To the Graduate Council:

I am submitting herewith a thesis written by Deanna Susanne Rogers entitled " Sex Differences in Acceptable Noise Levels." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Audiology.

Ashley W. Harkrider, Assistant Professor

We have read this thesis and recommend its acceptance:

Acceptance for the Council

Vice Provost and Dean of Graduate Studies

SEX DIFFERENCES IN ACCEPTABLE NOISE LEVELS

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DEDICATION

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This thesis is dedicated to my family, friends and professors for always believing in me, inspiring me and encouraging me to always reach for the stars in order to achieve my dreams.

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ABSTRACT

Listener's sex was investigated as a possible explanation for individual variability in previously reported measures of acceptable noise levels (ANL) by comparing ANLs from young normal hearing males and females (25 each). Acceptable noise levels (ANL) were assessed by having each subject indicate the maximum amount of background noise they were willing to put up with while following the words of a story presented at a comfortable listening level. ANLs were calculated based on the individual's most comfortable level and the average accepted background noise. All testing was administered within a sound field with the story and background noise coming from the same speaker, located at 0 degree azimuth. MCLs, average background noise levels and ANLs were compared between the males and females. A significant difference was found between the MCLs and average acceptable background noise levels of males versus females. However, no difference was found in the ANLs of males and females. Male subjects had a higher intensity MCL and accepted a higher intensity of background noise than the females. Results indicate that even though males preferred a higher intensity MCL and would accept a higher intensity of background noise, males and females preferred to listen to speech at similar signal-to-noise ratios. Great individual variability is present within the results of this study and previous studies, however those variations cannot be explained based on the sex of listener.

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Chapter I

Introduction

Studies have documented numerous sex differences within physical, physiological, and psychophysical areas of the auditory system. For example, physiological differences are present in auditory brainstem responses, including latency and amplitude measures of wave V (Don et al., 1993; Jerger and Johnson, 1988) as well as middle latency responses and long latency responses (McFadden and Champlin, 2000). Differences have been found in psychophysical measures of hearing sensitivity, binaural tasks, and noise-induced hearing loss. One explanation for sex differences in the auditory system is the difference in hormonal levels and concentration between males and females. Clinical studies have shown that the menstrual cycle has an effect on the auditory system, including hearing sensitivity and the auditory brainstem response (Baker and Weiler, 1977; Hirsch et al., 1992).

Studies have also documented individual differences in the acceptance of background noise. The acceptable noise level (ANL) has been defined as the difference between the most comfortable level (MCL) for speech and the accepted background noise both expressed in decibels (dB) (Nabelek and Burchfield, 2000). The ANL has been investigated in six previous experiments with small groups of subjects. Results of there investigations have shown that the ANL is reliable over a three-week period, that ANL scores are related to hearing aid use, and that the ANL is not related to age, hearing loss, preference for background noise, or uncomfortable listening levels (UCL). The most consistent finding in the preliminary investigations has been the large between subject variability. These finding are consistent with the findings of Thomas and Jones (1982)

that some individuals were intensely annoyed by very low levels of noise while others were able to accept (termed "tolerated" in this study) extremely high levels of noise with no signs of annoyance.

The large individual differences in the acceptance of background noise seen in prior investigations have not been addressed. Previous investigations have documented differences in the male and female auditory system, however, these differences have not been investigated as a possible source for some of the individual differences seen in prior ANL data. This study attempts to define any differences in ANL across listeners that may be due to the listener's sex.

Chapter II

Review of the Literature

Sex Differences in the Auditory System

A number of sex differences have been reported in the human auditory system (for review see McFadden, 1998). McFadden (1998) discussed these differences on the basis of three categories: physical, physiological and psychophysical differences. Physically, male heads, pinnas, external auditory canals, middle-ear volumes, and cochleas are larger than females (Burkhard and Sachs, 1975).

Sex differences are evident in some physiological response in the auditory system. For example, the auditory brainstem response (ABR) has a sex difference at Wave V, in normal hearing listeners. Females have greater amplitudes and shorter latencies, which is true in both the masked and unmasked conditions versus males (Don, Ponton, Eggermont and Masuda, 1993). These differences were still present when the differences in hearing sensitivity and head size were taken into account (Don et al., 1993). Don et al. (1993) argued that these ABR differences in latency and amplitude arise primarily from the physical difference in length of the cochleae, such that the shorter cochlea of females allows for a shorter response time to the acoustical stimulus and therefore a shorter latency of Wave V. Also, it allows for a more synchronized response and therefore greater amplitude. Jerger and Johnson (1988) examined 325 subjects with cochlear hearing loss and 87 subjects with retrocochlear hearing loss. The results showed an interaction between gender and hearing loss. Consistent with the findings reported by Don et al (1993), the female subjects had short latencies for wave V, but not for waves III or I, than did the male subjects. Jerger and Johnson attributed this difference to

difference in head and brain size, difference in whole body temperature, and difference in hormonal milieu.

McFadden and Champlin (2000) compared nineteen auditory evoked potentials between heterