf Courses in Heaven?”) of which participants selected one comedian speech for the experiment.

4.5 Procedure

Study I was conducted to determine the effects of frequency bandwidths on ANL. Preliminary procedures included obtaining “informed consent” through the university’s Institutional Review Board (IRB). A copy of the informed consent form is included in Appendix B. Participants were recruited through posted flyers and personal acquaintance. Prior to the start of the experiment, the audiometer and the loudspeakers in the acoustic chamber were set to predetermined readings. Pre-run tests of the signal and the noise on the loudspeakers were conducted to ensure that all loudspeakers worked perfectly before the experiment began. As the participants arrived, they were welcomed and briefed about the purpose of the experiment, and any questions that arose from the briefing were answered. Participants who agreed to proceed with the experiment were given an informed consent form to sign and a pre-test hearing screening form to complete the demographic portion. Next, the researcher explained the hearing screening task to all the participants. Participants were asked to push a button in response to every tone they heard, and to do nothing if no tone was heard. At the beginning of the hearing screening test, each participant was asked to sit at the center of the acoustic booth with a headphone and a push button provided by the researcher. Participant responses were recorded on their hearing screening form. The hearing screening was conducted on the participant's ears at 25 dB for octave band at frequencies between 250 and 4000 Hz. With the use of pure tone, the hearing screening was conducted to ensure that all participating subjects had normal hearing. The audiometric testing was performed using a Fonix Hearing Evaluator (FA-10 Digital Audiometer) and TDH-39P, C13357 Telephonics headphones calibrated according to ANSI specifications for audiometers (ANSI, 1996). Participants who passed the hearing screening continued with the experiment, and those who failed were released from the experiment.

Prior to starting the experiment, the researcher instructed each participant to imagine himself/herself working in a factory performing a mundane task and listening to a recording of a comedian's performance for on-the-job relaxation. At a certain point, a coworker started a noisy operation that made listening to the recording more difficult. The noise from the operation was represented by the background noise from the speaker. The listener's task was to first adjust the signal level (i.e., the volume of the recording) to a most comfortable listening level and then to adjust the noise level to the maximum tolerable level above which he or she would simply stop listening to or turn off the source of the signal. Participants were told to use hand gestures (i.e., hand up, hand down, hand flat) to request changes in the signal levels. Hand up, hand down, and hand flat indicated volume up, volume down and volume okay, respectively. There were two signal sources (sound field and earphones), two noise types (babble and white), and two noise frequency levels (high and low) used in the experiment.

Each participant went through eight sessions (2 signal sources x 2 noise types x 2 noise frequency levels). A simple randomization technique was used with each participant to determine which session would come first. Eight papers were wrapped in a box with each paper indicating a session. Papers were labeled 1 to 8, with each number representing a particular combination of signal source, noise type, and noise frequency level, (e.g., sound field, babble noise, and high frequency level). Each participant randomly picked one paper at a time without replacement. The experiment was conducted according to the order of the session the participant had randomly picked. Participants were also asked to choose one of four comedian recordings, according to preference. The comedian recordings on the CD were from the Army Research Laboratory in Aberdeen, Maryland. These recordings included (a) “Bar Jokes,” (b) “Complimentary Peanuts,” (c) “Mad Cows & Udder,” and (d) “Are There Golf Courses in Heaven?” from the “Delight Yourself and Be the Enemy of Others” CD (Garrison Keillor, Prairie Home Companion, 2004).

During the data collection, all loudspeaker heights were adjusted to each participant’s seated ear level. Three loudspeakers delivered the noise in unison. Noise loudspeakers were located at 45-, 180-, and 270-degree azimuths, three feet away from the participant’s seated position. Participants were given a magazine as the mundane task. The magazine was used to prevent the listeners’ full attention from focusing on the signal presented. The comedian speech chosen by the participant was played first, starting from 0 dBA, and controlled from a computer outside the booth. This was controlled by the researcher with the help of Sound Forge software for looping. The signal was delivered to the acoustic booth through the loudspeaker located at a 0-degree azimuth three feet away from the seated position of the participant. Participants used the hand gestures to indicate the intensity level at which he or she was most comfortable while the researcher controlled the signal intensity level through the computer. The intensity settings at the level of the comedian speech determined the most comfortable listening level (MCLL). This information was recorded by the researcher. Participants were allowed to enjoy the comedian's speech at this level for about 2–3 minutes before introducing the background noise.

Thereafter, as the recording was still playing, the background noise was introduced, starting from 0 dBA. Each participant used the same hand gestures to indicate the maximum level of background noise they were willing to accept and still be comfortable with the comedian's speech and the mundane task. The researcher controlled the level of the noise from another computer outside the booth. The participant's intensity settings at the level of maximum background noise accepted at the frequency bandwidths chosen by the participant (high or low), determined the participant's BNL. This result was also recorded by the researcher. The levels of the comedian's speech and noise were adjusted in 1.5 dB steps by pressing the up and down arrow keys on the computer's keyboard. The procedure for determining the 1.5 dB step, is shown in Appendix D. Participants were allowed to remain at this condition (i.e. signal plus noise condition with the mundane task) for approximately three minutes, during which time they maintained the same signal and noise intensities as measured earlier by the researcher. This procedure was followed to ensure that each participant felt the effect of both the signal and the noise at the same time as well as to ensure that both the signal and the noise were still playing at the same time before BNL was measured. For each session, the participant's MCLL and BNL were determined three times, which ensured reliability of the participant's responses. Each trial took about six to seven minutes, but time varied based on the individual participant. The differences between the MCLL and BNL were calculated and recorded as the listener's ANL.

After every block of four experimental sessions, participants were given a 20-minute break, and the experiment continued after participants returned to the acoustics chamber. However, for any session that the signal was delivered through the earphones, the researcher checked the fitting of the earphones to ensure that there was no displacement from the ear canal. According to Roeser, Valente, and Hosford-Dunn (2000), a small displacement of the earphones away from the ear canal entrance can result in sound level threshold shift between 25 dB and 30, dB or more.

There were two types of background noise (white noise and babble noise) each having two frequency levels: low and high. Figure 7 represents white noise generated from Sound Forge Audio Studio where (a) is high frequency noise and (b) is low frequency noise.

Figure 8 represents babble noise generated from Sound Forge Audio Studio: (a) is high frequency noise and (b) is low frequency noise. There were two channels for each of the signal and noise processes.

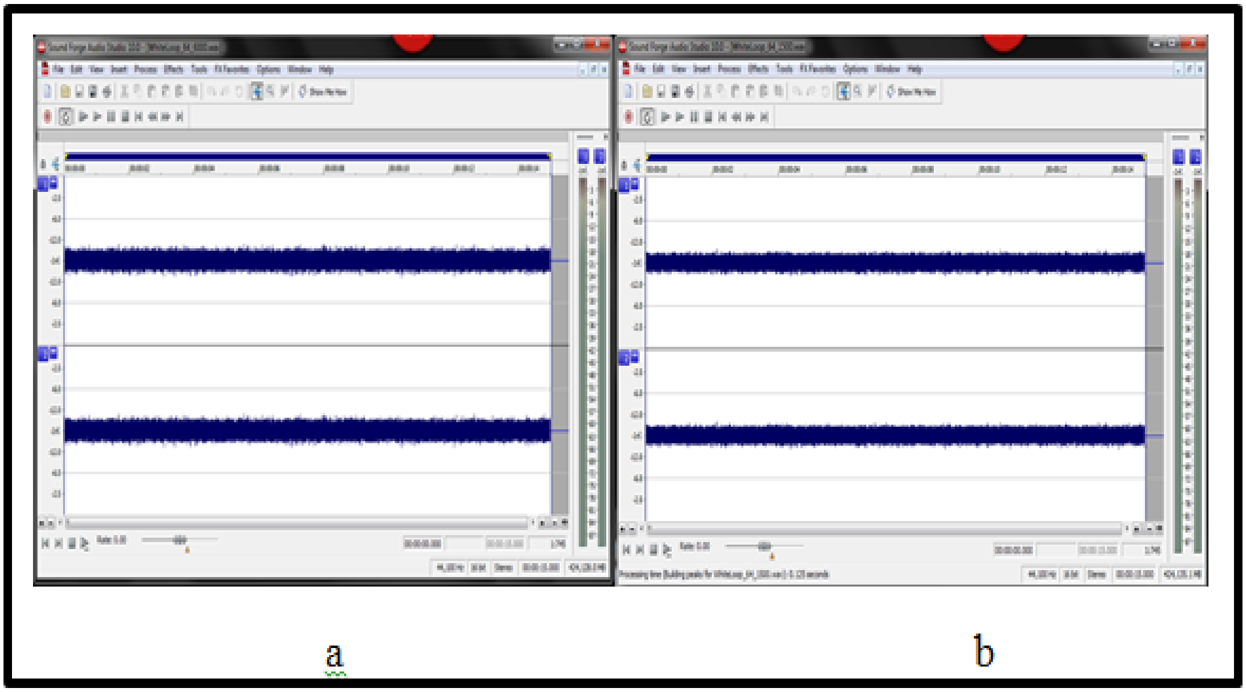


Figure 7. White noise from Sound Forge software.

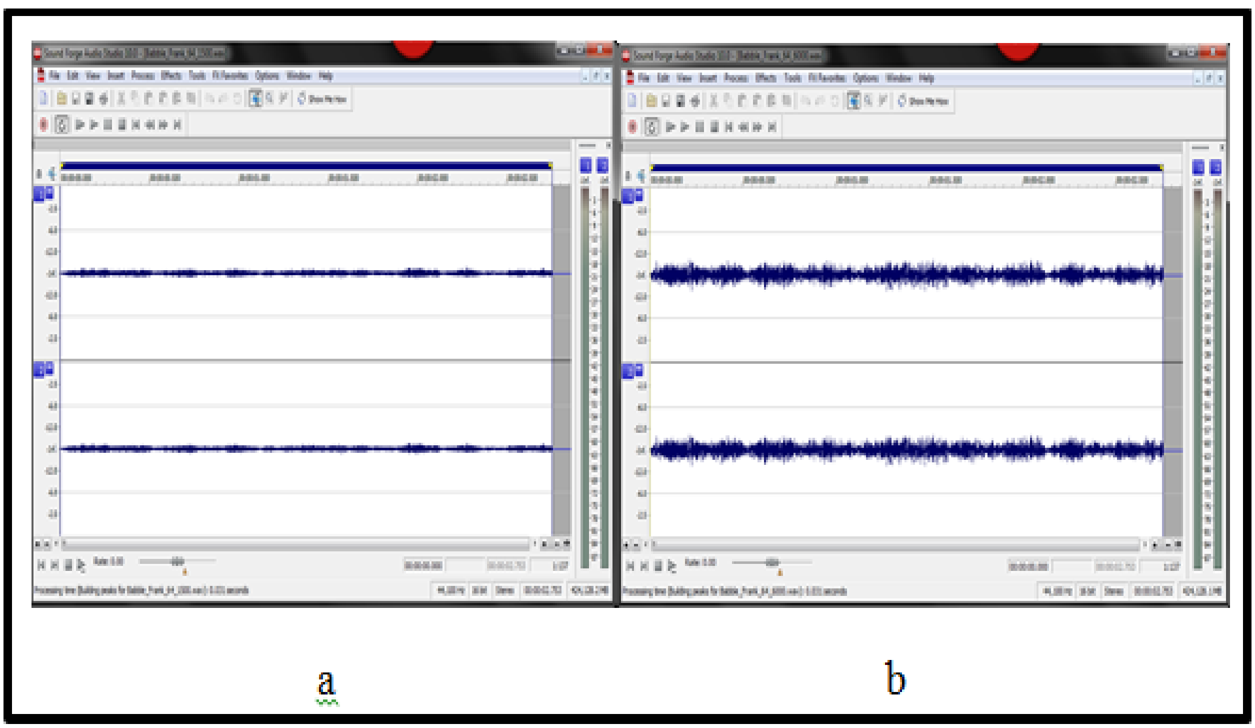


Figure 8. Babble background noise from Sound Forge software.

4.6 Frequency Bandwidth

The low frequency bandwidth set included a high-pass filtered (6 dB per octave) frequency bandwidth with a cutoff frequency at 6000Hz. These bandwidths were chosen to represent realistic bandwidths that a normal hearing listener might experience. According to Campbell (2011), measurements made of the filtering properties of a cochlea indicate that the filter shape is asymmetric with a steeper slope on the low frequency side. Figure 9 represents the low frequency spectrum plot of the background noise with (a) babble noise, and (b) white noise. The spectrum plot was generated from the Audacity software version 2010.

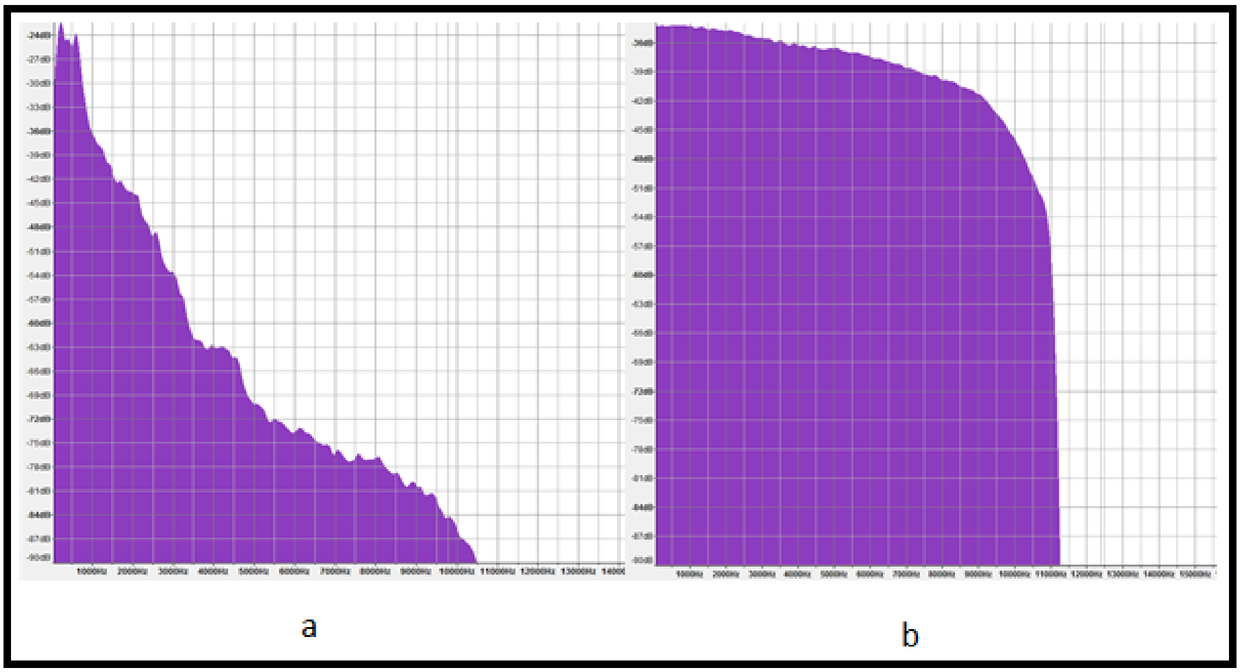


Figure 9. Spectrum plot using Hanning window at 6dB and High-pass filter for low frequency.

The high frequency bandwidth set included low-pass filtered (6 dB per octave) frequency bandwidth with a cutoff frequency at 1500Hz. These bandwidths were chosen to represent realistic bandwidths that a normal hearing listener may experience. High-frequency spectral slope of the background noise was used as a means of assessing possible differences in the spectrum shape of background noise on the ANL. Figure 10 represents the high frequency spectrum plot of the background noise with (a) babble noise, and (b) white noise. This high frequency was chosen because it was expected that smaller amounts of high-frequency energy within a background noise would decrease listeners' ANL values.

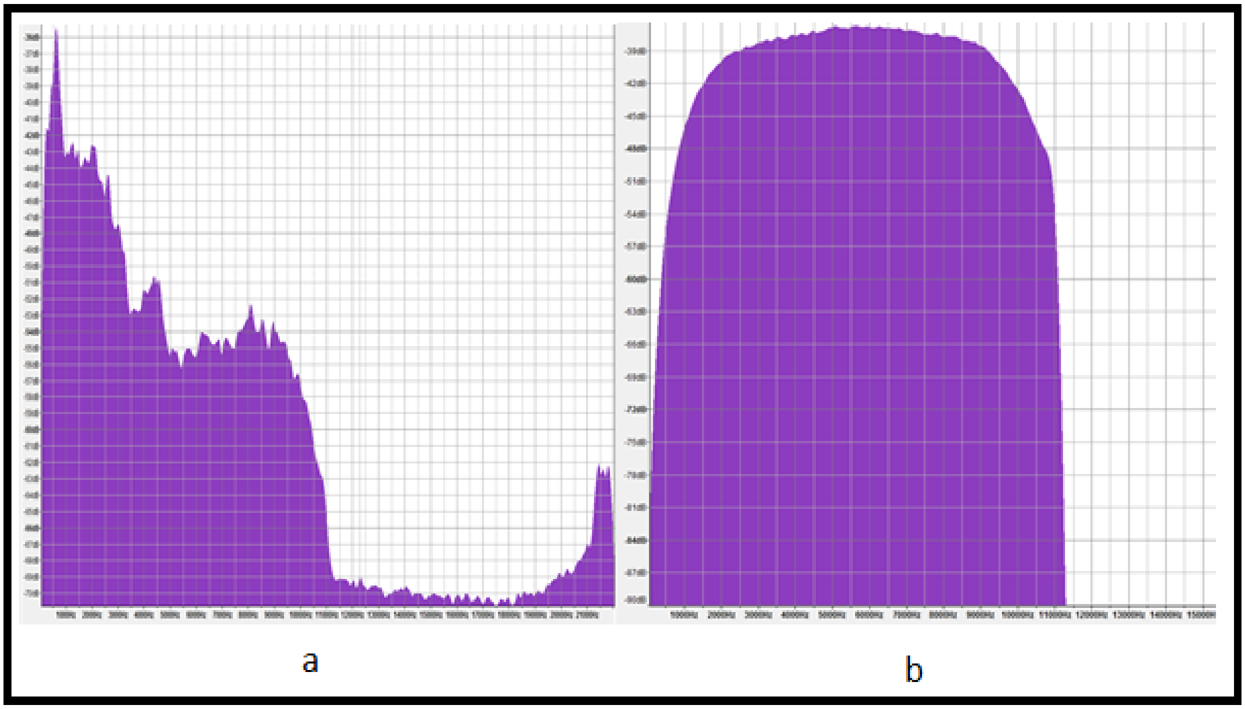


Figure 10. Spectrum plot using Hanning window at 6dB and low-pass filter for high frequency.

4.7 Results

4.7.1 Descriptive statistics. Table 3 shows the average, the standard deviation, and the range of ANLs for the three trials for low and high frequency levels under the sound field (loudspeaker) and the earphones for all twenty-eight participants. The ANLs in (dB) were calculated by subtracting the BNLs from the MCLLs. ANL was the dependent variable. Since ANL was derived by subtracting BNL from MCLL, it was important to examine the normality of the measurements. The data passed the normality test using Shapiro-Wilk tests, Anderson-Darling test, Lilliefors test, and Jarque-Bera test.

Table 3 shows that the average ANL value was lower for the high frequency noise when white noise was the background noise for sound field listening conditions; the average ANL for high frequency was higher for the listening condition through earphones. For babble noise, the results were opposite.

Table 3

Means, Standard Deviations, and Range of ANLs with Different Frequencies

	Earphone				Sound field			
	White		Babble		White		Babble	
	HIGH	LOW	High	Low	HIGH	LOW	High	Low
Ave	5.04	3.79	5.45	6.77	5.65	6.34	10.01	6.93
SD	5.46	4.45	5.18	4.18	2.61	2.48	1.99	2.25
Range	(-7.28) - 19.01	(-4.943)- 18.06	(-4.14) - 19.95	0.37- 19.93	(-0.86)- 10.76	3.11- 13.06	6.06- 14.30	3.96- 12.96

The descriptive results are plotted as shown in Figure 11. The graphical plots show that participants accepted more background noise under low frequency bandwidth when listening to signal through the earphones. This made the ANL smaller compared with ANLs of other researches. The blue bars represent high frequency bandwidths and the red bars represent low frequency bandwidth. More detailed data collected with different background noises under different listening modes is shown in Table 4.

When babble noise was the background, Figure 12 shows that high frequency under sound field listening conditions have the highest ANL values. On the other hand, high frequency under earphone conditions was found to have the lowest ANL values while low frequency conditions under the two listening situations had lower ANL values. It was observed thata listener at high frequency noise level in a sound field situation had more masking effect than at a low frequency noise level for babble noise.

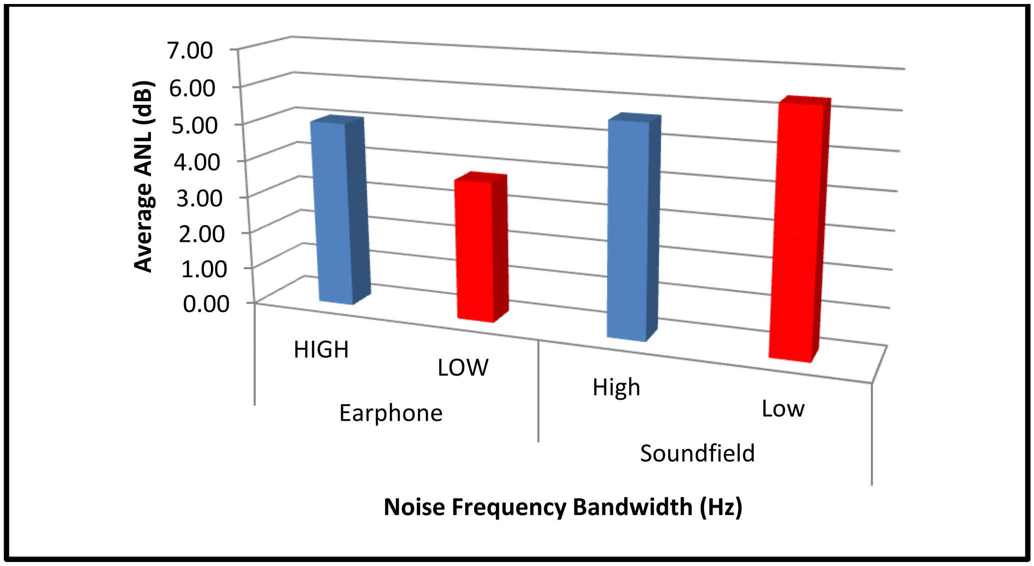


Figure 11. Mean ANLs for white noise under both conventional and earphone listening conditions and error bars with percentage.

Table 4

Average ANLs (dB) for each Participant for High and Low Frequencies for All Participants

Earphone				**Sound field**			
White		Babble		White		Babble	
High	Low	High	Low	High	Low	High	Low
2.251	3.233	2.518	5.128	4.745	4.363	8.461	5.014
3.215	1.353	2.650	2.169	6.309	6.225	9.404	6.453
4.378	4.601	4.936	6.978	10.308	9.932	14.252	10.708
5.433	4.760	5.415	7.105	4.908	5.134	9.198	5.187
-1.096	-0.720	-0.385	2.202	3.646	3.119	7.983	4.040
5.472	5.397	5.746	7.955	7.684	7.304	12.065	8.093
9.301	6.825	10.347	11.586	7.749	9.018	12.383	9.997
1.144	1.520	1.856	4.457	7.366	6.837	11.854	7.911
12.938	8.220	13.583	8.924	4.757	8.112	8.839	8.602
3.879	3.813	3.876	6.264	5.055	4.673	8.907	5.032
9.894	-0.998	7.579	4.898	-0.860	6.862	6.065	7.777
4.996	3.745	4.745	5.119	10.343	10.714	13.467	10.935
6.032	6.561	6.604	8.953	7.045	6.216	10.399	7.283

Table 4

(Cont.)

Earphone				Sound field			
White		Babble		White		Babble	
High	Low	High	Low	High	Low	High	Low
-7.278	-4.943	-4.141	0.370	-0.346	4.207	6.686	5.649
5.993	5.773	6.427	8.769	5.225	5.141	9.273	5.807
0.903	1.877	1.600	5.027	4.718	4.044	9.419	4.951
3.879	3.813	3.876	6.264	5.055	4.367	9.179	5.032
-0.474	-0.388	0.405	2.049	5.508	5.132	10.132	6.053
15.963	5.237	14.771	9.000	6.677	10.765	10.588	8.563
19.011	18.059	19.947	19.934	10.761	13.064	14.301	12.956
2.111	2.489	2.830	5.260	5.183	4.203	9.339	5.270
2.528	-2.204	3.151	3.111	3.220	3.591	7.978	3.958
-0.422	-1.099	-0.294	2.078	6.638	7.003	10.896	7.683
0.763	0.831	1.460	4.191	4.571	4.352	9.438	4.960
11.860	10.435	12.892	15.228	4.176	5.145	9.855	5.971
4.352	4.428	4.771	7.243	4.908	4.981	9.062	5.479
6.592	6.819	7.456	9.756	6.124	5.444	10.188	6.226
7.520	6.547	8.107	9.467	6.809	7.624	10.581	8.311

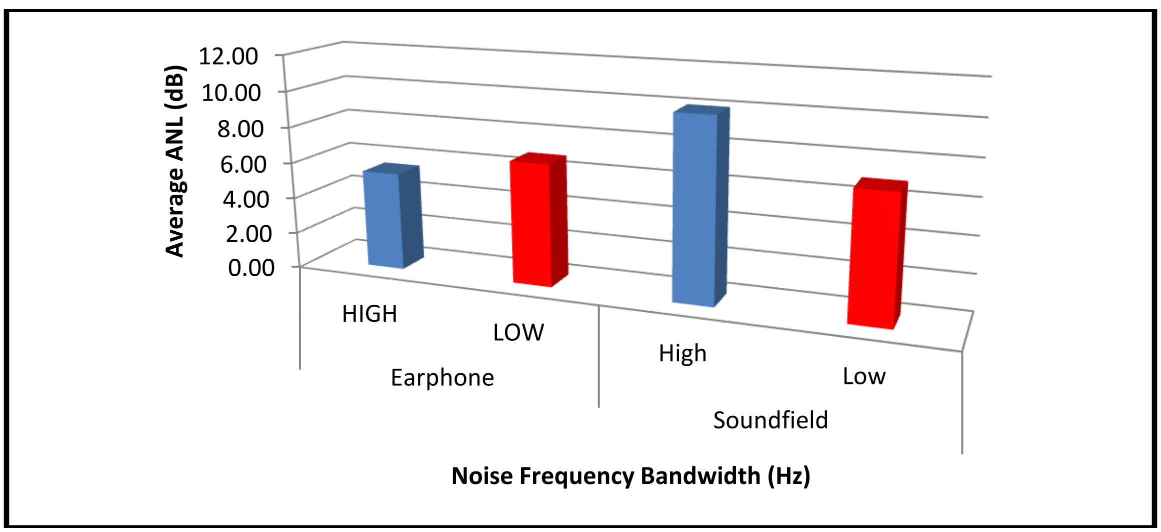


Figure 12. Mean ANLs for babble noise under both conventional and earphone listening conditions.

The study revealed that participants have lower ANL values under low and high frequency conditions when listening to signals through earphones than when the signal was played through the sound field. Figure 13 is used to illustrate these results. The results indicate that participants accepted more background noise under earphone conditions when compared with sound field conditions.

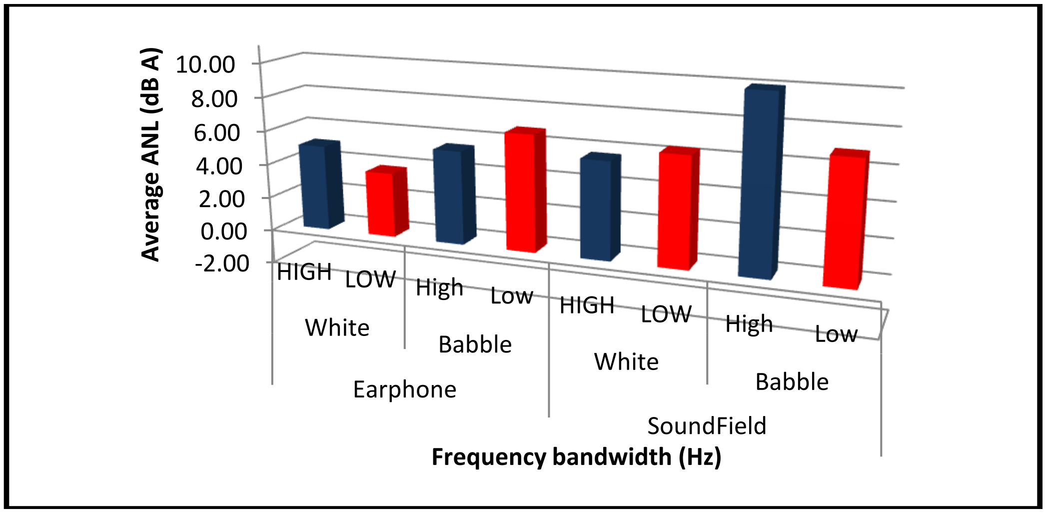


Figure 13. Mean ANLs for both conditions across the four different background noise frequencies. Low ANL scores represent better tolerance to background noise than high ANL scores.

The percentage differences of ANL across frequency levels are shown in Table 5. The average ANL for high frequency was found to be 5.8% lower compared with low frequency background noise under sound field listening condition with white noise in the background. When babble noise was the background noise, the ANL values averaged approximately 14% higher for high frequency than during the low frequency condition.

Under the earphone listening condition with white noise in the background, ANL average values averaged approximately 18% higher for high frequency compared with low frequency background noise. For babble noise, the ANL average value for high frequency was found to be approximately 10% lower compared with low frequency background noise. The variations in the ANL values indicated that there were differences in the level of background noise that participants were willing to accept without being tensed or fatigued. The statistical significance in the differences was calculated.

Table 5

Percentage Differences of ANL across Frequency Level

Signal Source	Noise	Freq. Level	Relationship in %	Direction
Sound field	White	High Low	5.8%	High < Low
Earphone	White	High Low	14%	High > Low
Sound field	Babble	High Low	18%	High > Low
Earphone	Babble	High Low	10%	High < Low

Statistical Analysis Software (SAS Institute Inc., 2010) using 2^k factorial design (with k = 3 factors) was used to assess if there were statistically significant differences within the main effects and any interactions between the signal sources, the noise types and the noise frequency levels. Prior to the analysis, model adequacy checks were performed to test for the three ANOVA assumptions of normality, independence, and homogeneity of variance. If the original data violates any of the assumptions, an appropriate transformation is applied to the data until all the assumptions are met. Model adequacy was analyzed using SAS software. The test for normality showed that the dataset for high frequency bandwidth white noise with earphones were normally distributed with Shapiro-Wilk, $W = 0.962$, $p = 0.401$; with Anderson-Darling, $A^2 = 0.479$, $P = 0.216$. Dataset for low frequency bandwidth white noise with earphones were normally distributed with Shapiro-Wilk, $W = 0.939$, $p = 0.117$; with Anderson-Darling, $A^2 = 0.436$, $P = 0.277$. Dataset for high frequency babble noise under earphone signal listening conditions were normally distributed with Shapiro-Wilk, $W = 0.946$, $p = 0.169$; Anderson-Darling, $A^2 = 0.580$, $P = 0.119$. Dataset for low frequency babble noise under earphone signal listening conditions were normally distributed with Anderson-Darling, $A^2 = 0.592$, P = 0.112; with Lilliefors test $D = 0.134$, $p = 0.242$. Dataset for high frequency white noise under sound field signal listening conditions were normally distributed with Shapiro-Wilk, $W = 0.927$, $p = 0.06$ with Lilliefors test $D = 0.152$, $p = 0.114$. Dataset for high frequency babble noise under sound field signal listening conditions were normally distributed with Shapiro-Wilk, $W = 0.949$, $p = 0.197$. A statistically significant difference was found between signal sources ($p = 0.0001$). This suggested that signal sources play a significant role in the level of background noise that participants were willing to accept without being tired when listening to speech in a quiet condition.

A significant difference was also found in noise type ($p < 0.0001$). This means that there is a difference between white and babble noise under both sound field and earphone signal listening conditions. The results suggested that noise type also plays a vital role in the level of noise that the participants can accept when listening to a speech in a noisy environment. This finding compliments the Nabelek et al. (1991) study which showed that ANLs are related to the type of background noise distraction.

As shown in Table 6, no statistically significant main effects were found between background noise frequency level, that is between low and high frequency bandwidth ($p = 0.2521$). However, a significant interaction was found between the signal source, noise types and the noise frequency levels ($p = 0.0021$). The results of the analyses revealed that there were no statistically significant interactions between noise types and the signal sources, noise frequency level and the signal sources and the noise types and the noise frequency levels.

A post hoc test using Tukey revealed that the participants accepted more background noise when listening to signal via earphone condition than via sound field listening.

Table 6

Output of ANOVA Test for Signal Source, Noise Type, and Noise Level ANOVA

Source of Variations	DF	SS	MS	*F*	*p*
Signal _Source	1	217.278	217.278	15.00	0.0001
Noise_Type	1	243.039	243.039	16.78	< 0.0001
Noise_Frequency_level	1	19.100	19.100	1.32	0.2521
Signal_source*Noise_Type	1	8.312	8.312	0.57	0.4495
Signal_source*Noise_Frequency_level	1	21.010	21.010	1.45	0.2297
Noise_Type*Noise_Frequency_level	1	5.060	5.060	0.35	0.5551
Signal_source*Noise_Type*Noise_Freq_Level	1	140.625	140.625	9.71	0.0021

Interaction occurs among signal source, noise type and noise frequency level. This means that one or more 2-way interactions differ across the levels of a third variable. Therefore, an interaction plot was graphed with Excel 2010®. Figure 14 shows the interaction plots between the signal source, noise types and the noise frequency levels.

Further statistical analysis was conducted on the interaction between signal sources, noise type, and noise frequency levels effect sliced by noise types and noise frequency level for ANL. Least squares mean results showed that statistically significant interaction existed between the three independent variables, and it occurred when the background noise was babble noise at high frequency ($p < 0.0001$). Likewise, statistically significant interaction existed at low frequency level with white noise in the background ($p = 0.0127$). Table 7 shows the ANOVA results from the SAS output. When sliced by signal sources and noise frequency level, ANOVA results revealed a statistically significant effect with earphones at low noise frequency ($p = 0.0037$).

Significant difference also occurred when the signal was delivered with the sound field method at noise high frequency level ($p < 0.0001$). The ANOVA results are shown in Table 8. When sliced by signal sources and noise type, ANOVA results allowed for the conclusion that a statistically significant effect with sound field with babble noise in the background existed. The P-value is 0.0027. The ANOVA results are shown in Table 9.

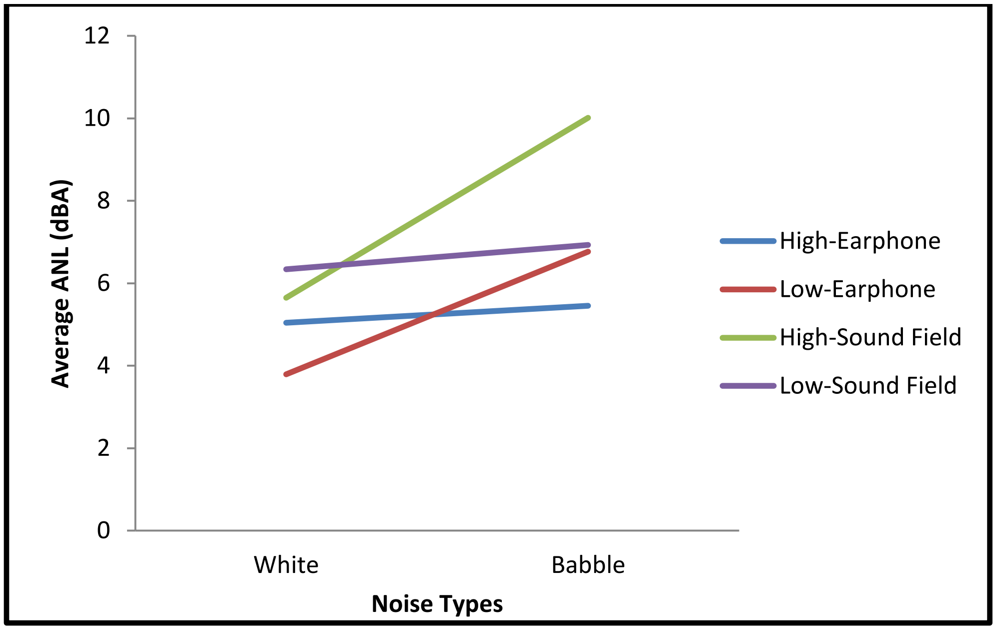


Figure 14. Interaction plots of frequency effects on ANL.

Table 7

Noise Types and Noise Frequency Level Effect Sliced by Noise Type and Noise Frequency Level for ANL

Noise type	Noise level	*df*	*SS*	*MS*	*F*-Value	*Pr* > *F*
Babble	High	1	290.114	290.114	20.03	<0.0001
Babble	Low	1	0.3488	0.3488	0.02	0.8768
White	High	1	5.2498	5.2498	0.36	0.5478
White	Low	1	91.5109	91.5109	6.32	0.0127

Table 8

Noise Types and Noise Frequency Level Effect Sliced by Signal sources and Noise Frequency Level for ANL

Signal Sources	Noise level	*df*	*SS*	*MS*	*F*-Value	*Pr > F*
Earphone	High	1	2.397	2.397	0.17	0.6884
Earphone	Low	1	124.5	124.5	8.6	0.0037
Sound field	High	1	265.373	265.373	18.32	<0.0001
Sound field	Low	1	4.763	4.763	0.33	0.5669

Table 9

Noise Types and Noise Frequency Level Effect Sliced by Signal sources and Noise Type for ANL

Signal Sources	Noise Type	*df*	*SS*	*MS*	*F*-Value	*Pr > F*
Earphone	Babble	1	24.122	24.122	1.67	0.1982
Earphone	White	1	22.069	22.0692	1.52	0.2184
Sound field	Babble	1	132.957	132.957	9.18	0.0027
Sound field	White	1	6.641	6.641	0.46	0.499

The main effects sliced by one variable at a time were also studied. The observed ANOVA results revealed a significant difference at high noise frequency level (p < 0.0001) and at low noise frequency level (p = 0.0068). When sliced by noise type for ANL, babble noise effect was found to be significant (p = 0.0001), while white noise effect was not significant (p = 0.0804). When sliced by signal source for ANL, earphone effect was found to be significant (p = 0.0349); furthermore, sound field effect was significant (p = 0.0001).

4.8 Psychophysical Results

The psychophysical models in Chapter 3 were used to analyze the data. Regression analyses were performed using the model: $MCLL = cd'^{\beta}$ as described in Chapter 3, that is

$\log MCLL = \log c + \beta \log d'$. The same model was applied to BNL data. The data used is given in Appendix C. The normality test showed that MCLL dataset were normally distributed with the Shapiro-Wilk test, $W = 0.953$, $p = 0.380$. The dataset for listeners' d' were normally distributed with the Shapiro-Wilk test, $W = 0.971$, $p = 0.766$. Table 10 shows the results obtained from the regression analysis on MCLL when earphones were the signal source, under high frequency noise and with white noise in the background.

Table 10

Parameter Estimates for MCLL, c_1, and β_1 under Earphone-High-White Condition

Variable	*df*	Parameter Estimates	*SE*	*t*-Value	Pr > |t|
Intercept	1	1.604	0.003	599.36	< 0.0001
Slope(β_1)	1	0.213	0.012	17.84	< 0.0001

The R^2 for the regression analysis was found to be 94%. From Table 10, linear equation 29 was deduced for the relationship between the logarithm of MCLL and the d'.

$$\log MCLL = 1.60402 \log d' + 0.21286 \quad (29)$$

The values of log c_1 and β_1 were calculated from the observed data and the results were 1.60402 and 0.21286, respectively.

The Shapiro-Wilks' test for normality showed a normally distributed BNL dataset with $W = 0.931$, $p = 0.163$. The Normality test for the listeners' d' indicated that the dataset was normal with the Shapiro-Wilks test $W = 0.971$, $p = 0.766$. Table 11 summarizes the results obtained for background noise from the regression analysis, when the earphone was the signal source, under high frequency noise and with white noise in the background.

Table 11

Parameter Estimates for BNL c_2, and β_2 under Earphone-High-White Condition

Variable	*df*	Parameter Estimates	*SE*	*t*-Value	Pr > |t|
Intercept	1	1.600	0.003	510.26	< 0.0001
Slope(β_1)	1	0.039	0.009	4.54	0.0001

The R^2 for the regression analysis was found to be 45% and the model is shown in Equation 30.

$$\log BNL = 0.038641 \log d' + 1.60041 \tag{30}$$

The values of $\log c_2$ and β_2 were calculated to be 1.60041 and 0.03864 respectively.

With $\log c_1$ = 1.60402, β_1 = 0.21286, $\log c_2$ = 1.60041, β_2 = 0.03864. From Equation 27a of the models derived in Chapter 3,

$$\log ANL = (\log c_1 - \log c_2) + (\beta_1 - \beta_2) \log d'$$

$$\log ANL = (1.60402 - 1.60041) + (0.21286 - 0.03864) \log d'$$

$$\log ANL = 0.17422 \log d' + 0.00361 \tag{31}$$

Similar procedures were followed and the corresponding c, β and R^2 values under each condition used in this hypothesis were determined. The corresponding c-values, β-values, R^2 values, and psychophysical ANL regression equations are shown in Table 12.

The standard errors and the proportions of the total variation in the values of logANL(R^2) between the predicted ANL from the psychophysical models and the measured ANLs under different listening conditions are shown in Table 13. The graphical illustration is shown in Appendix D.

Table 12

Psychophysical ANL Regression Equations, c-values, β-values and the Corresponding R-squared Values under Different Conditions Tested

		Earphone			
		White-Noise		Babble-Noise	
		High	Low	High	Low
	Regression	logANL= 0.174logd' + 0.0036	logANL= 0.148logd' + 0.0167	logANL=0.208logd' + 0.0300	logANL= 0.155logd' + 0.0011
	logc	1.604	1.613	1.599	1.591
MCLL	β	0.213	0.184	0.224	0.172
	R^2	94%	70%	90%	71%
	logc	1.600	1.597	1.569	1.590
BNL	β	0.039	0.037	0.016	0.018
	R^2	45%	43%	44%	41%
		Sound field			
		White-Noise		Babble-Noise	
		High	Low	High	Low
	Regression	logANL=0.136logd' + 0.013	logANL=0.128logd' + 0.015	logANL=0.1869logd' – 0.1576	logANL= 0.0354logd' + 0.736
	logc	1.662	1.654	1.051	1.648
MCLL	β	0.162	0.190	0.072	0.186
	R^2	56%	92%	72%	89%
	logc	1.648	1.638	1.208	0.912
BNL	β	0.027	0.062	-0.115	0.151
	R^2	39%	48%	44%	32%

Table 13

Standard Errors between the Predicted ANL and the Measured ANL

Condition	Standard Error	R-Squared
EHW	0.3374	0.5478
ELW	0.265	0.59
EHB	0.2869	0.6308
ELB	0.453	0.0558
SHW	0.1392	0.8144
SLW	0.0279	0.964
SHB	0.0127	0.98
SLB	0.0219	0.9731

*EHW = Earphone high frequency white noise, ELW = Earphone low frequency white noise, EHB = Earphone high frequency babble noise, ELB = Earphone low frequency babble noise, SHW = Sound field high frequency white noise, SLW = Sound field low frequency white noise, SHB = Sound field high frequency babble noise, SLB = Sound field low frequency babble noise.

Table 14 shows the listeners' discriminability biases toward the different background noise under different frequency bandwidths at the different signal listening conditions.

Table 14

Participants Discriminability Bias (β) toward Both Noise and Signal under ANL

	Bias Toward Noise				Bias Toward Signal			
	Earphone		Sound field		Earphone		Sound field	
	High	Low	High	Low	High	Low	High	Low
White	0.03864	0.03651	0.02684	0.06190	0.21286	0.18370	0.16234	0.18956
Babble	0.01649	0.01760	-0.11540	0.15080	0.22424	0.17213	0.07152	0.18615

Table 15 shows the differences in the listeners' discriminability biases calculated with the psychophysical ANL model between signal and background noise when listening through earphones and through sound field means. The data in Table 15 shows that approximately 33%

of the listeners preferred earphones as a means of listening to sound under high frequency background white noise.

Table 15

Participant Discriminability Bias (β) toward Signal Source in the Determination of the Intensity of Experienced ANL

	White-High	White-Low	Babble-High	Babble-Low
Earphone	0.1742	0.1479	0.2078	0.1545
Sound field	0.1360	0.1280	0.1869	0.0354

Listeners had approximately 14% discriminability bias toward listening to the speech signal through sound field means than they did through the earphones when the background noise was white noise with high frequencies. This is the percentage difference between the listeners' discriminability bias when signal was delivered through sound field and through earphones. Under the babble background noise at high frequency, listeners had approximately 52% discriminability bias toward listening through sound field means than listening through earphones. Lastly, listeners had approximately 14% discriminability bias toward listening to signals through the earphones than they did through the sound field means.

Figure 15 graphs the discriminability bias for listeners toward background noises at different frequencies when listening to a speech through earphones. Figure 16 graphs the discriminability bias for listeners toward background noises at different frequencies when listening to a speech signal through sound field methods.

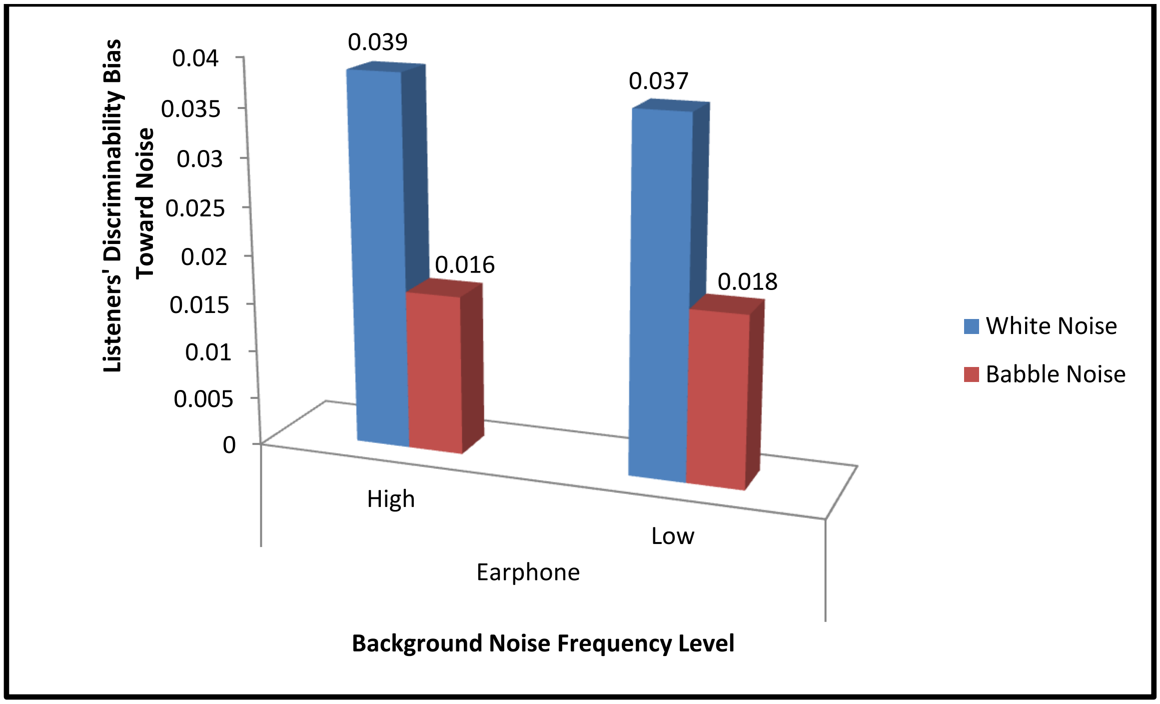


Figure 15. Relationship between listeners' discriminability bias toward noise intensity when the signal is presented through earphones

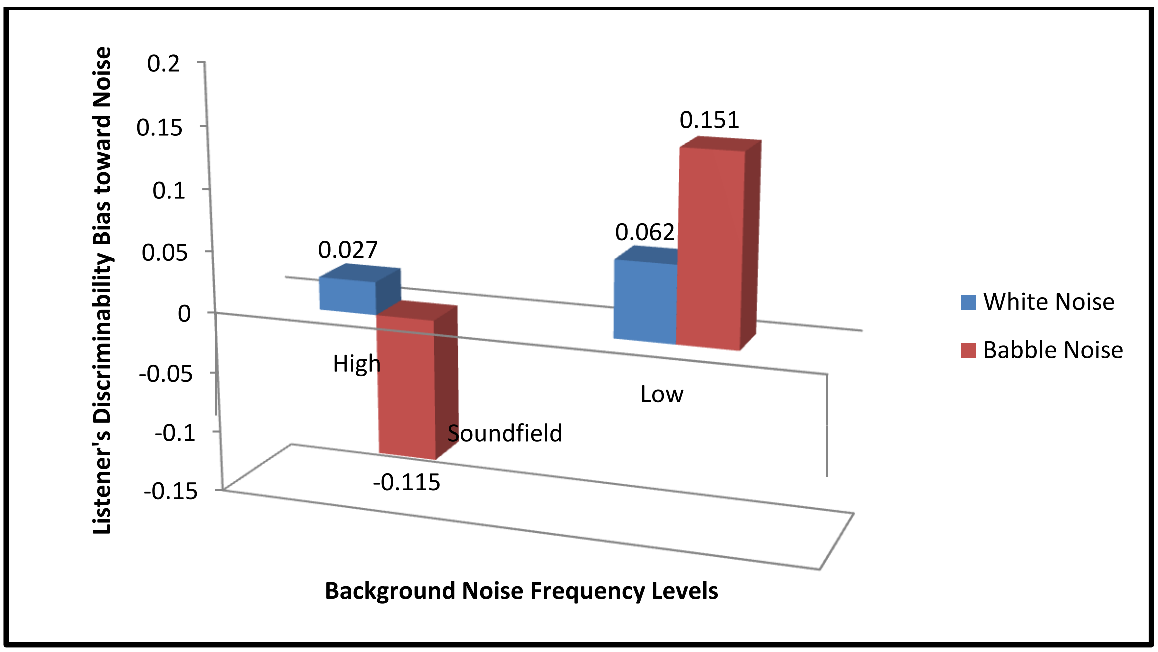


Figure 16. Relationship between listeners' discriminability bias toward noise intensity when the signal is presented via sound field.

From the graphical illustration in Figures 15 and 16, it can be observed that the listeners had higher positive discriminability bias toward white noise, both at high and low frequencies when the signal was delivered through the earphones. This indicated that when listening to speech signals in a noisy condition, the listeners were likely to tolerate white background noise of any frequency as much as they would tolerate babble noise. This made the listener discriminability biases toward the babble noise to be a little higher than that of white noise. Different trends were observed when the speech signal was delivered through sound field means. With the high frequency, the listeners' discriminability biases toward the white noise were found to be positive from Figure 16. While at high frequency listeners' discriminability bias toward babble noise was found negative and positive toward low frequency. This means that listeners had low tolerance toward babble noise at high frequency and high tolerance at low frequency. At low frequency, listeners had more positive discriminability bias toward listening to babble noise compared with listening to white noise. This means that listeners had more tolerance of the white noise.

Figure 17 presents the relationship of listeners' discriminability bias toward the speech signal at different background noise frequencies when the speech signal was delivered through earphones. It is shown in figure 17 that listeners had more positive discriminability bias toward speech signal when the background distraction noise frequencies were high and less at low frequency for babble noise than for white noise. This indicated that under the distraction of high frequency babble background noise, listeners increased the level of speech signals that they accepted.

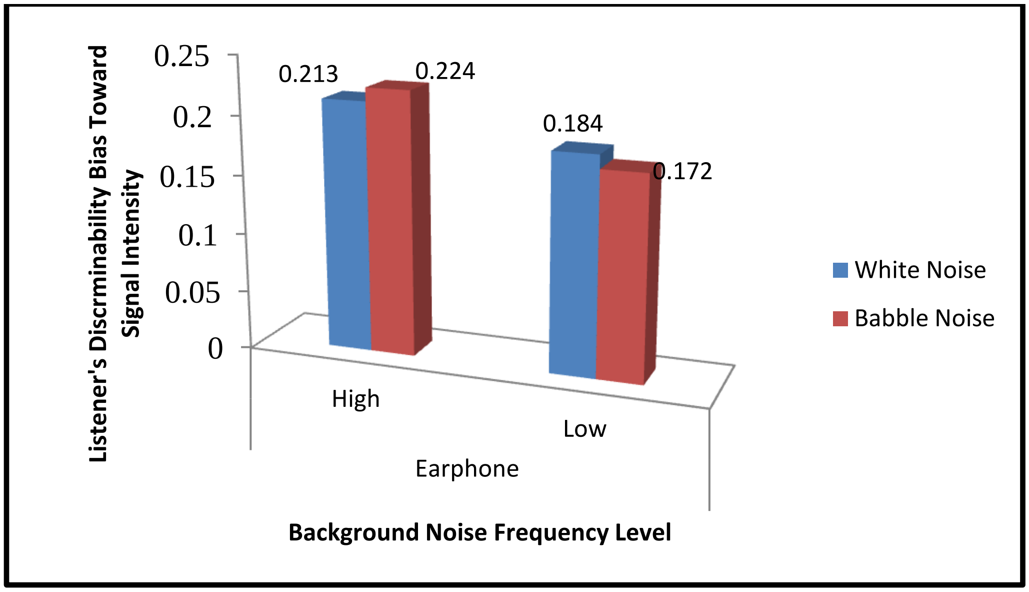


Figure 17. Relationship between listeners' discriminability bias toward speech signal intensity when it was delivered through earphones under different background noise frequencies.

Figure 18 presents the relationship of listeners' discriminability bias toward the speech signal at different background noise frequencies when the speech signal was delivered through sound field means.

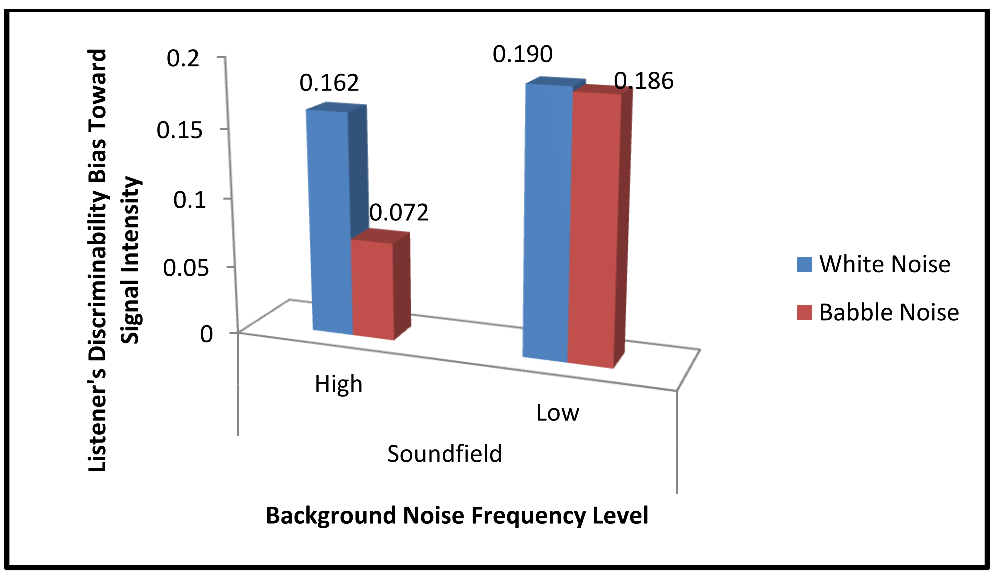


Figure 18. Relationship between listeners' discriminability bias toward speech signal intensity when it was delivered through sound field under different background noise frequencies.

Graphically, no difference was noticed in Figure 18 on the discriminability bias for the speech signal under low frequencies between white noise and babble noise when the speech signal was delivered through sound field means. At high frequency, listeners had higher positive discriminability bias toward white noise than they did for babble noise.

To illustrate the implication of log c in the equations, the logarithm of ANL values and the logarithm of d' were graphed against each other. The intercepts on logANL give the constant values denoted by logc in the model. As shown, each intercept value represents logc or the minimum threshold ANL (MANL) under different experimental conditions. The values of **c** are in parenthesis.

Table 16

Predicted MANL Threshold under Experimental Conditions as a Function of d'

Condition	Earphone	Sound field
White, high frequency	0.00361(1.008)	0.013 (1.030)
White Low Frequency	0.0167 (1.039)	0.015 (1.035)
Babble, high frequency	0.0300 (1.072)	-0.1576 (0.696)
Babble Low Frequency	0.0011 (1.003)	0.736 (5.445)

Figure 19 illustrates the relationship between participants' computed ANL and the computed sound discriminability. It is shown in the graphical relationship that as the participants' computed sound discriminability increases, so did the computed ANL.

A paired *t*-test on the predicted minimum ANL threshold was conducted on the listeners' minimum ANL threshold regardless of the noise type and the frequency levels. Results of the *t*-test showed no statistically significant difference between listening through the earphones and through the sound field method ($p = 0.5448$).

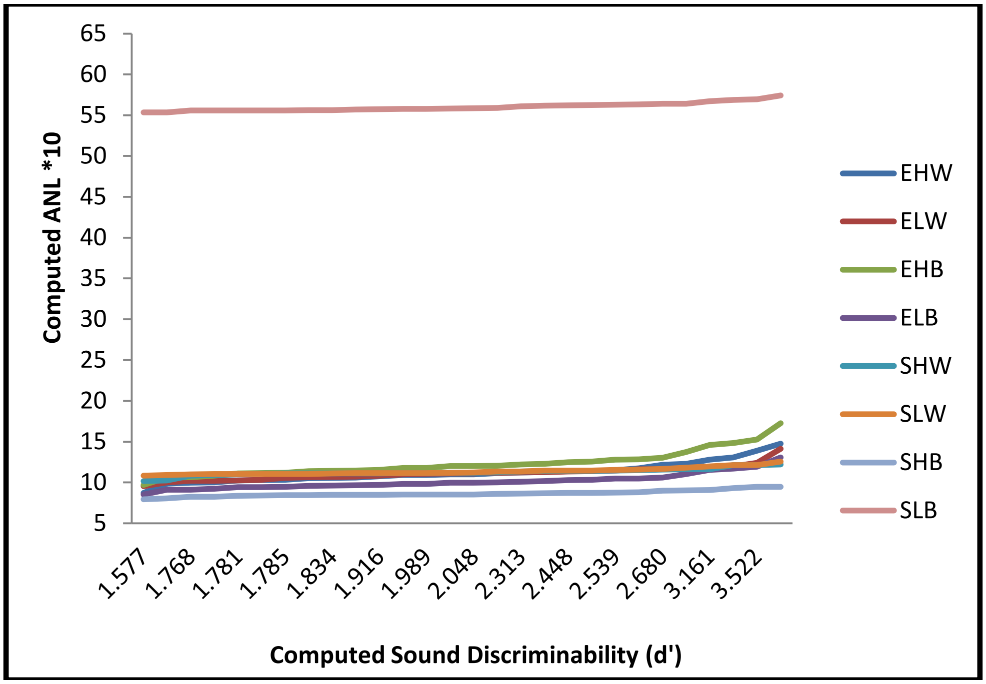


Figure 19. Relationship between computed ANL and the computed sound discriminability

A paired *t*-test on the predicted minimum ANL threshold was conducted to investigate the differences in noise frequency bandwidths based on minimum ANL thresholds. Results of the *t*-test showed that there is no statistically significant difference between high frequency bandwidth and low frequency bandwidth at an alpha level of 0.05 (p = 0.3999).

Listeners' discriminability biases (β) toward sound were compared between listeners' responses when the signal was delivered through the earphones and through sound field methods. The results of the paired t-test predicted data showed that there was no statistically significant difference between earphone and sound field methods (p = 0.5524).

4.9 Discussion on the Effects of High Frequency Bandwidth on ANL

4.9.1 The effect of signal source on ANL. The results clearly showed that participants had lower ANLs when the signal source was delivered through earphone conditions and higher ANLs when signal source was via a sound field method. This means that signal sources have significant effects on participants' ANL. Participants tended to accept more signal levels as comfortable when the source was via loudspeaker (sound field); meanwhile the reverse was the case when the signal source was via earphones. This contributed to the significant effect shown in participant ANL values because of the signal sources.

4.9.2 The effect of frequency bandwidth on the ANL. The results clearly showed some differences in values of ANL obtained when high frequency bandwidth was used and those obtained during the use of low frequency bandwidth. ANL values were found to be 1.07 dB higher for high frequency white noise, 1.32 dB higher for low frequency babble noise under earphone listening condition, and 0.69 dB higher for low frequency white noise, and 3.08 dB higher for high frequency babble noise under sound field listening conditions. Statistically, noise frequency bandwidth levels showed significant effects on ANL.

4.9.3 The effects of background noise type on ANL. The results showed that ANL recorded with babble noise was found higher than that recorded with white noise by 3.39 dB under earphone listening condition. Under sound field listening condition, the ANL recorded with babble noise was also found higher by 4.95 dB than that measured with white noise in the background. Statistically, the effect of babble noise was found significant while the effect of white noise on ANL was not statistically significant.

4.9.4 The effect of the interaction between independent variables on ANL. The results showed no significant interaction in the relationship between different combinations of the two independent variables. The effect of the interaction within the three variables was found significant. The signal sources were varied with the noise types to study the sources of the significant effect on ANL. The ANOVA results revealed that a significant effect occurred when the signal was delivered through sound field with babble background noise. Other combination effects were not statistically significant. When noise type and noise frequency level were varied with constant signal sources, the effects on ANL were statistically significant with babble noise at high frequency level and with white noise at low frequency level. ANOVA results also revealed statistically significant effects with earphones at low frequency level and with sound field at high frequency level when noise type was left constant.

4.9.5 Meta-analysis with psychophysical parameters. The results of the ANL model showed that listeners had higher positive discriminability bias to sound (meaning higher tolerance) toward speech signals when listening through earphones under both white and babble background noise distraction at high frequency bandwidths. The results showed that the listeners had high negative discriminability bias of sound toward babble noise at high frequencies, when the signal was delivered through the sound field. With the low frequency, listeners' discriminability bias toward babble noise was found to be positive. Different ANL thresholds were found in the results under different conditions. The minimum MANL was noticed when the listeners heard the speech signal through sound field (loudspeaker) means with babble noise in the background at high frequency. The maximum MANL value of 5.445 dBA was noticed when the signal was delivered with earphones with babble noise in the background at low frequency. MANL represents the point people begin to accept the presence of noise. The results also revealed that as the listener's sound discriminability (d') increased, so did the ANL.

The results of the paired t-test on the participants' MANL showed no significant difference when the signal was delivered through earphones and when it was delivered through sound field methods. Likewise, the t-test results on listener' discriminability biases toward signal revealed that there was no significant difference between listening through earphones and through the sound field methods.

4.10 Summary

This section investigated the effects of noise frequency bandwidths on ANL. Findings are as follows:

1. Statistically, a significant main effect of background noise frequency levels on ANL was found.
2. Babble noise effect was significant, while white noise effect was not.
3. Signal sources effects on ANL were found to be statistically significant.
4. No statistically significant interactions existed between any of the two independent variables.
5. There was a statistically significant interaction among the three independent variables.
6. Signal sources and noise type effects on ANL were found to be significant when listening through the sound field under babble noise background distraction.
7. Noise type and noise frequency level effects on ANL were found to be statistically significant with babble noise at high frequency and with white noise at low frequency.
8. Signal source and noise frequency level effects on ANL were found to be statistically significant with earphones at low frequency background noise and with sound field at high frequency background noise.
9. Background noise types and noise frequency bandwidths can predict the listener's discriminability bias toward the noise and toward the signal intensity.
10. Different listening conditions had different MANL thresholds.
11. No significant difference existed between listeners' MANL threshold when listening through earphones and when listening through the sound field methods.

12. No significant difference existed in discriminability bias between listening through earphones and through the sound field methods.
13. The results also revealed that as the listener's sound discriminability (d') increased, so did the ANL.

CHAPTER 5

Effects of Listening Modalities and Loudspeaker Locations on ANL (Study II)

This chapter investigates hypothesis two stated in Chapter 1. The hypothesis states that there will be no significant differences in listeners' ANL when noise loudspeakers are located at different angles.

5.1 Effects of Loudspeakers Location on ANL

The loudspeaker location is an important cue for the listener's speech understanding with background noise. Research has shown that listeners better understand speech when it is presented in front of them at their standing or sitting position (i.e., at 0^{o} azimuth). Ahlstrom, Horwitz, and Dubno (2009) conducted a study on ANL and evaluated the spatial benefit of bilateral hearing aids. The study centered on the effects of the noise source location on ANL. In the study, speech sentences and multi-talker babble noise were presented at 0° azimuth (i.e., spatially coincident) or 90° (i.e., spatially separated) azimuth. Ahlstrom et al. (2009) showed that participants tolerated more babble noise when the multi-talker babble noise and speech signal were spatially separated. In other words, ANLs varied according to the location of the noise source (0° versus 90°).

Several research studies have justified the effects of speaker location on listeners' speech understanding. However, not much research has been done to study the effects of loudspeaker location on the level of background noise that a listener can tolerate. The hypothesis states that average ANLs recorded at different loudspeakers location will not be significantly different from one another (i.e. the average ANL at all loudspeaker positions will be equal). The alternative hypothesis is that at least on the average, the ANL recorded at one loudspeaker location will be different from the others at a 0.05 level of significance.

Four loudspeakers were used to deliver the background noises, one at a time, while only one loudspeaker delivered the signal. Based on the set up, the experimental design employed for this session of the study is a repeated measure design. The independent variables are the loudspeaker locations (four levels), and the dependent variable is the ANL value. Table 17 shows the experimental design used.

Table 17

Experimental Design for Loudspeaker Locations

	Loudspeaker Locations			
Subject #	45 Degree	180 Degree	225 Degree	315 Degree
1				
2				
3				
..				
n				

5.2 Participants

The minimum sample size was calculated based on the *F*-test formula from the Engineering Statistic Handbook by the U.S. Commerce Department (2010). This formula is shown in Equation 37 with $\alpha = 0.05$, $\beta = 0.2$, $\sigma = 7.9$, and $d = 7.5$; n was calculated to be 16.

$$n = \left(Z_\alpha + Z_\beta\right)^2 \left(\frac{\sigma}{d}\right)^2 \qquad (37)$$

The minimum sample size was found to be 16; however, 23 subjects (11 males and 12 females) participated in the study. All the participants were students from different departments at NC A&T State University. Participant recruitment was done through flyers approved by the University's IRB office and posted across the university and by personal acquaintances. The age of the participants ranged from 18 to 43 years (*M* = 24 years, *SD* = 6.7); they had normal hearing measured at the intensity of 25 dB HL (hearing level) at octave frequencies in the 250 Hz to 4000 Hz frequency range.

The American Speech-Language-Hearing Association (ASHA, 1997) recommends a screening level of 25 dB HL from 1000 through 4000 Hz for an adult hearing screening. The American National Standards Institute (ANSI, 1989), however, requires a stronger criteria, a screening level of 20 dB HL from 250 to 4000 Hz for adults. Tye-Murray, Sommers, and Spehar (2007) screened participants in their speech reading study at a level of 20 dB HL from 250 to 4000 Hz. All participants spoke and understood the English language and were able to follow the speech presented without any difficulty. None had an active speech and language disorder or neurologic disorder. The selection criteria were similar to that of experiment I, and all participants signed a statement of informed consent approved by the University IRB before the experiment commenced.

5.3 Method

Multi-talker babble noise stimulus was used. The multi-talker babble noise cutoff frequency is 1000 Hz with Rolloff 6 dB per octave as shown in the spectrum plot shown in Figure 20.

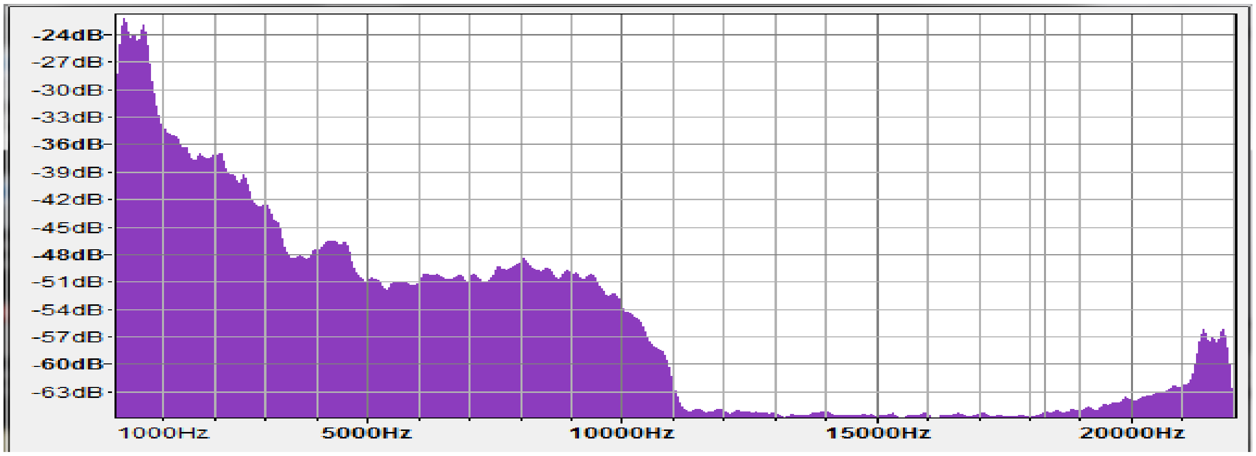


Figure 20. Spectrum plot using Hanning window at 6dB with cutoff frequency 1000 Hz.

The experiment was divided into four stages. In each stage, only one loudspeaker delivered background noise at a time. Noise loudspeakers were positioned at 45, 180, 225, and 315 degrees azimuth; three feet away from the listener's seated position (see Figure 21). The signal loudspeaker was positioned at 0 degrees azimuth; three feet away from the listener's seated position.

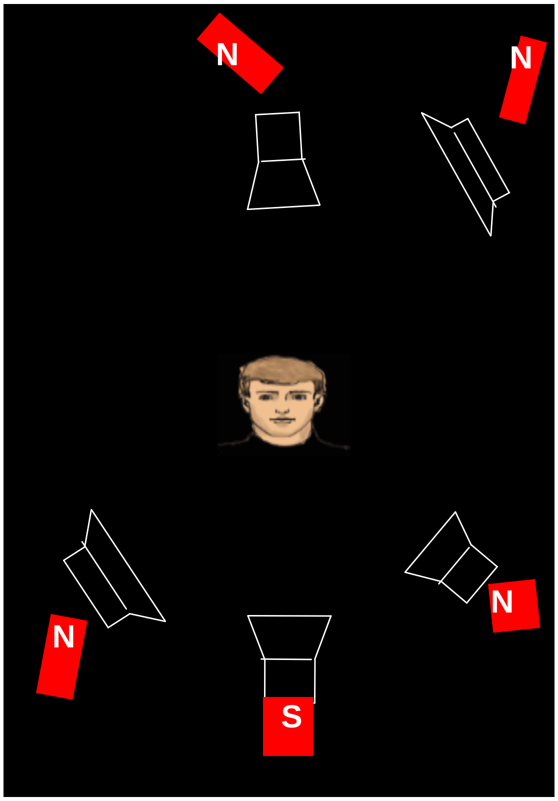


Figure 21. Experimental set-up for experiment II

5.4 Materials

Five loudspeakers were used; four loudspeakers delivered the noise (one at a time), and one delivered the signal. An audiometer was used for the hearing screening, and a sound level meter was used for the sound intensity calibration. Other materials included a magazine, a push button cord, one type of noise (multi-talker babble noise) and four comedian speech signals

(“Bar Jokes,” “Complimentary Peanuts,” “Mad Cows & Udder,” and “Are There Golf Courses in Heaven?). Participant selected a signal type one at a time.

5.5 Procedure

Study II was conducted to determine the effect of the loudspeaker location on ANL. Prior to the start of the experiment and before the arrival of the participants, the noise and the signal files were opened on the computer. The audiometer was set up, and all loudspeakers for noise and signal in the acoustic chamber were prepared. Loudspeaker tests on the signal and the noise were conducted in advance to ensure that all loudspeakers would work flawlessly. Once participants arrived, they were welcomed and briefed about the purpose of the experiment and introduced to the experimental station. Participants who agreed to proceed with the experiment were given an informed consent form to sign and a pre-test hearing screening form to fill out the demographic portion. Next, participants’ tasks during the hearing screening were explained by the researcher. Participants were asked to push a button to respond to every tone they heard, and to do nothing if no tone was heard. To begin the hearing screening test, each participant was asked to sit at the center of the acoustic booth with headphones on and a push button provided by the researcher. Participant responses were recorded on their hearing screening form. The hearing screening was conducted on the participant in both ears at 25 dB for octave band at frequencies between 250 and 4000 Hz. Using pure tone, the hearing screening was conducted to ensure that all participating listeners had normal hearing. The audiometric testing was performed using a Fonix Hearing Evaluator (FA-10 Digital Audiometer) and TDH-39P, C13357 Telephonics headphones calibrated according to ANSI specifications for audiometers (ANSI, 1996). Participants who passed the hearing screening continued with the experiment, and those who did not meet the requirements were released from the experiment.

Prior to starting the experiment, the researcher instructed each participant to imagine that he or she worked in a factory performing a mundane task and listening to a recording of a comedian's performance for on-the-job relaxation. At a certain point, a coworker started a noisy operation that made listening to the recording more difficult. The noise from the operation was represented by the background noise from the speaker. The listener's task was to first adjust the signal level (i.e., the volume of the recording) to his/her most comfortable listening level and then adjust the noise level to the maximum tolerable level above which they would simply stop listening or turn off the source of the signal. Participants were told to use hand gestures (e.g., hand up, hand down, hand flat) to request changes in the signal levels. Hand up, hand down, and hand flat indicated volume up, volume down, and volume okay, respectively.

This experiment involved four sessions with each session indicating noise loudspeaker locations (45-, 180-, 225-, and 315-degree azimuths, each three feet away from the participant's seated position). Each of the sessions involved listening to a recording of a comedian's performance and background noise while simultaneously glancing at a magazine. The magazine was used to prevent the listeners from focusing their full attention on the signal presented. Only one noise type was used (babble noise), and participants chose any one of four comedic recordings they preferred. These recordings included (a) "Bar Jokes," (b) "Complimentary Peanuts," (c) "Mad Cows & Udder," and (d) "Are There Golf Courses in Heaven?" from the "Delight Yourself and Be the Enemy of Others" CD (Garrison Keillor, Prairie Home Companion, 2004). Sessions were randomized within subjects with a simple randomization technique. Four papers were wrapped in a box with each paper indicating a session. On each paper was written the loudspeaker location. Each participant picked one paper at a time without replacement. The experiment was conducted according to the order in which participants picked the paper.

Prior to data collection, the loudspeaker located at the angle selected by the participant was adjusted to the participant's seated ear level. This was done for every session of the experiment. Likewise, the signal source loudspeaker was also adjusted to the same height level. The comedic speech chosen by the participant was played first starting from 0 dBA, from the computer outside the booth. The researcher controlled the computer with the help of Sound Forge software for looping. The signal was delivered to the acoustic booth through the loudspeaker located at 0-degree azimuth, three feet away from the participant's seated position. Participants used hand gestures to indicate the intensity level at which he or she was most comfortable. The intensity settings the participant selected for the level of the comedian's speech determined the most comfortable listening level (MCLL). This result was recorded by the researcher. Participants were allowed to enjoy the comedian recording at this level for approximately 2 to 3 minutes before introducing the background noise.

Thereafter, as the recording was still playing, the background noise was introduced, starting at 0 dBA from another computer outside the booth. The researcher controlled the noise level and the noise was looped with the help of Sound Forge software. The location of the loudspeaker that delivered the background noise in each instance was based on the angle chosen by the participant, but always three feet away from the participant's seated position. Each participant used the same hand gestures to indicate the maximum level of background noise he or she was willing to accept and still be comfortable with the comedian's speech and the mundane task. The participant's intensity settings of the maximum level of background noise accepted determined the participant's BNL. This result was also recorded by the researcher. The levels of the signal and the noise were adjusted in 1.5 dB increments by pressing the up and down arrow keys on the computer's keyboard. The procedure to determine the 1.5 dB step increment was similar to that shown in Chapter 4. The participant was allowed to remain at this condition (i.e., signal and noise condition with the mundane task) for approximately three minutes, maintaining the same signal and noise intensities measured earlier by the researcher. This was done to ensure that the participant felt the effect of the signal and the noise at the same time, and to ensure that both the signal and the noise were still playing at the same time before BNL was measured. In each session, the participant's MCLL and BNL were determined three times. This was done to ensure reliability of the participant's responses. Each trial took approximately six to seven minutes, but trials varied based on each individual. During each session, the listener was instructed to maintain the same seated position throughout the experiment to ensure the listener was at a constant distance of three feet away from each loudspeaker. There was no time limit set for the adjustment procedure (but it usually took less than 30 seconds). The differences between the MCLL and BNL were calculated and recorded as the listener's ANL. Participants were given a ten-minute break after the first two sessions. Table 18 shows the research design for masking noise and the speech signal used.

Table 18

Research Design for Masking Noise and the Signal on Loudspeakers Position Effects on Human Tolerance to Noise

			Signal			
			SF			
Masker			SF1	SF2	SF3	Earphone
SF	Front	White noise Speech spectrum Babble noise				

Table 18

(Cont.)

Masker			Signal			
			SF			
			SF1	SF2	SF3	Earphone
SF	Rear	White noise				
		Speech spectrum				
		Babble noise				
	Omni	White noise				
		Speech spectrum				
		Babble noise	X	X		
Earphone		White noise				
		Babble noise				

5.6 Noise Stimulus

The noise stimulus was calibrated with Sony Sound Forge software and routed through a LENOVO desktop computer into the acoustic chamber, where the listener was seated. Figure 22 shows the capture of the noise wavefront on Sound Forge.

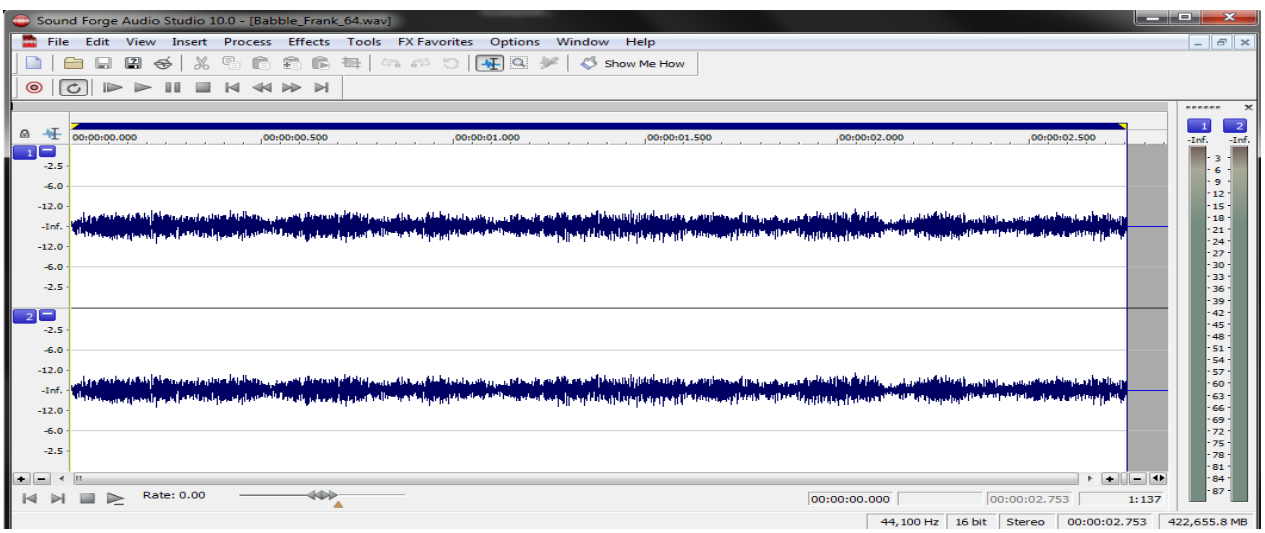


Figure 22. Babble background noise from Sound Forge software.

5.7 Results

The descriptive statistical data show that the mean MCLL of the 23 participants was 52.07 dB (*SD* = 5.02), with a range of 44.85–64.68 dB. Overall, ANLs ranged from 2.97 dB to 13.45 dB. The ANL for the 45^o azimuth loudspeaker position was 7.07 dB (*SD* = 3.040); 6.87 dB (*SD* = 2.661) for the 180^o azimuth loudspeaker position; 6.87 dB (*SD* = 1.914) for the 225 dB loudspeaker position; and 7.35 dB (*SD* = 2.537) for the 315^o azimuth loudspeaker position. Table 19 shows the descriptive statistics of the analysis. It is shown from this table that the mean ANLs for all participants at 45^o azimuths is 1.5 dB in percentage higher than the ANLs average at 180^o azimuths; while at 315^o azimuths the ANLs average is 3.38 dB in percentage higher than the ANLs average at 180^o azimuths.

Table 19

Means and Standard Deviations of ANLs for the 23 Participants Based on the Loudspeaker Locations

NLL*	45 Degree	180 Degree	225 Degree	315 Degree
Average	7.067 dB	6.866 dB	6.952 dB	7.345 dB
SD	3.040	2.661	1.914	2.537

*NLL = Noise Loudspeaker locations.

Figure 23 shows a graphical representation of the ANLs based on the background loudspeaker locations. Pictorially, it is also shown in this figure that the mean ANL of the participants at the noise loudspeaker location of 315^o azimuths is higher compared to the other locations. Table 20 shows all the participants ANLs averaged from the three trials for each noise loudspeaker location.

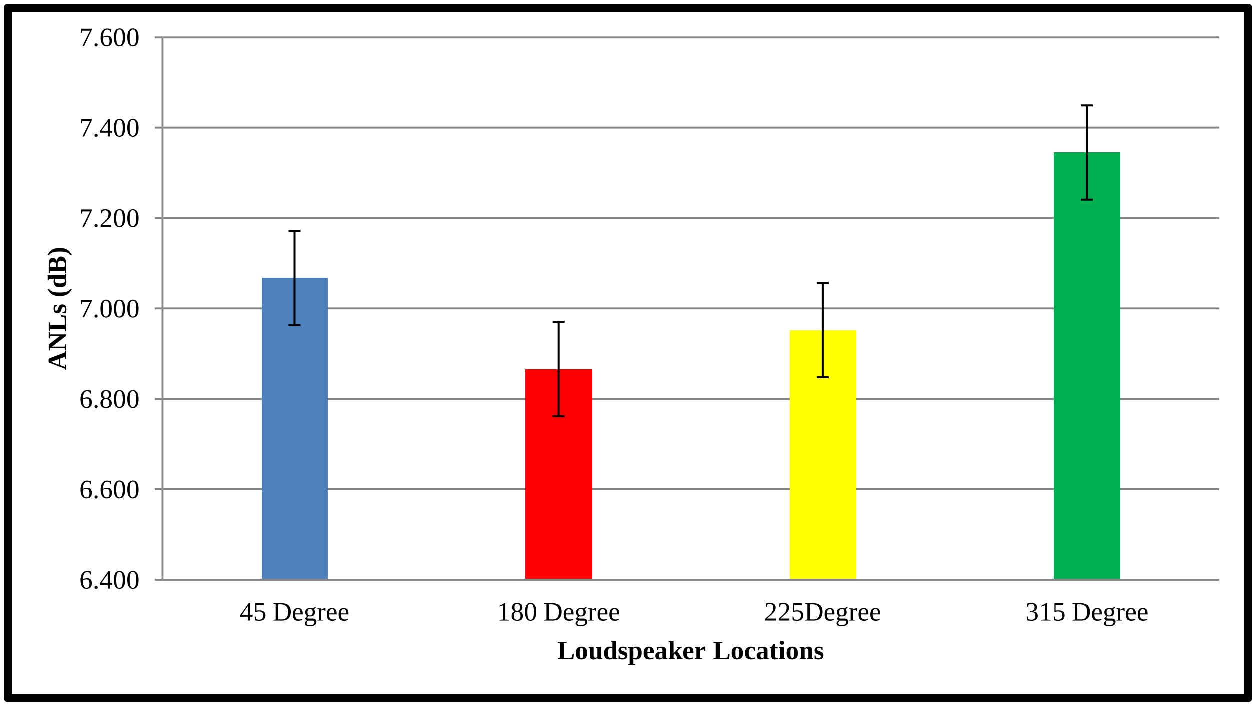


Figure 23. Mean ANL values for the 23 participants for each loudspeaker locations with error bars and standard errors.

Table 20

Mean ANLs for Each Participant from the Three Trials under Different Loudspeaker Locations

Average ANL Loudspeaker Location						
	Degree Azimuth				Demographic Data	
n[*]	45 Degree	180 Degree	225 Degree	315 Degree	Gender	Age
1	2.968	3.314	7.308	5.450	F	21
2	5.870	8.321	7.890	9.099	M	21
3	5.640	8.137	7.482	5.738	M	30
4	5.618	5.057	7.188	6.310	F	19
5	5.457	6.091	6.682	7.050	F	27
6	6.556	5.738	5.443	4.986	F	29
7	7.294	6.999	6.563	6.718	F	43
8	5.133	5.317	4.831	5.465	M	24
9	3.609	3.609	3.938	3.643	F	24

Table 20

(Cont.)

Average ANL Loudspeaker Location						
	Degree Azimuth				Demographic Data	
n[*]	45 Degree	180 Degree	225 Degree	315 Degree	Gender	Age
10	4.301	3.660	3.546	3.399	M	40
11	4.141	5.111	6.178	5.634	F	33
12	4.967	6.653	10.161	11.801	M	23
13	11.163	8.638	6.551	11.015	F	23
14	6.565	7.185	5.461	5.606	M	20
15	13.448	11.597	9.989	8.917	M	19
16	11.583	9.553	10.065	10.540	M	19
17	9.601	7.634	5.872	8.606	M	21
18	12.963	12.597	8.933	11.212	M	19
19	7.132	4.681	7.861	7.033	F	18
20	7.182	7.165	6.847	8.230	F	20
21	6.512	5.237	6.203	5.365	F	20
22	4.119	3.790	4.964	5.711	M	21
23	10.720	11.830	9.941	11.398	F	22

*n = Participant's serial numbers

When comparing ANLs from the different loudspeaker positions, participants have the lowest average ANLs when the background noise loudspeaker was positioned at a180^o azimuth, followed by the position at a 225^o azimuth. This indicates that participants tolerated more background noise when the noise was emitted from the loudspeaker located at an angle of 180^o azimuth to the seated position ear level of the participants. At a 315^o azimuth, the participants' ANLs were higher than all the other three different locations. This indicated that at these locations, participants could not tolerate a large amount of background noise before becoming tense or tired.

Further, gender differences were also examined among participants. Table 21 shows the descriptive gender statistics for participants' ANLs average for the three trials in the different loudspeaker locations.

Table 21

Mean and Standard Deviation ANLs for Males and Females under Different Loudspeaker Location

Gender	45 Degree	180 Degree	225 Degree	315 Degree
Male	7.65 (3.56)	7.68 (2.86)	7.20 (2.39)	7.83 (2.77)
Female	6.85 (2.51)	6.38 (2.34)	6.67 (1.42)	7.03 (2.33)

Figure 24 shows a graphical representation of the mean ANL in dB for both males and females under different loudspeaker locations. Results show that not much difference was found among male ANLs. It is noticed from this graph that variation in the average ANLs for different loudspeaker locations was because of the ability of females to accept different levels of background noise at different loudspeaker locations.

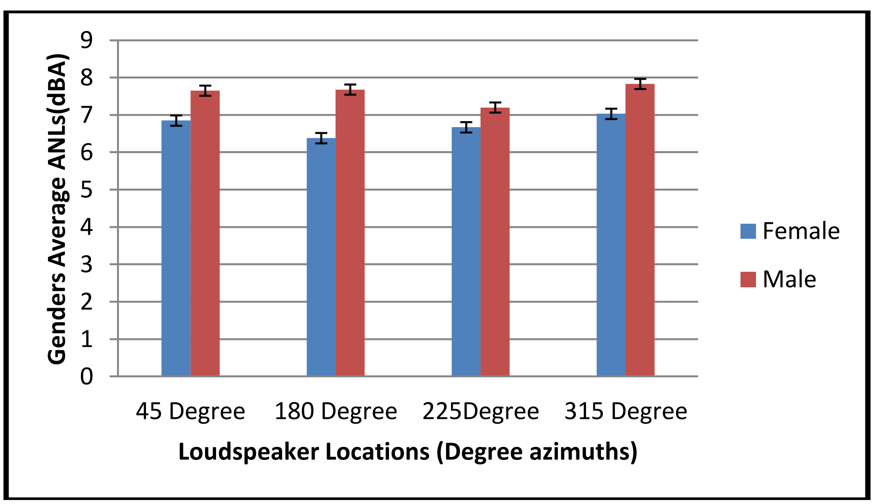


Figure 24. Male and female average ANLs in (dB) for different loudspeaker locations.

Statistical Analysis Software (SAS) was used to analyze data. Prior to the data analysis, a normality test was conducted. The test for normality showed that the dataset obtained at the 45-degree azimuth loudspeaker location was normally distributed with the Jarque-Bera test (JB (observed value) = 2.785; JB (critical value) = 5.991; $p = 0.248$). The test for normality showed that the dataset obtained at the 180-degree azimuth loudspeaker location was normally distributed with the Jarque-Bera test (JB (observed value) = 1.854; JB (critical value) = 5.991; $p = 0.396$). The test for normality showed that the dataset obtained at the 225 degree azimuth loudspeaker location was normally distributed with the Jarque-Bera test (JB (observed value) = 0.802; JB (critical value) = 5.991; $p = 0.670$). The test for normality showed that the dataset obtained at the 315-degree azimuth loudspeaker location was normally distributed with the Jarque-Bera test (JB (observed value) = 1.425; JB (critical value) = 5.991; $p = 0.490$). There is only one independent variable, which is loudspeaker location in the four levels, namely 45^o, 180^o, 225^o, and 315^o azimuths and one dependent variable, the average ANL. Descriptive statistics results showed some differences between ANLs for different loudspeaker locations. However, the ANOVA results revealed no statistically significant difference in the average ANLs for all the loudspeaker locations at 0.05 significant level ($F(3, 88) = 0.15$; $p = 0.9286$). Levene's Test for Homogeneity of ANL Variance was also conducted. The results revealed that there was no significant difference ($F (3, 88) = 1.74$; $p = 0.1641$). Table 22 shows the ANOVA results for the analysis.

ANOVA results on gender comparison for the average ANLs at the different loudspeaker locations revealed no significant difference at 0.05 significant levels. Table 24 has the detail statistical values at each of the loudspeaker locations.

Table 22

ANOVA Results for the ANLs at Different Loudspeaker Locations

Source	*df*	Sum of Square	Mean Square	*F*	*p* > *F*
NLL*	3	2.999	0.9995	0.15	0.9286
Error	88	581.275	6.605		
Corrected Total	91	584.274			

*NLL = Noise Loudspeaker Location

Table 23

ANOVA Results for Contrast Analysis

Contrast	*df*	Contrast SS	Mean Square	*F*	*p* > *F*
NLL 45 vs. the others	1	0.00286	0.00286	0.00	0.9834
NLL 180 vs. NLL 225 and 315	1	1.2237	1.2237	0.19	0.6679

Table 24

P-values of ANLs between Genders at Different Loudspeaker Locations

NLL	45 Degree	180 Degree	225 Degree	315 Degree
p-Values	0.198	0.086	0.288	0.200

A further analysis to assess the dependency of ANLs inter-subject variability on gender was also conducted. The ANOVA results also revealed gender independency of ANL inter-subject variability at the alpha level of 0.05 when the analysis was done separately (i.e., females across ANLs at different loudspeaker locations and males across ANLs at different loudspeaker locations); for females, F (3, 47) = 0.23; p = 0.839, and for male, F (3, 43) = 0.09; p = 0.9628 (see Table 25 for detailed results). The results of the analysis between gender and noise loudspeaker locations showed no significant interaction (p = 0.9130).

Table 25

ANLs Inter-subject Variability on Gender at Different Loudspeaker Locations

Source	*df*	Sum of Square	Mean Square	*F*	*p > F*
		Female Results			
Model	3	4.042	1.347	0.28	0.8393
Error	44	211.368	4.804		
Corrected Total	47	215.408			
		Male Results			
Model	3	2.421	0.807	0.09	0.9628
Error	40	342.598	8.565		
Corrected Total	43	345.019			

5.8 Psychophysical Results for Air Conduction

Regression analyses were performed with the logarithm of listeners' MCLL, BNL, and sound discriminability. The test for normality showed that the logarithms of the dataset obtained at all noise loudspeaker locations with the exception of the logarithm of MCLL at a 315-degree azimuth were normally distributed. An **inverse** transformation was performed on the MCLL dataset at a 315-degree azimuth dataset and it passed the normality test with the Shapiro-Wilk test (W = 0.936; p = 0.405) and the Anderson-Darling test (A^2 = 0.322; p = 0.487).

The psychophysical ANL models developed for each loudspeaker location from the data are contained in Table 26 with the listeners' discriminability biases for both the BNL and the MCLL, and the R^2.

Table 26

Psychophysical ANL Regression Equations for Different Loudspeaker Locations under Air Conduction

		45-Degree	180-Degree
	Regression	logANL = 0.12179logd' + 0.03096	logANL = 0.15978logd' + 0.01494
MCLL	logc	1.643	1.626
	β	0.201	0.2488
	R^2	53%	65%
BNL	logc	1.612	1.611
	β	0.0795	0.0890
	R^2	48%	42%
		225-Degree	315-Degree
	Regression	logANL= 0.1236logd' + 0.02641	logANL= 0.000083log(Invd') - 2.130
MCLL	logc	1.605	0.587
	β	0.31566	0.000087
	R^2	57%	34%
BNL	logc	1.579	2.717
	β	0.1921	0.0000032
	R^2	47%	32%

The standard errors recorded between the computed ANL from the psychophysical models (called predicted model) and the measured ANLs are shown in Table 27. The table also contains the R^2 values for the predicted and actual logANL. The graphical illustration for the relationship is shown in Appendix E.

Table 27

Standard Percentage Errors between the Predicted ANL and the Measured ANL

Condition	*SE*	R^2
45-Degree	0.0378	0.958
180-Degree	0.0342	0.960
225-Degree	0.0212	0.973
315-Degree	0.55122	0.043

The participants' discriminability biases toward noise and signal at different noise loudspeaker locations were extracted from the developed model. The results are contained in Table 28, which shows that listeners had a higher discriminability bias toward signal when the noise loudspeaker was located at a 225-degree azimuth and the lowest when the noise loudspeaker was located at a 315-degree azimuth. As shown in Table 28, at a 315-degree azimuth the listeners' discriminability bias toward noise, signal, and computed ANL were found to be zero. This indicates that listeners had the lowest discriminability bias for ANL at a 315-degree azimuth.

Table 28

Participants' ANL Biases, Predicted Discriminability, and MANL for Different Noise Loudspeaker Locations

	45-Degree	180-Degree	225-Degree	315-Degree
Signal (β)	0.201	0.249	0.315	0.000
Noise (β)	0.08	0.089	0.192	0.000
Discriminability bias (β) for ANL	0.122	0.16	0.124	0.000
MANL	1.07	1.03	1.063	0.339

Table 29 presents male listeners' discriminability bias toward the noise and toward the signal, as well as the psychophysical ANL regression equations for the sound at different loudspeaker locations. The R^2 for each regression analysis under the signal and the noise are also shown in the table.

Table 30 presents female listeners' discriminability bias toward the noise and toward the signal, as well as the psychophysical ANL regression equations for the sound at different loudspeaker locations. The R^2 for each regression analysis under the signal and the noise are also shown in the table.

Table 29

Psychophysical ANL Regression Equations for Male at Different Loudspeaker Locations

		45-Degree	180-Degree
	Regression	logANL = 0.078logd' + 0.058	logANL = 0.130logd' + 0.033
MCLL	logc	1.669	1.645
	β	0.170	0.226
	R^2	42%	55%
BNL	logc	1.611	1.612
	β	0.092	0.0968
	R^2	66%	58%
		225-Degree	315-Degree
	Regression	logANL= 0.080logd' + 0.0400	logANL= 0.198logd' + 0.555
MCLL	logc	1.620	1.655
	β	0.315	0.210
	R^2	62%	41%
BNL	logc	1.58	1.100
	β	0.235	0.0115
	R^2	71%	65%

Table 30

Psychophysical ANL Regression Equations for Female at Different Loudspeaker Locations

		45-Degree	180-Degree
	Regression	logANL = 0.257logd'^{2} – 1.0581	logANL = 0.144logd' + 0.016
MCLL	logc	1.663	1.625
	β	0.0916	0.220
	R^2	25%	80%
BNL	logc	2.720	1.9
	β	-0.165	0.076
	R^2	29%	57%
		225-Degree	315-Degree
	Regression	logANL= 0.173logd' + 0.00724	logANL= 0.148logd' + 0.016
MCLL	logc	1.60947	1.622
	β	0.260	0.230
	R^2	81%	82%
BNL	logc	1.602	1.606
	β	0.087	0.083
	R^2	68%	58%

The differences in gender discriminability bias toward the signal and the noise were analyzed. Table 31 contains listeners' discriminability biases by gender under different loudspeaker locations. The percentage difference in listeners' discriminability biases toward the signal showed that the males had a higher positive discriminability bias by approximately 30.1% than females when the noise loudspeaker was located at the 45-degree azimuth. The percentage difference in listeners' discriminability biases toward the noise showed that males had a higher positive discriminability bias by approximately 35.2% than the females at a 45-degree azimuth. The results show that females had negative biases toward the noise, and males had positive biases toward the noise at the 45-degree azimuth noise loudspeaker location. This indicated that males tended to be comfortable under higher noise intensity than their female counterparts. Table 32 details the percentage differences between biases toward the noise and the signal at different loudspeaker locations by gender. These findings are supported by McFadden (1998) who studied gender differences in the auditory system. McFadden found that females had a greater hearing sensitivity to noise exposure and would not accept a high level of noise.

Table 31

Gender Discriminability Biases toward Noise and Signal at Different Noise Background Locations

	45-Degree	180-Degree	225-Degree	315-Degree
		Male		
Signal	0.17017	0.22642	0.31482	0.2095
Noise	0.09221	0.09679	0.23462	0.01147
		Female		
Signal	0.09155	0.22042	0.26037	0.23042
Noise	-0.16525	0.07602	0.08693	0.08209

Table 32

Gender Differences in Listeners' Discriminability Bias toward Sound

Speaker Location	Sound	Percentage Difference	Direction
45-Degree	Signal	30.10%	M > F
	Noise	35.2%	F < M
180-Degree	Signal	1.10%	M > F
	Noise	12.00%	F < M
225-Degree	Signal	9.50%	M > F
	Noise	46.00%	F < M
315-Degree	Signal	4.80%	F > M
	Noise	78.00%	F > M

5.9 Discussions on the Effects of Noise Loudspeaker Locations

5.9.1 Psychophysical ANL. The results from psychophysical model revealed that the minimum ANL threshold occurs at the 315-degree loudspeaker location with a value of 0 dBA. The results also showed that at the 315-degree azimuth loudspeaker location, the listeners' discriminability biases toward both noise and signal were zero. This indicates that listeners were not comfortable listening to speech when the noise source was at the 315-degree azimuth. The listeners had a higher discriminability bias of 0.16 and MANL of 1.03 dBA toward noise when the noise loudspeaker was located at the 225-degree azimuth. This indicates that at a 225-degree azimuth, listeners were comfortable at high noise intensity. The results revealed that listeners had higher positive biases toward signal at all noise loudspeaker locations. The results of the gender differences indicate that males had a higher bias toward both signal and noise at the 45-, 180-, and 225-degree azimuth loudspeaker locations. The reverse was the case at a 315-degree azimuth loudspeaker location in which the discriminability bias was zero.

5.9.2 Discussion on ANL. The results revealed no statistically significant difference among the average ANLs at the different loudspeaker locations. This finding at 0.05 significant levels agreed with results from Nabelek et al. (1991, 2004) and Rogers et al. (2003), who concluded in their studies that ANL is gender independent. Approximately 42% of the participants in this study have ANL values less than 6 dB.

The analyses on the gender effect at different loudspeaker locations showed that the acceptance of noise was not statistically significantly affected by noise from the loudspeaker locations. The average MCLL and BNL were noticed to be higher in males than in females. The results revealed that there was no statistically significant gender difference in ANL values. On average, male participants had approximately 5 dB higher average MCLL than the female participants. The male participants also tolerated approximately 4 dB more background noise while listening to the discourse at their MCLL than did their female counterparts.

5.10 Summary

In summary, this chapter tested the hypothesis that no difference will be found in the ANL recorded when the noise loudspeaker is located at different angles. The findings are as follows:

1. ANLs at different loudspeaker locations were not statistically significantly different from one another (F (3, 88) = 0.15; p = 0.9286).
2. No statistical significant difference in ANL existed between genders (p = 0.198 at a 45-degree azimuth; p = 0.086 at a 180-degree azimuth; p = 0.288 at a 225-degree azimuth; and p = 0.200 at a 315-degree azimuth).
3. Males had a higher positive discriminability bias toward signal and noise at all locations, except at the 315-degree azimuth.
4. Males had higher positive discriminability biases toward sound at three different noise loudspeaker locations.

5. Females' discriminability biases were found to be positively higher toward sound at the 315-degree azimuth of the noise loudspeaker location.
6. Psychophysical results showed that the least MANL thresholds and the listeners' discriminability bias toward sound were zero at the 315-degree loudspeaker location.

CHAPTER 6

Differences in Signal Comprehension in Noise Level (SCNL) and Acceptable Noise Level (Study III)

6.1. Background

Nabelek et al. (2004) compared speech perception and ANL in background noise and confirmed that speech perception in background noise was not related to hearing aid use or satisfaction, but ANL was related to hearing aid use satisfaction. Adams and Moore (2009) studied diverse listening conditions in background noise or reverberation that frequently cause communication difficulty for listeners with normal hearing and for those with hearing impairment (Houtgast & Steeneken, 1973; Killion, Niquette, Gundmundsen, Revit, & Banerjee, 2004; Peissig & Kollmeier, 1997). Several studies have been conducted to study factors that affect speech understanding in such an environment. Different researchers have reported different procedures for ANL. Some reported ANL procedures such as speech comprehension/understanding in background noise.

Listening in degraded environments, such as with background noise, is a frequent occurrence. Research is needed to help establish strategies for better speech understanding and worker performance without tiredness or distraction. One of the hypotheses, stated in Chapter 1, is that the mean ANL of a listener will not be significantly different from the mean Speech Comprehension in Noise Level (SCNL). The alternative hypothesis is that there will be a statistically significant difference between listeners' mean SCNL and mean ANL when measured under the same signal type and noise type. The two loudspeakers that delivered the noise were positioned at different angles surrounding the listener seated position, three feet away (90^o and 270^o azimuths).

In 2004, Nabelek tested the reliability of individuals' ANL with the reliability of Speech Perception in Noise (SPIN) scores. No significant relationship was found in the study between word recognition and ANL when speech was presented at a SNR of 8 dB. It was suggested in the study that speech understanding in noise may not be as important as the willingness to listen in the presence of noise. A completely randomized design was employed for the experimental design. The independent variable was the background noise in two levels (speech spectrum and multi-talker babble), and the dependent variables were ANL and SCNL.

6.2 Participants

Thirty subjects participated in this session of the study. Their ages ranged from 19 to 44 years old, with an average age of 27 years and a standard deviation of 6.7 years. Subject selection criteria were similar to that of experiment I. There were 10 females and 20 males. The females' ages ranged from 20 to 32 years old, with an average age of 22.7 years and a standard deviation of 3.8 years. The males' ages ranged from 19 to 44 years old with an average age of 30.9 years and a standard deviation of 7.6 years.

6.3 Method

The background noise types used for this session of the study were multi-talker babble and speech spectrum noise. This experiment was divided into two stages. In each stage, two loudspeakers delivered background noise at the same time. The noise loudspeakers were positioned at 0- and 180-degree azimuths (see Figure 25), three feet away from the listener's seated position. The signal loudspeaker was positioned at a 90-degree azimuth, three feet away from the listener's seated position. Kattel et al. (2008) used the same degree azimuths for both the signal and the background noise loudspeaker locations in their study. Likewise, the study conducted by Rosenblum (2008) on auditory theory claimed that listeners are sensitive primarily to the auditory components of speech sounds rather than to articulatory components. In other words, listeners can identify the spoken message without actually detecting movements of the articulatory components or their underlying control structures. In stage one, the listeners comprehended the signal and the difference between the speech comprehension comfort levels (SCCL) and the BNL was recorded as SCNL (i.e. SCNL = SCCL – BNL). In stage two, speech comprehension was not an issue. Therefore, the difference between listener's MCLL and the BNL was recorded as ANL.

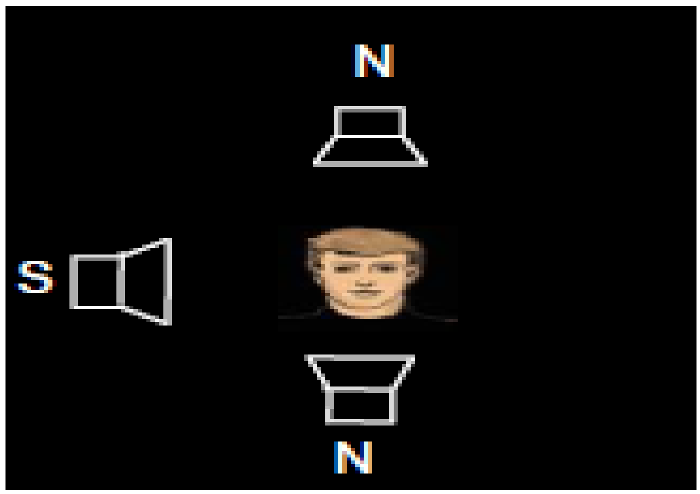


Figure 25. Experimental set-up for experiment III.

6.4 Materials

Three loudspeakers were used for this experiment; two delivered the noise and one delivered the signal. An audiometer was used for the hearing screening. A sound level meter was used for calibrating the sound intensity prior to the start of the experiment. A sound attenuated booth served as the listening environment. All equipment was previously shown in Figures 6 and 7. Two noise types were used (multi-talker babble and speech spectrum noise) and one signal type, participant-selected signal type between ("Complimentary Peanuts," and "Are there Golf Courses in Heaven" on "Delight Yourself and Be the Enemy of Others").

6.5 Procedure

This experiment required the measurement of ANL and the participant's SCNL. Similar procedures were followed as in Study I and Study II experiments in welcoming participants and preparing them for the hearing screening. Prior to data collection, the researcher instructed each participant to imagine that he or she worked in a factory performing a mundane task and listening to a recording of a comedian's performance for on the job relaxation. At a certain point, a coworker started a noisy operation that made listening to the recording more difficult. The noise from the operation was represented by the background noise from the speaker. The listener's task was to first adjust the signal level (i.e., the volume of the recording) to his/her most comfortable listening level, and then to adjust the noise level to the maximum tolerable level above which they would simply stop listening or turn off the source of the signal. Participants were instructed to use hand gestures (i.e., hand up, hand down, hand flat) to request changes in the signal levels. Hand up, hand down, and hand flat indicated volume up, volume down, and volume okay, respectively. The researcher also explained to the participants that to ensure that they comprehended the speech signal, they should be able to paraphrase the content of the speech signal orally to the researcher after each trial during any session that involved SCNL.

This study involved four sessions, and all sessions were randomized with each participant. A simple randomization technique was used. Four papers were wrapped in a box with each wrapped paper indicated a different session. For example, papers were labeled ANL-babble, ANL-speech spectrum, SCNL-babble, and SCNL-speech spectrum. The experiment was conducted according to the order in which the participant picked the paper. For the comedian's recording, participants were allowed to choose one of four comedian's recordings they preferred.

These recordings included (a) “Bar Jokes,” (b) “Complimentary Peanuts,” (c) “Mad Cows & Udder,” and (d) “Are There Golf Courses in Heaven?” from the “Delight Yourself and Be the Enemy of Others” CD (Garrison Keillor, Prairie Home Companion, 2004).

Prior to data collection, all loudspeakers were adjusted to each participant’s seated ear level. The comedian’s speech chosen by the participant was first played starting at 0 dBA from the computer outside the booth. The researcher controlled the computer and Sound Forge software was used for looping. The signal was delivered to the acoustic booth through the loudspeaker located at a 90-degree azimuth three feet away from the seated position of the participant. The participant used hand gestures to indicate the intensity level at which the participant was most comfortable. The intensity setting to the level of the comedian’s speech determined the participant’s most comfortable listening level (MCLL). This was recorded by the researcher. Participants were allowed to enjoy the comedian’s recording at this level for approximately 2 to 3 minutes. Thereafter, as the recording was still playing, the background noise was introduced from another computer outside the booth controlled by the researcher. This was delivered to the booth through the two loudspeakers located at 0- and 180-degree azimuths, three feet away from the participant’s seated position. Participants used the same hand gestures to indicate the maximum level of background noise that he or she was willing to accept and still be comfortable with the comedian’s speech and the mundane task. The participant’s intensity settings at the level of maximum background noise accepted determined the participant’s BNL. This was also recorded by the researcher. The levels of the signal and the noise were adjusted in 1.5 dB increments by pressing the up and down arrow keys on the computer keyboard. Participants were allowed to remain at this condition (i.e. signal and noise condition with the mundane task) for approximately 3 minutes during which time they maintained the same signal and noise intensities measured earlier by the researcher. This was done to ensure that the participant felt the effect of the signal and the noise at the same time, and that both the signal and the noise were still playing at the same time before BNL was measured. In each session, each participant's MCLL and BNL were determined three times (i.e., three trials for each session). This was done to ensure the reliability of the participant's responses. Each trial lasted approximately six to seven minutes, but varied based on the individual. During each session, the listeners were instructed to maintain the same seated position throughout the experiment so as to ensure the listener remained at a constant distance of three feet away from each loudspeaker. There was no time limit set for the adjustment procedure (but it usually took less than 30 seconds). The differences between the MCLL and BNL were calculated and recorded as the listener's ANL.

For SCNL, the speech signal was presented to the listener through the same loudspeaker positioned at a 90-degree azimuth, as used for the ANL experiment. The listener adjusted the comedian's recording to their speech comprehension comfort level. This level was recorded by the researcher as SCCLs when no other task, such as gazing at the magazine, was being performed. The comedian's recording was played by the researcher outside the booth from a computer with the help of Sound Forge software for looping. After the SCCLs were completed, the BNL measurements were performed. The noise was introduced to the participant from another computer outside the booth with the help of Sound Forge software for looping, and the level adjustment was controlled by the researcher. The same noise loudspeaker locations used for determining the participant's BNL during the ANL experiment were also used. During this procedure, background noise was introduced via the loudspeakers when the speech signal was still playing. The level of the background noise was gradually increased in 1.5dB increments by pressing the up and down arrow keys on the computer keyboard. The procedure to determine the 1.5 dB step increment was similar to that shown in the procedure in Chapter 4. Participants used the same method of adjustment used for SCCLs to request intensity changes. The listeners were instructed to ensure that they could still comprehend the recorded message delivered in the background noise throughout the BNL adjustments. The level of background noise at which the listeners responded okay was recorded as the listeners' maximum BNL. Participants were allowed to remain at this condition (i.e., signal and noise condition without the mundane task) for approximately three minutes while they maintained the same signal and noise intensities as measured earlier by the researcher. This was done to ensure that participants felt the effect of the signal and the noise simultaneously. This was done three times, representing three trials for each session. Each trial lasted roughly six to seven minutes, but varied based on the individual. The differences between the recorded SCCLs and BNLs for each trial were recorded as the participants' SCNL for that session. Participants were given a ten-minute break after the first two sessions.

6.6 Results

The mean, range, and the standard deviation results for both ANL and SCNL for the entire 30 participants are shown in Table 33. This table shows that the average SCNL for babble noise is 2% higher than that of the speech spectrum and the average ANL for the babble noise is 4% higher than that of the speech spectrum. However, when compared across the two metrics (i.e., SCNL and ANL) for babble noise, ANL was higher by 8% on the average than the SCNL. The speech spectrum ANL was higher by 6% on average than the SCNL.

Table 34 shows the detail SCNL and ANL values recorded for all participants and their demographics. Only one participant had a negative SCNL, and no one among the participants had a negative ANL. Figure 26 shows a graphical representation of the relationship between multi-talker babble noise and speech spectrum noise for SCNL.

Table 33

Means, Ranges, and Standard Deviations for Both SCNL and ANL under Both Babble and Speech Spectrum Noise

	SCNL		ANL	
	Babble Noise	Speech Spectrum	Babble Noise	Speech Spectrum
Ave	7.69	7.39	8.96	8.41
SD	2.62	3.05	3.04	3.25
Range	1.45 – 13.49	(-0.56) – 13.97	4.55 – 16.29	3.75 – 15.86

Table 34

Detail SCNLs and ANLs for All Participants and Their Demographics Information

	SCNL		ANL		Demographic Info	
Subject #	Babble Noise	Speech Spectrum	Babble Noise	Speech Spectrum	Gender	Age
1	4.766	4.082	4.553	3.751	F	24
2	4.111	3.751	4.700	3.751	M	21
3	10.593	11.531	10.287	10.208	M	25
4	9.938	9.976	7.772	8.391	M	25
5	7.681	7.461	11.010	9.746	M	34
6	5.780	5.814	5.782	5.104	F	20
7	8.283	7.471	7.280	6.177	M	23
8	4.994	3.901	4.994	3.901	F	32
9	4.993	4.010	5.233	4.983	M	29

Table 34

(Cont.)

	SCNL		ANL		Demographic Info	
Subject #	Babble Noise	Speech Spectrum	Babble Noise	Speech Spectrum	Gender	Age
10	6.154	5.874	7.358	7.851	F	22
11	9.553	9.196	6.678	6.318	M	20
12	7.934	8.964	8.416	8.199	M	36
13	6.986	7.668	5.908	5.102	M	37
14	7.614	7.837	9.515	9.442	M	29
15	6.397	7.061	7.619	6.660	F	21
16	7.773	8.212	9.592	9.335	M	33
17	6.682	5.576	9.020	8.057	M	20
18	8.710	8.350	9.462	8.509	M	27
19	13.448	13.047	16.290	15.632	M	44
20	9.429	9.627	11.333	10.458	M	35
21	7.967	7.292	7.525	6.388	F	20
22	9.840	9.008	9.980	9.756	M	31
23	11.813	12.436	14.964	15.864	M	30
24	13.486	13.972	14.493	14.109	M	32
25	6.984	6.182	13.386	13.464	F	21
26	6.814	5.567	9.284	7.589	F	20
27	6.814	5.868	7.898	6.952	F	21
28	7.766	7.111	10.220	9.275	F	26
29	5.938	5.421	7.030	6.509	M	19
30	1.445	-0.563	11.366	10.845	M	38

Figure 26 shows the differences between SCNL and ANL under different background noises. This figure shows little difference between ANL and SCNL under the different background noises used. For this reason, inferential statistics were used.

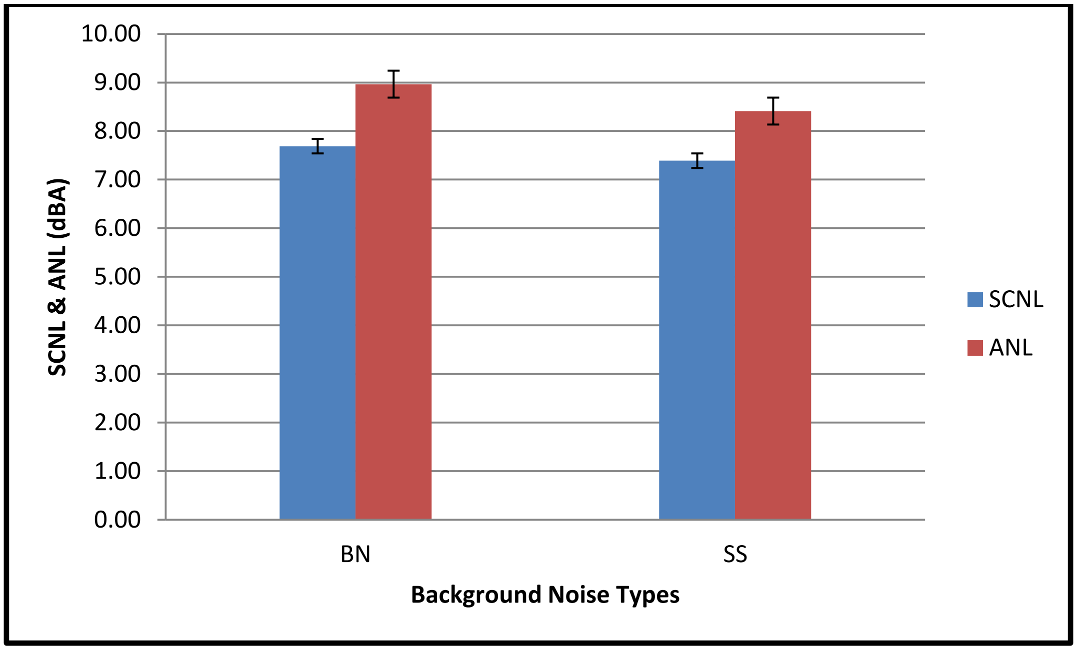


Figure 26. Mean and standard error bar chart for comparing SCNL and ANL under different background types.

Equation 38 shows the regression relationship between SCNL and ANL when the background noise was babble noise. Equation 39 shows the relationship when speech spectrum was the background noise. The results revealed that a statistically significant difference exists between the listeners' minimum ANL and the minimum SCNL, when the background noise was multi-talker babble noise (p = 0 .0278). There was no statistically significant difference found in the minimum threshold between ANL and SCNL, when the speech spectrum was the background noise (p = 0.0515). Regression graphical relationship between SCNL and ANL is shown in Figure 27.

$$SCNL(Babble) = 0.7457ANL + 3.2308 \quad (R^2 = 41\%) \tag{38}$$

$$SCNL(speechspectrum) = 0.57240ANL + 2.57575 \quad (R^2 = 37\%) \tag{39}$$

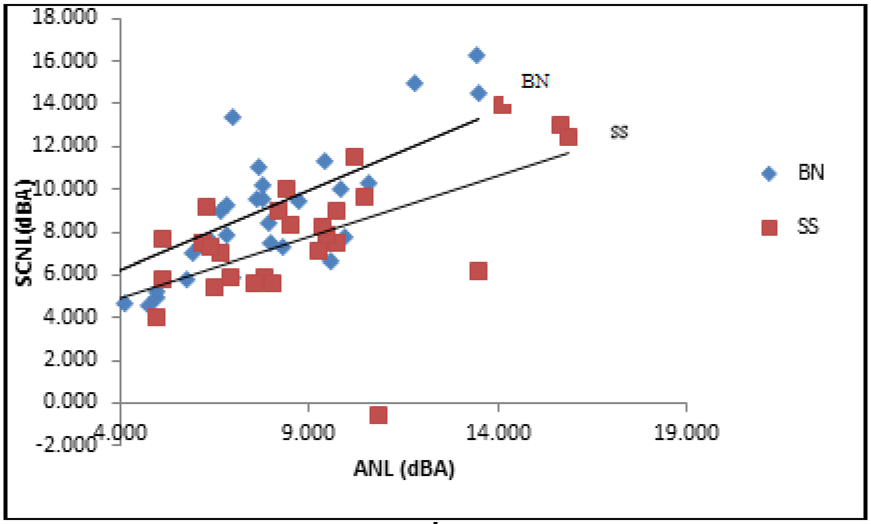


Figure 27. Graphical representation of the relationship between SCNL and ANL under the two background noises (BN=Babble noise, SS=Speech spectrum).

A one-way Multivariate Analysis of Variance (MANOVA) test using Statistics Analysis Software (SAS Institute Inc., 2008) was performed on the data collected. The normality test conducted on the data shows that data were normally distributed. The normality results for SCNL under the babble background noise condition with the Shapiro-Wilk test were (W = 0.966; p = 0.460), and with the Anderson-Darling test (A^2 = 0.427; p = 0.293). The normality results for SCNL under speech spectrum background noise condition with the Shapiro-Wilk test were (W = 0.968, p = 0.502), and with the Anderson-Darling test (A^2 = 0.381, p = 0.379). For ANL with the babble background noise, the results for the Shapiro-Wilk test was (W = 0.968, p = 0.502). For ANL with babble background noise, the Shapiro-Wilk test was (W = 0.948, p = 0.158) and with the Anderson-Darling test (A^2 = 0.466, p = 0.234). The dependent variables were SCNL and ANL, while the independent variable was the background noise type (two levels).

The MANOVA results show no significant difference between the participants' SCNLs and ANLs (Wilks's Lambda = 0.9920, p = 0.7964). Likewise, no significant difference was found in background noise types when ANL was the dependent variable (p = 0.4982), and no significant difference was found in background noise types when SCNL was the dependent variable (p = 0.685).

An ANOVA analysis was performed on SCNL and ANL dataset to investigate the effect of background noise. The results revealed that there were no significant differences of both noise types on either SCNL or ANL. Table 35 shows the ANOVA results for the differences on the effect of background noise on both listeners' SCNL and ANL.

Table 35

ANOVA Results of the Differences on the Effects of Background Noise Types

Source	*df*	Sum of Square	Mean Square	*F*	*p* > *F*
		SCNL			
Model	1	1.3456345	1.345635	0.17	0.6849
Error	58	469.225151	8.090089		
Corrected Total	59	470.570786			
		ANL			
Model	1	4.6042785	4.604279	0.46	0.4982
Error	58	574.839405	9.911024		
Corrected Total	59	579.443684			

6.7 Psychophysical Model

Regression models were used to predict the psychophysical parameters c and β as done previously. Table 36 contains the psychophysical regression equations for both ANL and SCNL at different background noise types. All the datasets passed the normality test except the two background noise types under ANL condition. As a result of the significant violations of the model adequacy checks by the noise types, the data underwent some transformations. Using Microsoft Excel® 2010, the logarithm of the BNLs (babble noise) during the ANL condition was transformed by a power of 1/5 (that is $X^{1/5}$). After the data transformation, the Jarque-Bera test was conducted (JB (observed) = 3.094; $p = 0.083$), and logBNL for babble noise under the ANL condition (JB (observed) = 3.470; $p = 0.176$). Table 37 contains the detail listener discriminability bias, logc, and values of c in parenthesis for the two conditions under the different background noise.

Table 36

Psychophysical ANL Regression Equations for both SCN and ANL

		SCNL-BABBLE	SCNL-SPEECH SPECTRUM
MCLL	Regression	logANL= 0.117logd' + 0.029	logANL=0.121logd' + 0.028
	logc	1.637	1.650
	β	0.174	0.150
	R^2	75%	76%
BNL	logc	1.608	1.622
	β	0.057	0.029
	R^2	32%	35%
		ANL-BABBLE	ANL-SPEECH SPECTRUM
MCLL	Regression	logANL= 0.190log(d')$^{1/5}$ + 1.018	logANL=0.111logd' + 0.560
	logc	1.625	1.652
	β	0.191	0.123
	R^2	88%	58%
BNL	logc	0.607	1.093
	β	0.0013	0.012
	R^2	18%	15%

Table 37

Listeners' Discriminability Biases and the Minimum ANL and SCNL Thresholds

	SCNL		ANL	
	Babble	S-Spectrum	Babble	S-Spectrum
β	0.029	0.028	1.018	0.560
logc	0.117 (1.31)	0.121(1.32)	0.190(1.55)	0.111(1.29)

*c-values = MANL

The listeners' discriminability biases under SCNL and ANL at different background noise were graphed against each other (see Figure 28). Listeners' psychophysical ANL results for babble noise were based on transformed data, not the original data. Figure 28 shows that the listeners had more positive discriminability biases toward noise during the speech comprehension in noise level than they did during the ANL. The listeners' discriminability biases toward babble noise were found to be higher under SCNL than biases toward speech spectrum noise. At ANL, the listeners' discriminability biases toward noise with speech spectrum as the background noise were found to be higher compared to the discriminability bias toward babble noise.

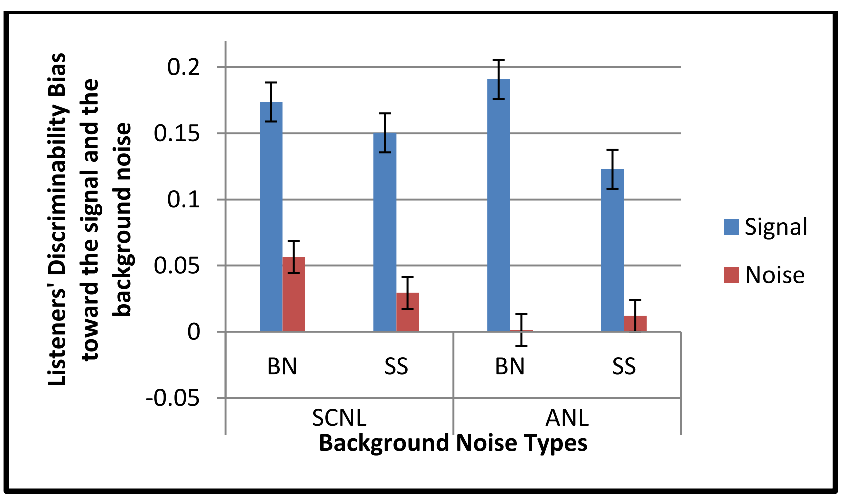


Figure 28. Relationship in listeners' discriminability biases during SCNL and ANL at different background noise.

The standard errors and R^2 between the predicted results for both ANL and SCNL from the psychophysical models are shown in Table 38. The graphical illustrations for the predicted and the measured ANL and the SCNL are shown in the Appendix G.

Table 38

Standard Percentage Errors between the Predicted ANL and the Measured ANL

Condition	Standard Error	R-Squared
SCNL-Babble	0.076	0.870
SCNL-S Spectrum	0.122	0.819
ANL-Babble	0.029	0.963
ANL-S Spectrum	0.034	0.948

6.8 Discussion on the Effects of Noise on SCNL and ANL

The ANOVA results show no statistically significant difference in noise type (babble noise and speech spectrum). Nabelek et al. (2004) suggested that speech understanding in noise may not be as important as the willingness to listen in the presence of noise. The MANOVA results showed no statistically significant difference between participants' average SCNL and the average ANL. The minimum ANL thresholds were observed under speech spectrum noise; this was found to be 3.63 dBA. However, under the SCNL condition, the minimum SCNL was observed when the background noise was speech spectrum and it was found to 1.07 dBA. Psychophysical results revealed higher listener positive discriminability bias toward sound during the ANL conditions than during the SCNL conditions. The results also revealed that the listeners had the highest discriminability bias toward the signal during ANL condition under the babble background noise.

6.9 Summary

This chapter studied the differences between listeners' SCNL and ANL under different background noise conditions. The following are the results of the data analysis:

1. No statistically significant difference exists between SCNL and ANL.
2. No significant differences were found in the noise types either when ANL was the dependent variable or when SCNL was the dependent variable.
3. Listeners have higher positive biases toward signal during ANL and a more positive discriminability bias toward noise during SCNL when multi-talker babble noise was the background noise distraction.
4. A minimum ANL threshold (logc) was found when the speech spectrum was the background noise. Likewise, the minimum SCNL threshold was also found to be the with speech spectrum background noise .

CHAPTER 7

Summary, Discussions, Observations, Future Research and Conclusion

7.1 General Summary

Chapter 1 introduced the background, objectives, hypotheses, and rationales for this study. It was observed from the literature that the ANL metric had only been applied to air conduction listening conditions. It was noted that the ANL metric did not consider any psychophysical parameters such as listeners' biases, sound familiarity, and the sound frequency bandwidths. It was also noted that more factors that may likely affect ANL have been neglected. Three objectives were studied to better understand the factors that may pose significant effects on listeners' ANLs.

Chapter 2 reviewed related literature and explored the different areas that contributed to the identified gaps. As explained in the body of the literature, factors responsible for ANL inter-subject variability need to be understood before a reasonable conclusion can be made in ANL application. It was noted that results found on the factors responsible for differences in ANL by different authors were context specific and hence difficult to generalize.

Chapter 3 discussed the processes involved in developing a psychophysical ANL model from a signal detection theory perspective and Stevens' power law. New formulas were developed for SNR and ANL. The psychophysical parameters in the new models included sound discriminability factor (d'), listeners' discriminability bias to sound intensity (β), sound familiarity (k), frequency bandwidth (ψ), listeners' most comfortable listening level (MCLL), and the maximum background noise level (BNL). Equipment used in the study was discussed, and a detailed explanation of each application was provided.

Chapter 4 presented the experimental methodology, protocols, procedures, and experimental design for Hypothesis 1 that studied the effect of frequency bandwidths on ANL. Two listening conditions were used: (a) listening through earphones, and (b) listening through a loudspeaker (referred to as the sound field method of listening). There were two types of noise: multi-talker babble noise and white noise, each in two frequency levels (High and Low). The results of the experiments revealed the following: (a) statistically significant main effects of background noise frequency levels on ANL; (b) the babble noise effect was statistically significant while the white noise effect was not; (c) signal source effects were found statistically significant on ANL; (d) no statistical significant interactions existed between any of the two independent variables; (e) there was a statistically significant interaction within the three independent variables; (f) signal sources and noise type effect were found significant when listening through the sound field under babble background noise distraction; (g) noise type and noise frequency level effects were found to be statistically significant with babble noise at high frequency and with white noise at low frequency; (h) Signal source and noise frequency level effects were found to be statistically significant with earphones at low frequency background noise and with sound field at high frequency background noise; (i) different listening conditions had different MANL thresholds; (j) no significant difference existed between listeners' MANL threshold when listening through earphones and when listening through the sound field method; (k) no statistically significant difference existed in discriminability bias between listening through earphones and through the sound field method; and (l) as the listeners' sound discriminability (d') increased, so did ANL.

Chapter 5 investigated the hypothesis that no differences would be found in the ANL recorded when a noise loudspeaker was located at different angles. The following results were found: (a) ANLs at different loudspeaker locations had no statistically significant difference from one another; (b) no statistically significant difference in ANL existed between genders; (c) the males had a higher positive bias toward signal and noise at all locations, except at the 315-degree azimuth; (d) the males had higher positive biases toward sound at three different noise loudspeaker locations; (e) the females discriminability biases were found to be positively high toward sound at the 315-degree azimuth of the noise loudspeaker location; and (f) psychophysical results showed that the least MANL thresholds and the listeners' discriminability bias toward sound were zero at the 315-degree loudspeaker location.

Chapter 6 presented the findings on the third hypothesis that investigated the differences between listeners' SCNL and ANL under different background noise conditions. The results revealed the following: (a) no statistically significant difference existed between SCNL and ANL; (b) no significant differences were found in the noise types either when ANL was the dependent variable or when SCNL was the dependent variable; (c) listeners have higher positive discriminability bias toward signal for ANL and a more positive discriminability bias toward noise for SCNL when the multi-talker babble noise was the background noise distraction; and (f) a minimum ANL threshold (logc) was found when the speech spectrum was the background noise. Likewise, the minimum SCNL was found under the same background noise with speech spectrum.

7.2 Discussions and Observations

The major findings associated with this study are as follows:

1. The effects of noise frequency bandwidths on ANL were found to be statistically significant, a finding aligned with Johnson et al.'s (2009) findings. Johnson et al.'s (2009) study revealed a significant increase in the mean ANL when high-frequency

bandwidth was extended from 3 to 9 kHz and from 6 to 9 kHz. In their study, the frequency bandwidth of both the signal and the background noise was varied from 3 to 6 KHz and from 6 to 9 KHz. The study was conducted on listeners with normal hearing and with mild sensorineural hearing loss. Likewise, Horwitz et al.'s (2008) study revealed a significant increase in speech recognition with the addition of high-frequency speech bands. Horwitz et al.'s (2008) study was conducted on speech recognition and measured monaurally under headphones for nonsense syllables low-pass filtered in one-third-octave steps between 2.2 and 5.6 kHz. Included in their study were 18 younger adults with normal hearing, and 16 older adults with sloping high frequency sensorineural hearing loss.

2. The psychophysical model revealed that background noise types and noise frequency bandwidths can predict listener discriminability bias toward the noise and the signal intensity.
3. The psychophysical model developed in Chapter 3 through the data collected revealed that different environmental conditions have different ANLs; therefore, the ANL threshold will depend on the condition where the experiment is conducted.
4. The psychophysical model results showed no significance difference between listeners' MANL threshold when listening through a headphone, and when listening through the sound field method.
5. The analysis across gender in ANL under different loudspeaker locations revealed that there were no significant differences in genders. However, the results revealed a significant difference between genders in discriminability bias toward sound intensity. Male discriminability bias toward sound was found to be higher positively than that of

females. This indicates that males will perform better in a noisy environment than the females. Meanwhile, the female gender had a higher negative discriminability bias toward noise intensity; this indicates that females had a low tolerance for noise when listening and following a presented signal in a noisy condition.

6. Although speech comprehension in noise level is different from the listeners' willingness to accept background noise, the results of this study showed that the differences between SCNL and ANL were not statistically significant. Therefore, the procedure for the two processes can be used interchangeably.

7.3 Limitations of the Current Study

Several limitations of the current study can be identified. First, the use of low and high frequency measures remain controversial among audiologists. This is an important factor to consider when deciding to implement the results of this study in clinical settings. The high and low frequency can be useful in helping individuals understand the level of noise to which they have been exposed.

Second, the results of this study were obtained only from university students who were normal-hearing listeners. This population may be unique compared to the general population, especially hearing aid users, although studies have proved that ANL is hearing independent. Nevertheless, caution should be taken if generalizing the results of this study to the hearing aid users of the entire population. Different results might have been obtained if hearing aid users were included in the study.

Third, the lack of incentives for the participants was another challenge faced during this study. Even though cans of soda were offered after the experiment, participants expected a reward of monetary value which limited the number of subjects who participated in the study.

Population size might have been the reason why the R-squared recorded with the model were small; therefore, caution should be taken when generalizing the results of this study to the entire population.

7.4 Recommendations

The results of this research could have been different if participants with impaired hearing were examined with the normal-hearing listeners. It is possible that high frequency or low frequency noise in the broadband condition will not have any significant difference on normal hearing listeners' ability to accept or reject more background noise using the clinical model. Therefore, hearing aid users are recommended as participants to adequately study the effect of frequency bandwidth on listeners' acceptance of background noise.

The size of the sample was also a limitation to this study. Even though the sample size proposed for this study was met, more subjects would be appropriate to increase the likelihood of producing significant results. Likewise, the number of hypotheses treated in a study should be limited to two in order to improve the chances of having a larger sample for each study.

7.5 Directions for Future Research

The results of this study have provided evidence that the listener psychophysical ANL is influenced by sound discriminability. However, the fact remains that the sound discriminability was determined based on assumed sound familiarity. It is important to develop a questionnaire that will explore listeners' sound familiarity in order to expand the knowledge of how ANL actually increases as sound discriminability increases. Further research should include a larger sample size of individuals who are matched for both gender and hearing sensitivity.

Further research that will specifically use this model should be conducted in a more conducive acoustic environment. More research is needed to determine the threshold of the psychophysical ANL parameters that can be generalized in context (e.g., environment, task, population). The study suggests further research that more specifically examines the differences between SCNLs and ANLs. It was found in this study that SCNLs are not statistically significantly different from ANLs across the participants. The psychophysical model showed differences in listeners' discriminability biases toward signal and noise. Therefore, it would be important to examine this issue in more detail. It would also be useful to conduct a study utilizing different modes of listening to speech signals and noises to determine if consistent results would be found that validate this study. Finally, the study should be extended to a bone conduction listening environment.

7.6 Conclusion

The results of this study supported previous investigations which indicated that ANLs are gender independent. ANLs under different background noise bandwidth frequency were found to have a significant effect. The interaction effect among signal sources, noise types, and noise frequency levels were found to be statistically significant. No significant interaction was found between any of the two independent variables. No statistically significant differences were found in noise loudspeaker locations on ANLs. Results revealed significant differences in participants' MCLL and BNL between genders where males had the higher values.

The results of the regression analysis with the psychophysical model showed that as listeners' sound discriminability increased, the ANLs also increased. Results showed that listeners have higher positive discriminability biases toward signals during ANL and more positive bias toward noise during SCNL when multi-talker babble noise was the background noise distraction. A minimum threshold under both ANL and SCNL was found when the speech spectrum was the background noise. The psychophysical model results showed that listeners had a higher minimum ANL threshold when the speech signal was delivered through earphones. Listeners' biases were higher toward signal with earphones. These findings may be important for the future design of hearing aid programs for listening to speech in the presence of broadband background noise. The findings may assist audiologists to better fit hearing aids for hearing-impaired listeners. Tables 39–42 summarize the major quantitative psychophysical values that could be used in audiometric studies.

Table 39

Effects of Frequency Bandwidths on ANL

	Earphone Listening				Sound field Listening			
	White-Noise		Babble-Noise		White-Noise		Babble-Noise	
Freq. Level	ANL Threshold (logc)	Bias (β)	ANL Threshold (logc)	Bias (β)	ANL Threshold (logc)	Bias (β)	ANL Threshold (logc)	Bias (β)
High	0.00361	0.1742	0.0300	0.2078	0.1360	0.013	-0.1576	0.1869
Low	0.0167	0.1479	0.0011	0.1545	0.1280	0.015	0.0354	0.0354

Table 40

Effects of Loudspeaker Locations under Normal Listening Conditions

	45-degree	180-degree	225-degree	315-degree
ANL threshold	0.03096	0.01494	0.02641	-2.13
β (listener bias)	0.12179	0.15978	0.1236	0.000083

Table 41

Gender Effects Based on Loudspeaker Locations

	45-Degree		180-Degree		225-Degree		315-Degree	
	Male	Female	Male	Female	Male	Female	Male	Female
ANL Threshold	0.0580	-1.0581	0.03276	0.0164	0.04059	0.0072	0.5551	0.01616
β (Listener bias)	0.0780	0.2568	0.12963	0.1444	0.0802	0.1734	0.1980	0.14833

Table 42

Effects of Speech Comprehension in Noise Level and ANL

	SCNL		ANL	
	Babble	Speech spectrum	Babble	Speech spectrum
ANL Threshold	0.02933	0.02773	1.01772	0.5596
B (listener's bias)	0.11707	0.12088	0.18958	0.11073

References

Adams, E. M., & Moore, R. E. (2009). Effects of speech rate, background noise, and simulated hearing loss on speech rate judgment and speech intelligibility in young listeners. *Journal of the American Academy of Audiology, 20*(1), 28–39.

Adams, E. M., Gordon-Hickey, S., Moore, R. E., & Morlas, H. (2010). Effects of reverberation on acceptance noise level measurements in younger and older adults. *International Journal of Audiology, 49,* 832–838.

Ahissar, E., Nagarajan, S., Ahissar, M., Protopapas, A., Henry Mahncke, H., & Merzenich, M. M. (2001). Speech comprehension is correlated with temporal response patterns recorded from auditory cortex. *Proceeding of the National Academic Sciences of the United States of America, 98*(23), 13367–13372.

Ahlstrom, J. B., Horwitz, A. R., & Dubno J. R. (2009). Spatial benefit of bilateral hearing aids. *Ear and Hearing, 30*(2), 203–218.

American National Standards Institute (ANSI). (2002). *Acoustical performance criteria design requirements & guidelines for schools.* ANSI S12.60-2002. New York, NY: Author.

Baird, J. C., & Elliot J. N. (1978). *Fundamentals of scaling & psychophysics.* New York, NY: John Wiley & Son Inc.

Beasley, D. S., Bratt, G. W. & Rintelmann, W. F. (1980). *Journal of Speech, Language, and Hearing Research, 23,* 722–731.

Becker, G., & Güdesen, A. (2000). Passive sensing with acoustics on the battlefield. *Applied Acoustics, 59*(2), 149–178. doi:10.1016/S0003-682X (99)00023-7

Békésy, G. V. (1960). *Experiments in hearing* (E. G. Wever, Trans.). New York, NY: McGraw-Hill Book Company, Inc.

Blue, M. A., Ntuen, C., & Letowski, T. (2010). Speech intelligibility measured with shortened versions of Callsign Acquisition Test (CAT). *Applied Ergonomics*, *41*(2), 291–294. doi:10.1016/j.apergo.2009.07.011

Chermak, G. D., Vonhof, M., & Bendel, R. B**.** (1989). Word identification performance in the presence of competing speech and noise in learning disabled adults. *Ear and Hearing, 10*, 90–93.

Ching, T. Y. C., Dillon, H., Katsch, R., & Byrne, D. (2001). Maximizing effective audibility in hearing aid fitting. *Ear Hear*, *22*(3), 212–224.

Choma, M. A., Sarunic, M. V., Yang, C., & Izatt, J. A. (2003). Sensitivity advantage of swept source and Fourier domain optical coherence tomography. *Optical Society of America*, *11*(18), 2183–2189.

Christensen, M. (1997). *A quantitative study of noise levels in a four bedded intensive care unit.* Unpublished dissertation. Bournemouth University, Bournemouth.

Crowley, H. J., & Nabelek, I. V. (1996). Estimation of client-assessed hearing aid performance based upon unaided variables. *Journal of Speech and Hearing Research, 39,* 19–27.

D’Agostino, R. B. & Roseman, B. (1974). The power of Geary’s test of normality. *Biometrika, 61*(1), 181–184.

DeCarlo, L. T. (1998). Signal detection theory and generalization linear models. *Psychological Methods, 3*(2), 186–205.

Dillon, H. (2001). *Hearing aids*. New York, NY: Thieme.

Dubno, J. R., Dirk, D. D., & Morgan, D. E. (1984). Effects of age and mild hearing loss on speech recognition in noise. *The Journal of the Acoustical Society of America, 76,* 87–96.

Engineering Statistic Handbook by U.S. Commerce Department. (2010). *NIST/SEMATECH e-Handbook of Statistical Methods*. Retrieved March 24, 2012, from http://www.itl.nist.gov/div898/handbook/index.htm

Estes, W. K. (1992). *Mental psychophysics of categorization and decision.* Mahwah, NJ: Lawrence Erlbaum.

Evans, G. W., & Maxwell, E. L. (1997). Chronic noise exposure and reading deficits: The mediating effects of language acquisition. *Environment and Behavior, 29*(5), 638–656.

Fasanya, B. K., & Letowski, T. (2009). *Acceptable Noise Levels (ANLs) for speech and music for young people with normal hearing.* Proceedings of the Human Performance in Extreme Environment (HPEE) Society Conference, San Antonio TX, USA.

Fechner, G. T. (1907). *Elemente der Psychophysik* (3rd ed.). Leipzig: Breithopf & Heartel.

Festen, J. M., & Plomp, R. (1990). Effects of fluctuating noise and interfering speech on the speech-reception threshold for impaired and normal hearing. *The Journal of the Acoustical Society of America, 88*(4), 1725–1736.

Finitzo-Hieber, T., & Tillman, T. (1978). Room acoustics effects on monosyllabic word discrimination ability for normal & hearing impaired children. *Journal of speech Hearing Research, 21,* 440–458.

Fitzpatrick, D. (2008). *Effects of auditory training on speech recognition for persons within binaural sensorineural hearing loss.* Doctoral Dissertation, Steinhardt School of Culture, Education and Human Development, New York.

Franklin, C. A., Jr., Thelin, J. W., Nabelek, A. K., & Burchfield, S. B. (2006). The effect of speech presentation level on acceptance of background noise in listeners with normal hearing. *Journal of the American Academy of Audiology, 17*(2), 141–146.

Franks, J. R. (1982). Judgments of hearing aid processed music. *Ear and Hearing, 3*(1), 18–23.

Freed, D. J., & Soli, S. D. (2006). An objective procedure for evaluation of adaptive antifeedback algorithms in hearing aids. *Ear and Hearing, 27*(4), 382–398.

Freyaldenhoven, M. C., Plyler, P. N., Thelin, J. W., & Hedrick, M. S. (2007). The effects of speech presentation level on acceptance of noise in listeners with normal and impaired hearing. *Journal of Speech, Language, and Hearing Research, 50*(4), 878–885.

Freyaldenhoven, M. C., & Newman, J. A. (2012). *Acceptable noise level.* Retrieved January 3, 2013, from http://www.audiologyonline.com/articles/acceptable-noise-level-update-2012-772

Freyaldenhoven, M. C., & Smiley, D. F. (2006). Acceptance of background noise in children with normal hearing. *Journal of Educational Audiology, 13,* 27–31.

Freyaldenhoven, M. C., Smiley, D. F., Muenchen, R. A., & Konrad, T. N. (2006). Acceptable noise level: Reliability measures and comparison to background noise preference. *Journal of the American Academy of Audiology, 17,* 640–648.

Fuller, M., Fuller, K., Fuller, P., & Levitt, H. (2012). Speech comprehension training and auditory and cognitive processing in older adults. *American Journal of Audiology, 21,* 351–357.

Gelfand, S. A., Ross, L. S., & Miller, S. (1988). Sentence reception in noise from one versus two source: Effects of aging & hearing loss. *The Journal of the Acoustical Society of America, 83*(1), 248–256.

Gelfand, S. A. (Ed.). (2009). *Audiology* (3rd ed.). New York, NY: Thieme.

Gengel, R. (1971). Acceptable speech-to-noise-ratios for aided speech discrimination by the hearing impaired. *Journal of Auditory Research, 11,* 219–222.

Gilden, D. L. (2001). *Cognitive Emissions of 1/f Noise.* Austin, TX: The University of Texas at Austin.

Gordon-Hickey, S., & Moore, R. E. (2008). Acceptance of noise with intelligible, reversed, and unfamiliar primary discourse. *American Journal of Audiology, 17*(2), 129–135.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics.* New York, NY: Wiley.

Hanley, T. D., & Steer, M. D. (1949). Effects of level of distracting noise upon speaking rate, duration and intensity. *Journal of Speech and Hearing Disorders, 14*, 363–368.

Harkrider, A. W., & Smith, S. B. (2005). Acceptable noise level, phoneme recognition in noise, and measures of auditory efferent activity. *Journal of the American Academy of Audiology, 16,* 530–545. doi:10.3766/jaaa.16.8.2

Harvey Jr., L. O. (2012). *Decision theory: Sensory and decision processes.* Unpublished Spring lecture, department of Psychology, University of Colorado at Boulder.

Health and Safety Executive. (2005). *Noise at work regulations.* London: Health and Safety Executive.

Heeger, D. (1997). *Lecture note on signal detection theory.* Retrieved August 23, 2011, from http://www.cns.nyu.edu/~david/handouts/sdt-advanced.pdf

Henry, P., & Letowski, T. R. (Eds.). (2007). *Bone conduction: Anatomy, physiology, and communication.* Aberdeen Proving Ground, MD: Army Research Laboratory.

Hogan, C. A., & Turner, C. W. (1998). High-frequency audibility: Benefits for hearing impaired listeners. *The Journal of the Acoustical Society of American, 104*(1), 90–119.

Horwitz, A. R., Ahlstrom, J. B., & Dubno, J. R. (2008). Factors affecting the benefits of high frequency amplification. *Journal of Speech, Language, and Hearing Research, 51*(3), 798–813.

Houtgast, T., & Steeneken, H. J. M. (1973). The modulation transfer function in room acoustics as a predictor of speech intelligibility. *Acoustica, 28*, 66–73.

Humes, L. E., Joellenbeck, L. M., & Durch, J.S. (2005). Noise and Military service: Implications for hearing loss and tinnitus. Retrieved from http://books.google.com/books?hl=en&lr=&id=lC4yhBPXPbsC&oi=fnd&pg=PA1&dq=papers+on+effects+of+noise+in+military+battlefield&ots=zl1EF0UGnW&sig=b5oqkKONzE-2L0lgAOVGKwiXwQA#v=onepage&q&f=false.

Hygge, S. (2003). Classroom experiments on the effects of different noise sources and sound levels on long-term recall and recognition in children. *Applied Cognitive Psychology, 17*(8), 895–914.

Iulian Rosu, YO3DAC/VA3IUL. Retrieved December 2, 2011, from http://www.qsl.net/va3iul

Jamieson, D. G., Parsa, V., Price, M. C., & Till, J. (2002). Interaction of speech coders and atypical speech I: Effects on speech intelligibility. *Journal of Speech, Language & Hearing Research, 45*(3), 482–493.

Johnson, E., Ricketts, T., & Hornsby, B. (2009). The effect of extending high-frequency bandwidth on the Acceptable Noise Level (ANL) of hearing-impaired listeners. *International Journal of Audiology, 48*(6), 353–362

Kanekama, Y. (2009). *Effects of speech reading and signal-to-noise ratio on understanding mainstream American English by American and Indian adults.* Doctoral Dissertation, Wichita State University, Wichita, KS.

Kantowitz, B. H., & Sorkin, R. D. (Ed.). (1983). *Human factors: Understanding people-system relationship.* Toronto: John Wiley & Son.

Kattel, B. P., Fasanya, B. K., Letowski, T. R., & Hargrove S. K. (2008). *The effect of types of background noise on the acceptable noise levels of individuals with normal hearing.* Proceeding of the 13th Annual International Conference of Industrial Engineering. Theory, applications and practice. Las Vegas, NV.

Killion, M. C., & Tillman, T. W. (1982). Evaluation of high-fidelity hearing aids. *Journal of Speech and Hearing Research, 25*(1), 15–25.

Killion M. C., Niquette, P. A., Gundmundsen, G. I., Revit L. J., & Banerjee, S. (2004). Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. *The Journal of the Acoustical Society of America, 116*(4 Pt. 1), 2395–2405.

Krause, J. C., & Braida L. D. (2002). Investigating alternative forms of clear speech: The effects of speaking rate and speaking mode on intelligibility. *The Journal of the Acoustical Society of America, 112*(5), 2165–2172

Krishnamurthy, N., & Hansen, J. H. L. (2009). Babble noise: Modeling, analysis, and applications. *IEEE Transactions on Audio, Speech, and Language Processing, 17*(7), 1394–1407.

Kryter, K. D. (1970). *The effects of noise on man.* New York, NY: Academic Press.

Kryter, K. D. (1976). Extra auditory effects of noise. In D. Henderson, R. P. Hamernik, S. Dosanjh, & J. H. Mills (Eds.), *Effects of noise on hearing* (pp. 531–546). New York, NY: Raven Press.

Kryter, K. D. (1980). Physiological acoustics and health. *The Journal of the Acoustical Society of*

America, 68, 10–14.

Lombard, E. (1911). Le signe de l'elevation de la voix. *Annales des Maladies de l'Oreille, du Larynx, du Nez et du Pharynx, 37*, 101–119.

Lovelace, C. T., Stein, B. E., & Wallace M. T. (2003). An irrelevant light enhances auditory detection in humans: A psychophysical analysis of multisensory integration in stimulus detection. *Cognitive brain research*, *17*(2), 447–453.

Luce, R. D., & Krumhansl, C. (1988). Measurement, scaling, and psychophysics. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology* (pp. 1–74). New York, NY: Wiley.

Lytle, S. R. (1994). *A comparison of amplification efficacy and toleration of background noise in hearing-impaired elderly persons*. Master's thesis, University of Tennessee, Knoxville.

Marchetto, E., Avanzini, F., & Flego, F. (2009). *An automatic speaker recognition system for intelligence applications.* In proceedings of European Signal Processing Conference (EUSIPCO'09), 1612–1616, Glasgow, Scotland.

Martin, F. N. (1998). *Exercises in audiology: A laboratory manual* (pp. 1–5). Boston, MA: Allyn and Bacon.

Maxwell, E. L., & Evans, W. G. (1999). *Design of child care centers and effects of noise on young children.* Minneapolis, IN: DesignShare.

McCabe, B. F. (1979). Autoimmune sensorineural hearing loss. *The Annals of Otology, Rhinology, and Laryngology*, *88*(5 Pt. 1), 585–589.

McFadden, D. (1998). Sex differences in the auditory system. *Developmental Neuropsychology, 14*(2-3), 261–298.

Moore, B. J. (1996). Perceptual consequences of cochlear hearing loss and their implications for the design of hearing aids. *Ear and Hearing*, *17*(2), 133–160.

Moore, B. C. J., & Tan, C. T. (2003). Perceived naturalness of spectrally distorted speech and music. *The Journal of the Acoustical Society of America, 114*(1), 408–419.

Mundorff, J. S. (2011). *Effects of speech signal type and attention on acceptable noise level in elderly, hearing-impaired listeners*. Doctoral Dissertation, James Madison University.

Nabelek, A. K., Freyaldenhoven, M. C., Tampas, J. W., Burchfield, S. B., & Muenchen, R. A. (2006). Acceptable noise level as a predictor of hearing aid use. *Journal of the American Academy of Audiology, 17*(9), 626–639.

Nabelek, A. K. (2005). Acceptance of background noise may be key to successful fittings. *The Hearing Journal, 58*(4), 10–15.

Nabelek, A. K., & Nabelek, I. V. (Eds.). (1994). Room acoustics and speech perception. In J. Katz (Ed.), *Handbook of clinical audiology* (pp. 624–637). Baltimore, MD: Williams and Wilkins.

Nabelek, A. K., Tampas, J. W., & Burchfield, S. B. (2004). Comparison of speech perception in background noise with acceptance of background noise in aided and unaided conditions. *Journal of Speech, Language & Hearing Research, 47*(5), 1001–1011.

Nabelek, A. K., Tucker, F. M., & Letowski, T. R. (1991). Toleration of background noises—relationship with patterns of hearing-aid use by elderly persons. *Journal of Speech and Hearing Research, 34*(3), 679–685.

National Institutes on Deafness and other Communication Disorders –NIDCD (2003). How your brain understand what your ear hears. Retrieved from https://science.education.nih.gov/supplements/nih3/hearing/guide/info-hearing.htm (Retrieved 08/16/2012)

Oxenham, A. J., & Simonson, A. M. (2009). Masking release for low- and high-pass-filtered speech in the presence of noise and single-talker interference. *The Journal of the Acoustical Society of America, 125*(1), 457–468.

Pascoe, D. P. (1975). Frequency responses of hearing aids and their effects on the speech perception of hearing-impaired subjects. *The Annals of Otology, Rhinology, and Laryngology, 84*(Suppl. 23), 5–40.

Penner, M. J., & Shiffrin, R. M. (1980). Nonlinearities in the coding of intensity within the context of a temporal summation model. *The Journal of the Acoustical Society of America, 67*(2), 617–627.

Peissig, J., & Kollmeier, B. (1997). Directivity of binaural noise reduction in spatial multiple noise-source arrangements for normal and impaired listeners. *The Journal of the Acoustical Society of America, 101*(3), 1660–1670.

Percival, L., & Loeb, M. (1980). Influence of noise characteristics on behavioral aftereffects. *Human Factors, 22*(3), 341–352.

Picheny, M. A., Durlach, N. I., & Braida, L. D. (1989). Speaking clearly for the hard of hearing III: An attempt to determine the contribution of speaking rate to differences in intelligibility between clear and conversational speech. *Journal of Speech and Hearing Research, 32*(3), 600–603.

Rao, M. D., & Letowski, T. (2003). Speech intelligibility of the Call Sign Acquisition Test (CAT) for army communication systems. [Auditory]. *Audio Engineering Society* (5836).

Robert Silver, (2000). About.com Guide to Home Theater. Retrieved from http://hometheater.about.com/od/hometheaterglossary/g/sndef.htm

Roeser, R. J., Valente, M., & Hosford-Dunn, H. (2000). *Audiology diagnosis* (1st & 2nd ed.). New York, NY: Thieme.

Rogers, D. S., Harkrider, A. W., Burchfield, S. B., & Nabelek, A. K. (2003). The influence of listener's gender on the acceptance of background noise. *Journal of the American Academy of Audiology*, *14*(7), 372–382.

Rosenblum, L. (2008). Primacy of multimodal speech perception. In D. B. Pisoni & R. E. Remez (Eds.), *The Handbook of speech perception* (pp. 51–78). Malden, MA: Blackwell.

Rosowski, J. J., & Merchant, S. N. (Eds.). (2000). *The function and mechanics of normal, diseased and reconstruction middle ears.* The Hague, The Netherlands: Kugler.

Ross, M. (2008). Cochlear implants and hearing aids: Some personal and professional reflections. *Journal of Rehabilitation Research and Development, 45*(5), xvii-xxii.

Rouse M. (2006). *Definition of pink noise.* http://whatis.techtarget.com/definition/pink-noise (Retrieved 03/21/2013).

Sandlin, R. E. (2000). *Textbook of hearing aid amplification: Technologies and clinical consideration* (2nd ed.). San Diego, CA: Singular.

Savaliya, S., Rakholiya, S., & Marar, A. (2008). Current Trends in Middle Ear Surgery: Ossiculoplasty and Stapedioplasty with Titanium Prostheses. Retrieved from http://www.eonmeditech.com/articles-certificates.html

Schneider, B. A., Daneman, M., Murphy, D. R., & Kwong-See, S. (2000). Listening to discourse in distracting settings: The effects of aging. *Psychology and Aging, 15,* 110–125.

Schneider, B. A., Daneman, M., & Pichora-Fuller, M. K. (2002). Listening in aging adults: From discourse comprehension to psychoacoustics. *Canadian Journal of Experimental Psychology, 56,* 139–152

Schomer, P. (2001). *Assessment of noise annoyance.* Champaign, IL: Schomer and Associates.

Sheridan, T. B., & Ferrell, W. (1974). *Man-machine systems.* Cambridge, MA: MIT Press.

Stolfi, J. (2013). White noise. Retrieved from http://en.wikipedia.org/wiki/White_noise

Sullivan, J. A., Allsman, C. S., Nielsen, L. B., & Mobley, J. P. (1992). Amplification for listeners with steeply sloping, high-frequency hearing loss. *Ear and Hearing, 13,* 35–45.

Summers, W. V., Pisoni, D. B., Bernacki, R. H., Pedlow, R. I., & Stokes, M. A. (1988). Effects of noise on speech production: Acoustic and perceptual analysis. *Journal of Acoustical Society of America, 84*(3), 917–928.

Summers, V., & Leek, M. R. (1998). F0 processing and the separation of competing speech signals by listeners with normal hearing and with hearing loss. *Journal of Speech, Language and Hearing Research, 41,* 1294-1306.

Swets, J. A., & Pickett, R. M. (1982). *Evaluation of diagnostic systems: Methods from Signal Detection Theory*. New York, NY: Academic Press.

Swets, J. A. (1996). *Signal Detection Theory and ROC analysis in psychology and diagnostics.* Mahwah, NJ: Erlbaum.

Tampas, J. W., & Harkrider, A. W. (2006). Auditory evoked potentials in females with high and low acceptance of background noise when listening to speech. *Journal of Acoustical Society of America, 119*(3), 1548–1561.

Tanner, W. P., Jr., & Swets, J. A. (1954). A decision making theory of visual detection. *Psychological Review, 61*(6), 401–409.

Trychin, S. (1993). *Communication issues related to hearing loss*. Washington DC: Gallaudet University Press.

Tucker, D. (2009). *Central auditory processing.* Department of Communication and Science Disorder, The University of North Carolina Greensboro.

Turner, C. W., & Cummings, K. R. (1999). Speech audibility for listeners with high-frequency hearing loss. *American Journal of Audiology, 8,* 47–56.

Turner, C. W., & Henry, B. A. (2002). Benefits of amplification for speech recognition in background noise. *The Journal of the Acoustical Society of America, 112*(4), 1675–1680.

Tuzlukov, V. P. (Ed.). (2001). *Signal detection theory.* Minsk, Belarus: Institute of Engineering Cybernitics.

Tye-Murray, N., Sommers, M. S., & Spehar, B. (2007). Audiovisual integration and lipreading abilities of older adults with normal and impaired hearing. *Ear and Hearing, 28,* 656–668.

Uchanski, R. M., Choi, S., Braida, L. D., Reed, C. M., & Durlach, N. I. (1996). Speaking clearly for the hard of hearing IV: Further studies of the role of speaking rate. *Journal of Speech and Hearing Research, 39*(3), 494–509.

U.S. Commerce Department. (2010). *NIST/SEMATECH e-Handbook of statistical methods.* Retrieved from http://www.itl.nist.gov/div898/handbook/index.htm

Valla, A. F., & Sweetow, R. W. (2000). Psychology on individuals with hearing impairment. In R. E. Sandlin, *Textbook of hearing aid amplification: Technical and clinical considerations* (2nd ed., pp. 557– 570). San Diego, CA.

Verghese, P. (2001). Visual search and attention: A signal detection theory approach. *Neuron, 31*(4), 523–535.

Vickers, D. A., Moore, B. C. J., & Baer, T. (2001). Effects of low-pass filtering on the intelligibility of speech in quiet for people with and without dead regions at high frequencies. *The Journal of the Acoustical Society of America, 110,* 1164–1175.

Walden, B., Surr, R., Cord, M., & Dyrlund, O. (2004). Predicting hearing aid microphone preference in everyday listening. *Journal of the American Academy of Audiology, 15*(5), 365–396.

Weber, E. H. (1967). Leipzig physiologist. *Journal of the American Medical Association, 199*(4), 272–273. doi:10.1001/jama.199.4.272

Wickens, T. D. (2001). *Elementary signal detection theory.* New York, NY: Oxford University Press.

Wingfield, A. (1996). Cognitive factors in auditory performance: Context, speed of processing, and constraints of memory. *Journal of the American Academy of Audiology, 7,* 175–182

World Health Organization (WHO). (2002). *Community noise-Environmental health criteria document, external review draft.* Geneva: WHO Publishing.

Yost, W., & Nielsen, D. (1977). *Fundamentals of hearing: An introduction.* New York, NY: Holt, Rinehart, and Winston.

Appendix A

Hearing Screening (Adults)

Hearing Screening (Adults)

Name ____ Date______________

Birth Date ______________________ Age__________ Gender: M F

Screening Examiner ______________________ Calibration Date__________________

Case History-circle appropriate answers

Do you think you have a hearing loss? No	Yes	No
Has a hearing aid(s) ever been recommended for you?	**Yes**	**No**
Is your hearing better in one ear? *If yes, which is the better ear? Right Left*	**Yes**	**No**
Do you have ringing or noises in your ears? *If yes, which is the better ear? Right Left*	**Yes**	**No**
Do you consider dizziness to be a problem for you?	**Yes**	**No**
Have you had recent drainage from your ear(s)? *If yes, which is the better ear? Right Left*	**Yes**	**No**
Do you have pain or discomfort in your ear(s)? *If yes, which is the better ear? Right Left*	**Yes**	**No**
Have you received medical consultation for any of the above conditions?	**Yes**	**No**

Pure-tone Screen (25dB HL)—Indicate the subject's response for each frequency. (R=Response, NR= No Response)

Frequency	500	1000	2000	4000Hz
Right Ear				
Left Ear				
PASS	**NO PASS**			

Appendix B

Informed Consent Form

North Carolina A&T State University

INFORMED CONSENT FORM

Study Title: Quantitative Analyses of Acceptable Noise Level for Air Conducion Listening

Principal Investigator: Bankole K. Fasanya

You have been asked to participate as a subject in a research project that requires you to pass through hearing screening measured at octave frequencies in the audiometric range from 500 Hz to 4000Hz conducted under the supervision of a certified audiologist. The level of the signal at your Most Comfortable Listening Level (MCLL) to the played speech and the maximum acceptable noise signal you can tolerate will be measured and recorded for analysis. The speech 4 CD's under study will be a connected speech of humorous character (Comedian's play) which you will be asked to select from a choice of four CDs. The signals will be played from a PC computer and a CD player. The noise types will be multi-talker noise (speech babble), white noise, speech spectrum and Pink noise. You will be listening to the speech and the noise through loudspeakers that will be placed at 45, 135, 225, and 315 degrees azimuth three meters away in the Human Factors Acoustics Chamber of Department of Industrial and System Engineering at NCA&T. The noise levels will be kept within the OSHA prescribed limits.

PURPOSE

The purpose of this research is to develop quantitative models for Acceptable Noise Level (ANL) under BC and AC listening conditions. Further the following objectives will also be addressed in this study (a) the effects of noise type (differences in noise spectra) and speech signal type (e.g., such as speech by males or females) on the ANL for normal hearing listeners. (b) The effects of mode of communication (sound field, earphones) on the ANL and speech comprehension in noise as measured by acceptable SNR. (c) The effects of loudspeakers configuration on ANL and speech comprehension under various listening conditions.

North Carolina A&T State University

SOURCE OF FUNDING

This project is under the direction of Bankole Kolawole Fasanya, a graduate student. There is no funding for this study. The researchers do not, however, hold a direct financial interest in the sponsor.

PROCEDURES

If you choose to participate in this study, you will be asked to complete a demographic form and a questionnaire to determine your internal sound responses. After which you will be involved in four sessions. The experiment will be conducted in a sound proof chamber located in Interdisciplinary Research Center (IRC) R222. The first session is to conduct hearing screening for each participant to ensure that participating listeners have normal hearing. The second session, listeners' ANL values will be determined in sound field under several experimental conditions involving four types of noise (pink noise, white noise, speech spectrum noise, and speech babble shaped as speech spectrum noise) and three configurations of noise delivering loudspeakers (front directional, rear directional, and omnidirectional noise sound fields) for both air (loudspeaker at 0º) listening with ears open. Various types of speech signals (three voices with different fundamental frequencies) will also be used. At the third session, listeners will complete the same tasks as in session two but for speech comprehension task (SNR) in the sound field. At the fourth session, listeners' ANL values will be determined for speech and noise delivered either through earphones conduction system.

RISKS AND BENEFITS

Your participation in this study will only involve minimal risk such as claustrophobia; plan to minimize this risk has been made by allowing break between sessions. If you have known history of cluastrophobia, you will be excluded from the study. Other than that no known physical or psychological stresses have been recorded in the past in similar experiments. Hence, it is believed that there will be no adverse effect on physical or psychological state of the participants due to the experiment. If you feel uncomfortable with the experiment you have the option of quitting at any time without penalty.

North Carolina A&T State University

COSTS TO STUDY PARTICIPANTS

There are no costs to you while participating in this study other than your time. It will take approximately 2 hours and 30 minutes to complete the task.

COMPENSATION

If you decided to participate, it will be a voluntary act and there will be no monetary compensation or any compensation in terms of incentives. You may choose to withdraw from participation at any time without any penalty. Such a withdrawal will not affect your relationship, if any, with the Department of Industrial, and Systems Engineering (ISE) or with the investigators**.**

CONFIDENTIALITY AND DISCLOSURE

Efforts, such as coding research records, keeping research records secure and allowing only authorized people to have access to research records, will be made to keep your information safe. A report of general and combined results from several participants in this project will be prepared for the department of Industrial and Systems at North Carolina A&T State University, and may be submitted to a professional publication or conference at a later time. All information obtained during this study by which you could be identified will be held in strict confidence.

Results of this experiment will not be provided for you.

QUESTIONS ABOUT THE STUDY

The investigator, Bankole K. Fasanya, is available to answer any questions that you have about your involvement in this project. Please contact Bankole at 443-939-0346 or by email, bkfasany@ncat.edu or fasanya2000@yahoo.com. You may also contact my advisor Dr. Celestine Ntuen at 336-334-7996 or by email at ntuen@ncat.edu.

WHAT HAPPENS IN CASE OF INJURY OR ILLNESS

This study involves no risk for injury. Therefore, there is no compensation for injury.

North Carolina A&T State University

RIGHTS AS A RESEARCH PARTICIPANT

Your participation is voluntary. You may end your participation at any time. Refusing to participate or leaving the study at a later time will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the experimenter or study staff first.

The investigators also have the right to stop your participation in the study at any time. Reasons the experimenter may stop your participation in this study will be due to unwillingness to follow task instruction or with hearing screening result thresholds higher than 25 dB at octave band frequencies between 250 and 6000 Hz.

If you have a question about your rights as a research participant, you should contact the Compliance Office at (336) 334-7995.

You will be given a copy of this form.

SIGNATURES

A signed statement of informed consent is required of all participants in this project. Your signature indicates that you voluntarily agree to the conditions of participation described above, and that you have received a copy of this Form.

I agree to take part in this study. I have had a chance to ask questions about being in this study and have those questions answered.

______________________________ ________________________

Signature of Subject Date

Using language that is understandable and appropriate, I have discussed this project and the items above with the subject and/or authorized representatives.

______________________________ ________________________

Signature of Principal Investigator Date

Appendix C

Sample Data

Logarithm Values of Listeners' MCLL, BNL and d' under Sound field and Earphone Signal Listening Conditions

	Earphone-High-White			Earphone-low-white			Earphone-high-babble			Earphone-low-babble		
n	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN
1	0.045	1.588	1.595	0.094	1.588	1.584	0.08	1.59	1.59	0.08	1.588	1.59
2	0.038	1.599	1.595	0.162	1.599	1.591	0.07	1.60	1.59	0.07	1.599	1.59
3	0.219	1.604	1.599	0.042	1.604	1.595	0.25	1.60	1.59	0.25	1.604	1.59
4	-0.055	1.605	1.600	0.230	1.605	1.596	-0.02	1.61	1.59	-0.02	1.605	1.59
5	0.057	1.605	1.600	-0.036	1.605	1.596	0.09	1.61	1.59	0.09	1.605	1.59
6	0.113	1.613	1.602	0.076	1.613	1.596	0.37	1.61	1.59	0.37	1.613	1.59
7	0.274	1.624	1.602	0.328	1.624	1.596	0.14	1.62	1.59	0.14	1.624	1.59
8	0.302	1.626	1.602	0.124	1.626	1.598	0.33	1.63	1.60	0.33	1.626	1.60
9	0.106	1.644	1.602	0.341	1.644	1.599	0.64	1.64	1.60	0.64	1.644	1.60
10	0.218	1.645	1.602	0.221	1.645	1.601	0.24	1.65	1.60	0.24	1.645	1.60
11	0.330	1.647	1.602	0.270	1.647	1.603	0.29	1.65	1.60	0.29	1.647	1.60
12	-0.021	1.648	1.604	0.191	1.648	1.609	0.13	1.65	1.60	0.13	1.648	1.60
13	0.272	1.648	1.607	0.289	1.648	1.609	0.02	1.65	1.60	0.02	1.648	1.60
14	0.300	1.654	1.607	0.191	1.654	1.609	0.52	1.65	1.60	0.52	1.654	1.60

Sample Data (cont.)

	Earphone-High-White			Earphone-low-white			Earphone-high-babble			Earphone-low-babble		
n	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN
15	0.194	1.658	1.609	-0.019	1.658	1.609	0.32	1.66	1.60	0.32	1.658	1.60
16	0.194	1.662	1.609	-0.055	1.662	1.611	-0.01	1.66	1.60	-0.01	1.662	1.60
17	0.593	1.663	1.609	0.238	1.663	1.614	0.41	1.66	1.60	0.41	1.663	1.60
18	0.376	1.667	1.609	0.327	1.667	1.619	0.27	1.67	1.61	0.27	1.667	1.61
19	-0.024	1.668	1.610	0.522	1.668	1.624	0.19	1.67	1.61	0.19	1.668	1.61
20	0.465	1.675	1.613	0.903	1.675	1.634	0.19	1.67	1.61	0.19	1.675	1.61
21	0.126	1.682	1.620	0.341	1.682	1.639	0.16	1.68	1.61	0.16	1.682	1.61
22	0.161	1.702	1.621	0.187	1.702	1.639	1.00	1.70	1.61	1.00	1.702	1.61
23	0.951	1.720	1.625	0.068	1.720	1.640	0.68	1.72	1.62	0.68	1.720	1.62
24	0.250	1.731	1.626	-0.110	1.731	1.667	0.13	1.73	1.63	0.13	1.731	1.63
25	0.647	1.746	1.631	0.411	1.746	1.676	0.24	1.75	1.63	0.24	1.746	1.63
26	0.495	1.785	1.643	-0.050	1.785	1.739	0.74	1.79	1.66	0.74	1.785	1.66
27	0.798	1.786	1.654	0.262	1.786	1.746	0.38	1.79	1.67	0.38	1.786	1.67
28	-0.364	1.888	1.927	-0.247	1.888	1.915	-0.21	1.89	1.91	-0.21	1.889	1.91

Sample Data (cont.)

	Sound field-high-white			Sound field-low-white			Sound field-high-babble			Sound field-low-babble		
n	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN
1	0.24	1.70	1.66	0.22	1.70	1.65	0.42	1.70	1.65	0.25	1.70	1.61
2	0.32	1.71	1.66	0.31	1.71	1.66	0.47	1.71	1.66	0.32	1.71	1.63
3	0.52	1.74	1.65	0.50	1.74	1.65	0.71	1.74	1.64	0.54	1.74	1.61
4	0.25	1.70	1.65	0.26	1.70	1.66	0.46	1.70	1.65	0.26	1.70	1.61
5	0.18	1.68	1.65	0.16	1.68	1.65	0.40	1.68	1.64	0.20	1.68	1.60
6	0.38	1.72	1.65	0.37	1.72	1.65	0.60	1.72	1.65	0.40	1.72	1.61
7	0.39	1.74	1.66	0.45	1.74	1.68	0.62	1.74	1.65	0.50	1.74	1.63
8	0.37	1.71	1.65	0.34	1.71	1.65	0.59	1.71	1.64	0.40	1.71	1.60
9	0.24	1.75	1.68	0.41	1.75	1.71	0.44	1.75	1.68	0.43	1.75	1.68
10	0.25	1.70	1.66	0.23	1.70	1.65	0.45	1.70	1.65	0.25	1.70	1.61
11	-0.04	1.83	1.78	0.34	1.83	1.83	0.30	1.83	1.77	0.39	1.83	1.78
12	0.52	1.75	1.66	0.54	1.75	1.66	0.67	1.75	1.66	0.55	1.75	1.63
13	0.35	1.71	1.65	0.31	1.71	1.64	0.52	1.71	1.64	0.36	1.71	1.61
14	-0.02	1.88	1.85	0.21	1.88	1.88	0.33	1.88	1.84	0.28	1.88	1.84
15	0.26	1.71	1.66	0.26	1.71	1.66	0.46	1.71	1.65	0.29	1.71	1.62
16	0.24	1.69	1.65	0.20	1.69	1.64	0.47	1.69	1.64	0.25	1.69	1.59
17	0.25	1.70	1.66	0.22	1.70	1.65	0.46	1.70	1.65	0.25	1.70	1.61

Sample Data (cont.)

	Sound field-high-white			Sound field-low-white			Sound field-high-babble			Sound field-low-babble		
n	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN	logd'	logMC	logBN
18	0.28	1.70	1.65	0.26	1.70	1.65	0.51	1.70	1.64	0.30	1.70	1.60
19	0.33	1.78	1.70	0.54	1.78	1.73	0.53	1.78	1.72	0.43	1.78	1.70
20	0.54	1.78	1.68	0.65	1.78	1.70	0.72	1.78	1.68	0.65	1.78	1.67
21	0.26	1.69	1.65	0.21	1.69	1.64	0.47	1.69	1.64	0.26	1.69	1.60
22	0.16	1.69	1.66	0.18	1.69	1.66	0.40	1.69	1.65	0.20	1.69	1.61
23	0.33	1.72	1.66	0.35	1.72	1.67	0.54	1.72	1.66	0.38	1.72	1.62
24	0.23	1.69	1.65	0.22	1.69	1.65	0.47	1.69	1.64	0.25	1.69	1.59
25	0.21	1.71	1.66	0.26	1.71	1.67	0.49	1.71	1.65	0.30	1.71	1.61
26	0.25	1.70	1.65	0.25	1.70	1.66	0.45	1.70	1.65	0.27	1.70	1.61
27	0.31	1.70	1.65	0.27	1.70	1.65	0.51	1.70	1.65	0.31	1.70	1.60
28	0.34	1.73	1.66	0.38	1.73	1.67	0.53	1.73	1.66	0.42	1.73	1.63

[*] MC = Most comfortable listening level, BN = Background Noise Level

Appendix D

Predicting Number of Clicks Using Sound-Level Meter Reading

Prior to starting the experiment, during the equipment set up, calibration of the sound was done to determine the sound intensity that corresponds to each step click of the arrow key on the computer keyboard. A sound level meter was used to measure the sound intensity in the acoustic booth before the introduction of any sound. The result was recorded as the sound level at zero clicks of the arrow key on the computer keyboard. Thereafter, random numbers of clicks were chosen and at each chosen click, the sound level meter was also used to measure the corresponding intensity in the booth. This was repeated several times. Table 1 shows sample results with the sound level meter reading as a well as the number of clicks on the computer keyboard. A simple mathematical method was used to determine the corresponding sound intensity in the booth to one click on the computer keyboard.

Click	Sound intensity (dB)	Volume
0	30.9	0
10	38.4	10
10	46.9	20
15	55.4	35
30	80.4	65

Sample Calculation method

First trial when 10 clicks were made

0 clicks gives 30.9 dB
10 clicks on the computer key board arrow give 38.4 dB
10 clicks on the computer key board actually give (38.4 – 30.9 = 7.5)
One click on the computer key board will give $\frac{7.5}{10}$ = 0.75 dB

Second trial when 20 clicks were made

0 clicks gives 30.9 dB
20 clicks on the computer key board arrow give 46.9 dB
20 clicks on the computer key board actually give (46.9 – 30.9 = 16)
One click on the computer key board will give $\frac{16}{20}$ = 0.8 dB

Third trial when 35 clicks were made

0 clicks gives 30.9 dB
35 clicks on the computer key board arrow give 55.4 dB
35 clicks on the computer key board actually give (55.4 – 30.9 = 24.5)
One click on the computer key board will give $\frac{24.5}{35}$ = 0.7 dB

Fourth trial when 65 clicks were made

0 clicks gives 30.9 dB
65 clicks on the computer key board arrow give 80.4 dB
65 clicks on the computer key board actually give (80.4 – 30.9 = 49.5)
One click on the computer key board will give $\frac{49.5}{65}$ = 0.76 dB

Therefore, the average of all one clicks =

$$\frac{0.75 + 0.8 + 0.7 + 0.76}{4} \approx 0.75$$

Appendix D Cont'd

Predicting Number of clicks Using Sound-Level Meter Reading

Regression Statistics	
Multiple R	0.998424
R Square	0.99685
Adjusted R Square	0.995801
Standard Error	1.238697
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1456.897	1456.897	949.5076	7.51E-05
Residual	3	4.603113	1.534371		
Total	4	1461.5			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	30.8241	0.842892	36.569	4.5E-05	28.14166	33.5066	28.14166	33.50658
X Variable 1	0.75292	0.024434	30.814	7.51E-05	0.675158	0.83068	0.675158	0.830679

Regression model for the relationship:

$Y = 30.82 + 0.75X$

Where,

X = # of clicks

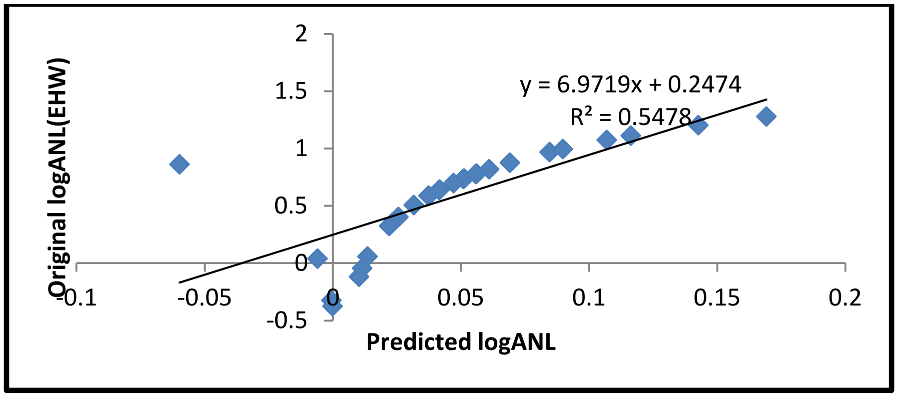
Y = Sound level meter reading

Slope = 0.753 dBA/clicks

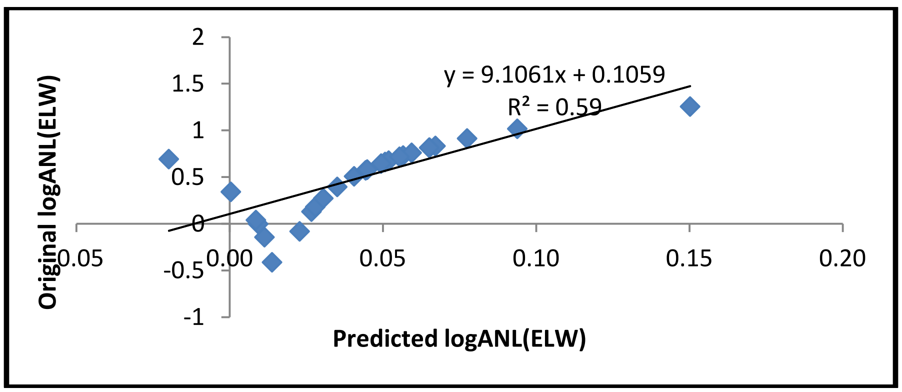
Therefore, two clicks on the computer arrow keyboard make 1.5 dB.

Appendix E

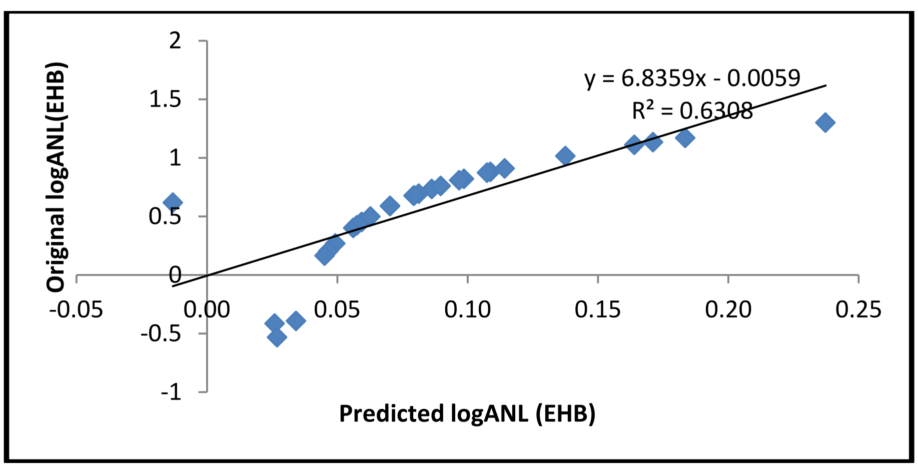
Graphical Illustrations of the Original ANL and the Predicted ANL for Chapter 4



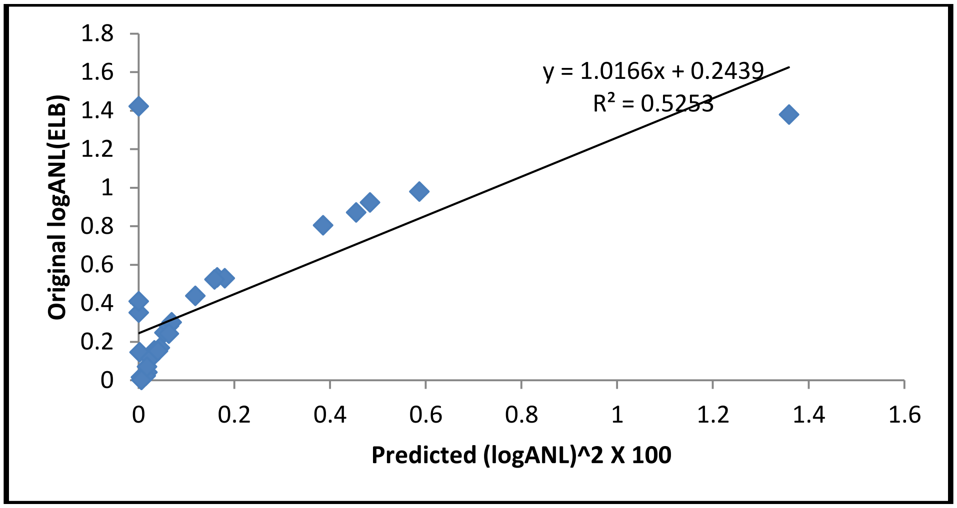
Predictive ANL model for Earphone-High-White Noise



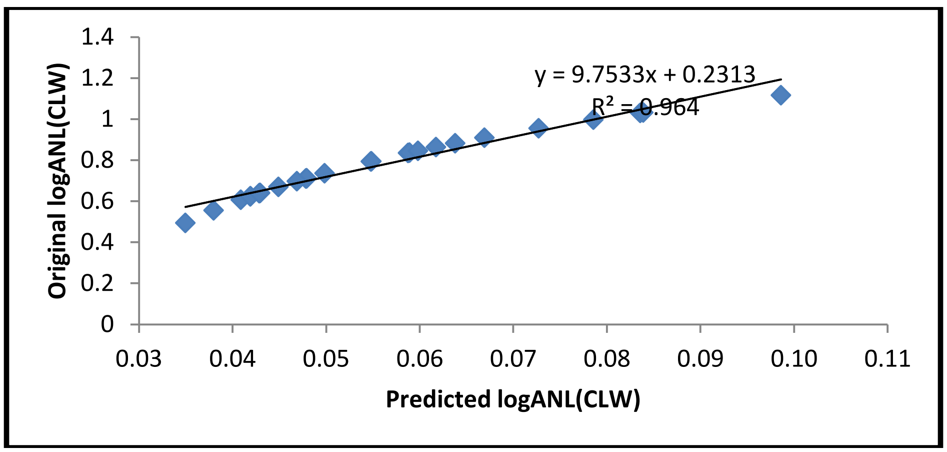
Predictive ANL model for Earphone-Low-White Noise



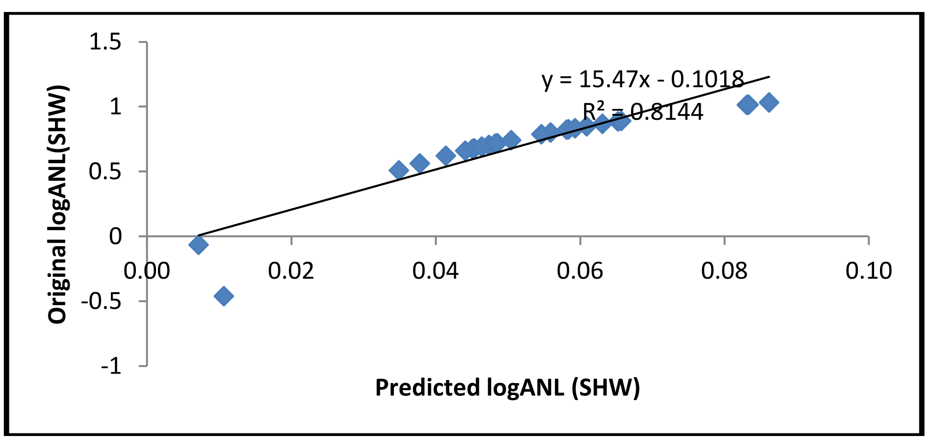
Predictive ANL model for Earphone-High-Babble Noise



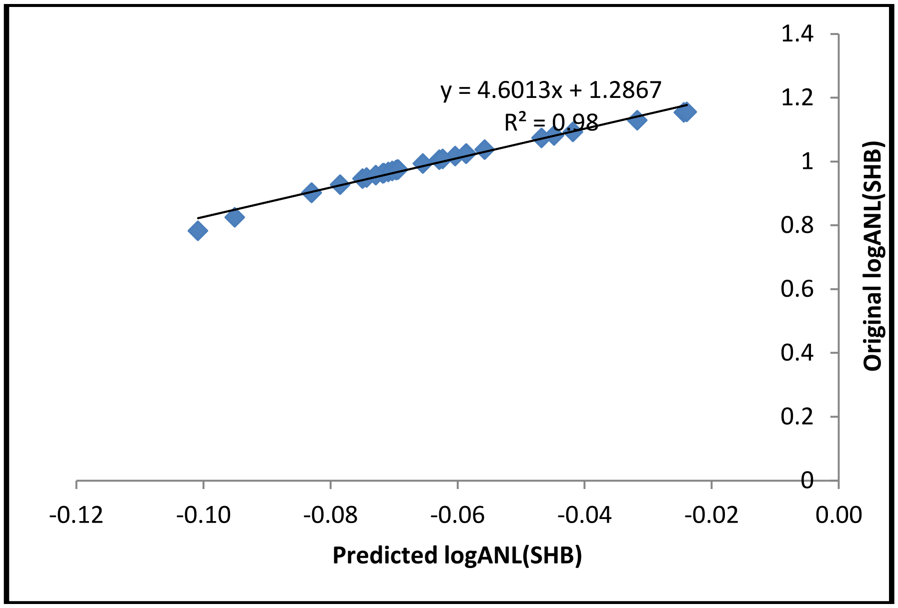
Predictive ANL model for Earphone-Low-Babble Noise (this was based on square power transformation of the predicted logANL)



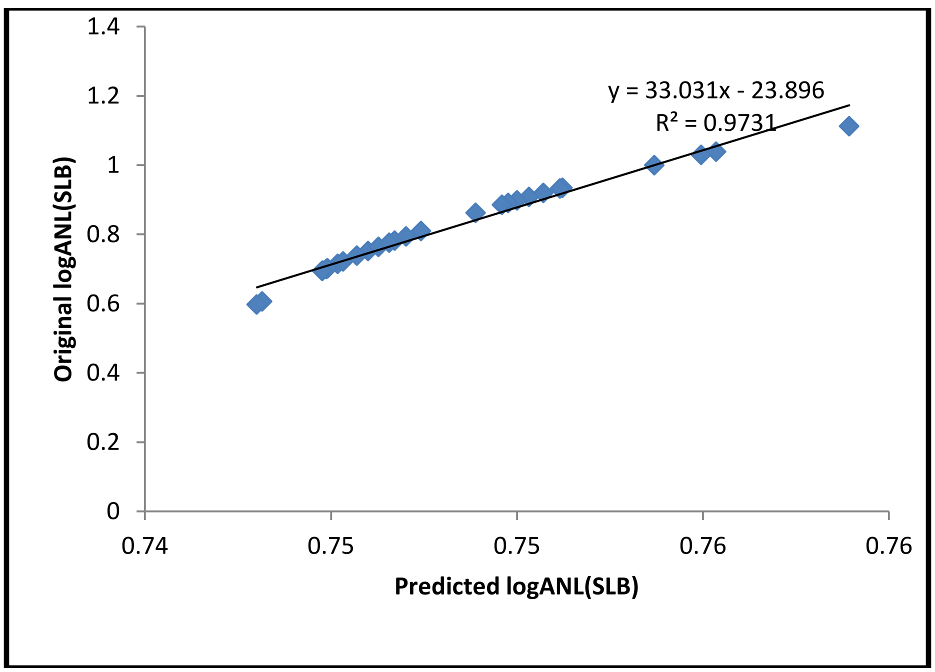
Predictive ANL model for Sound Field-Low-White-Noise



Predictive ANL model for Sound Field-High-White-Noise



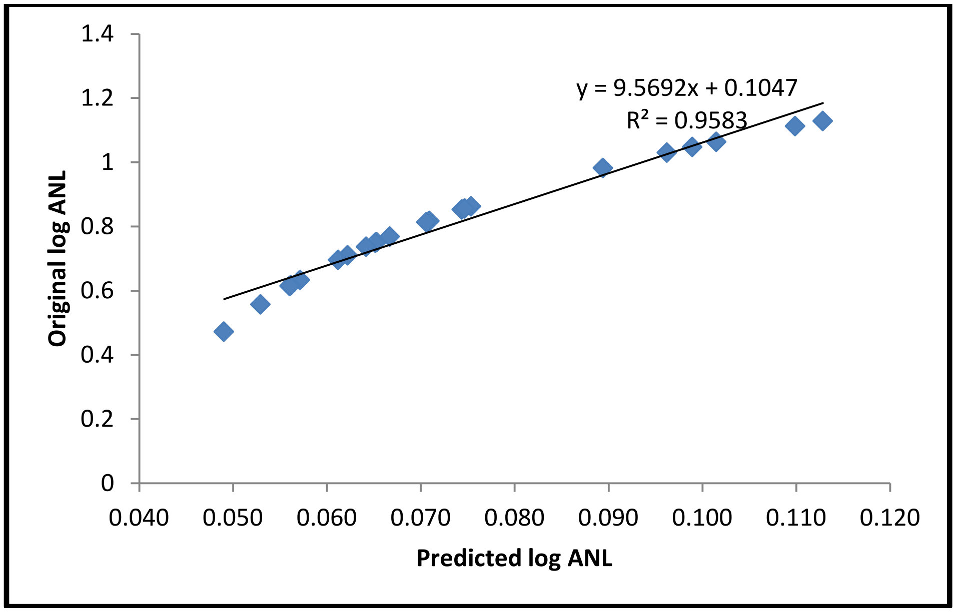
Predictive ANL model for Sound Field-High-Babble Noise



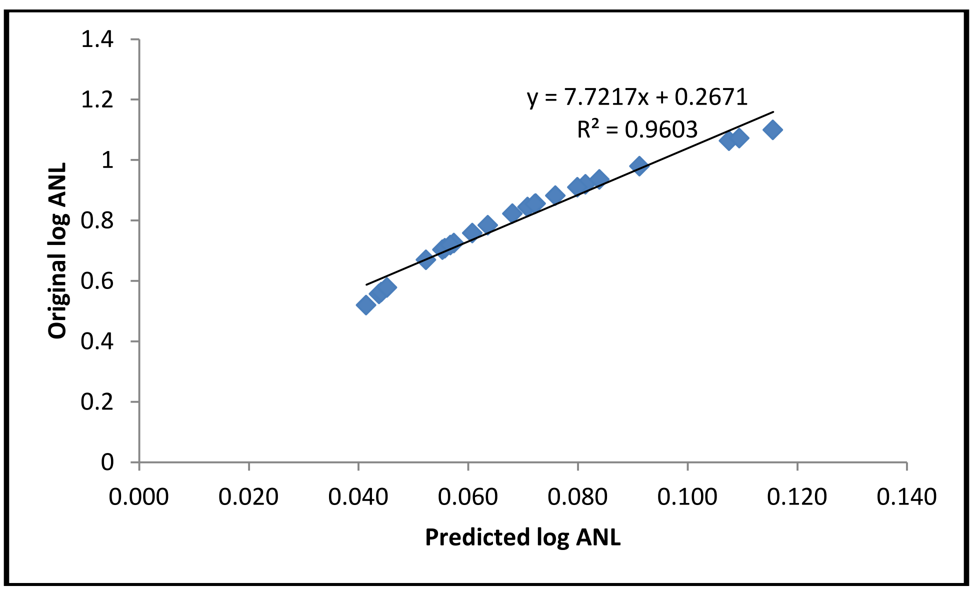
Predictive ANL model for Sound Field-Low-Babble Noise

Appendix F

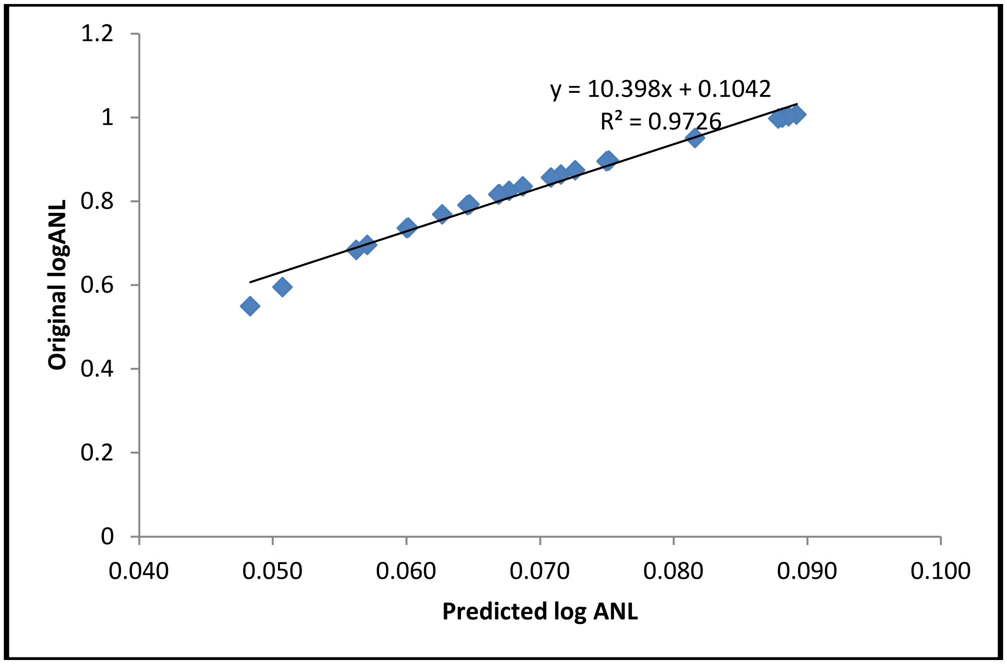
Graphical Illustrations of the Original ANL and the Predicted ANL under Different Loudspeaker Locations for Chapter 5



Predictive ANL model at 45-Degree Azimuth



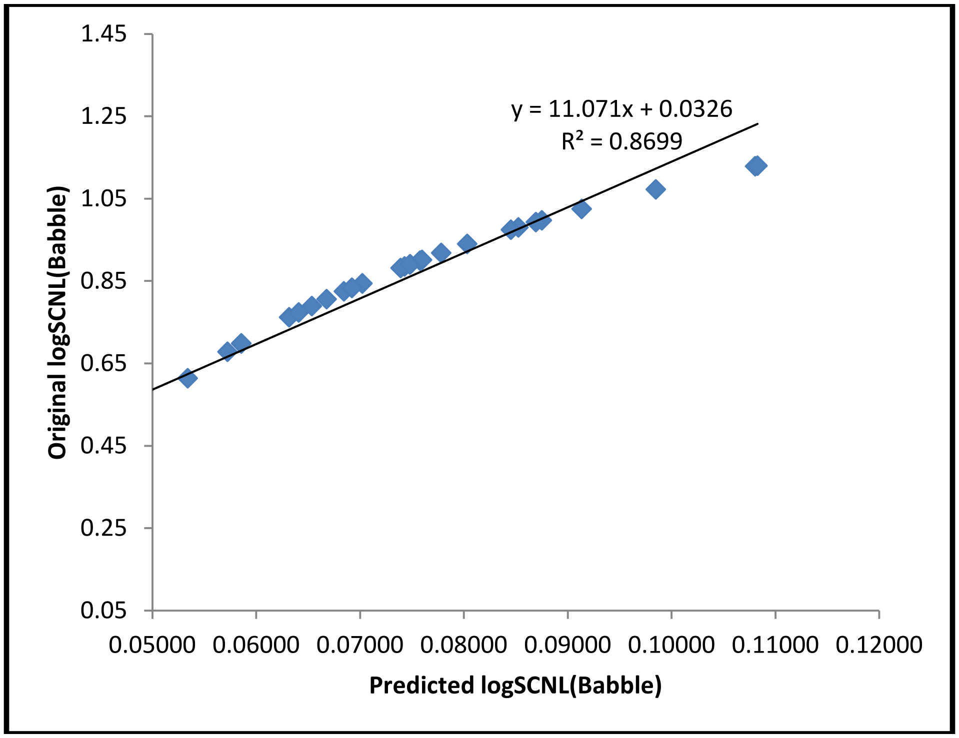
Predictive ANL model at 180-Degree Azimuth



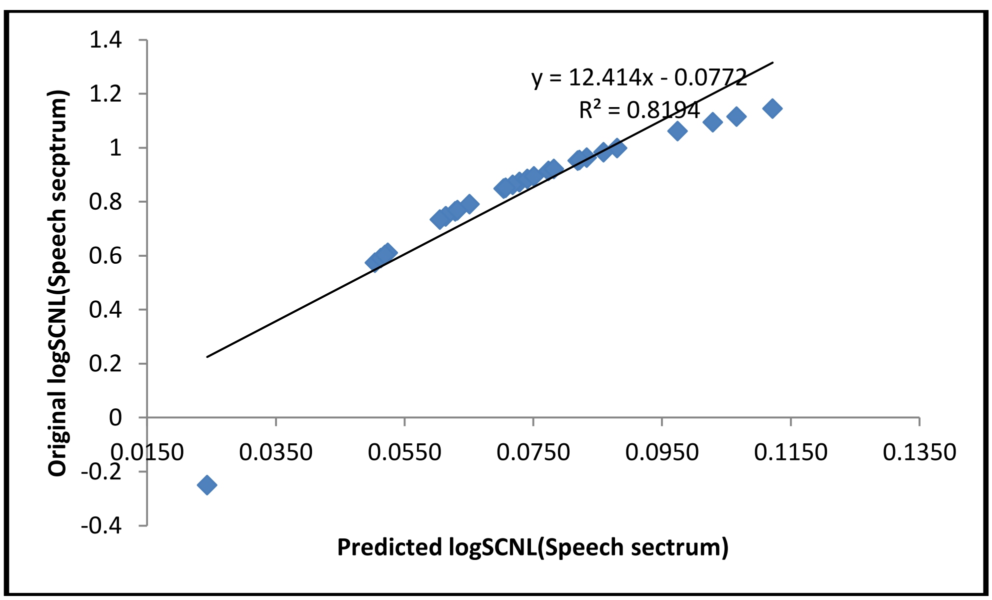
Predictive ANL model at 225-Degree Azimuth

Appendix G

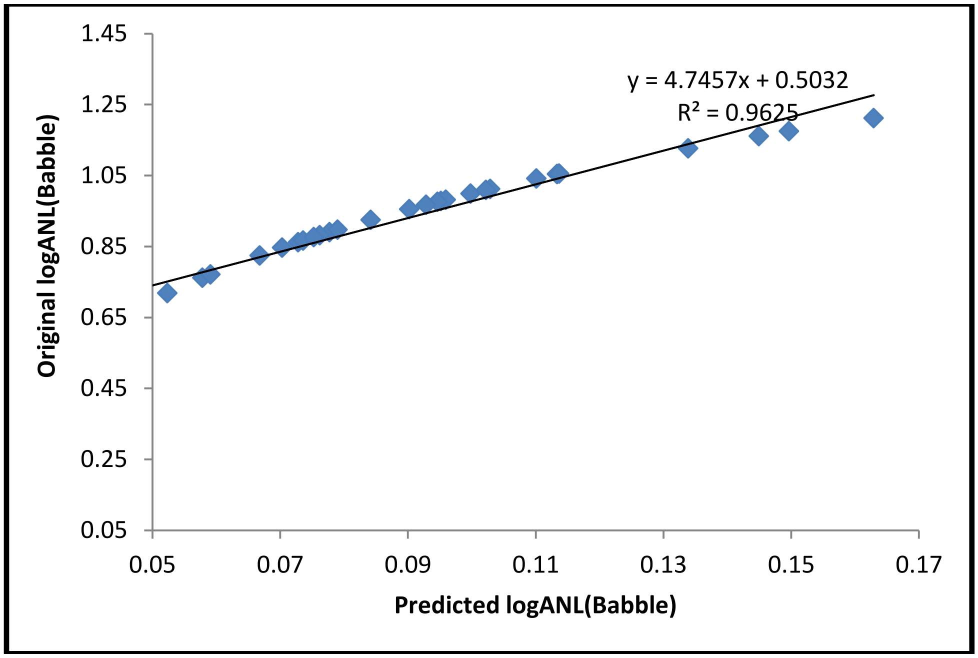
Graphical Illustrations of the Original (ANL and SCNL) and the Predicted (ANL and SCNL) under Different Background Noise for Chapter 6



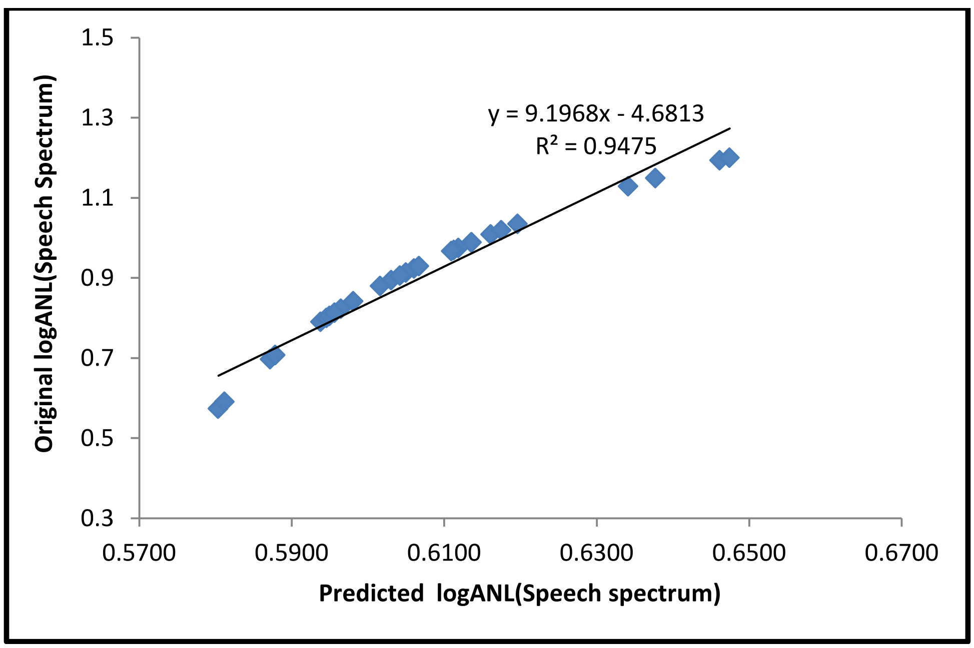
Predictive SCNL model for Babble Background Noise



Predictive SCNL model for Speech Spectrum Background Noise



Predictive ANL model for Babble Background Noise



Predictive ANL model for Speech Spectrum Background Noise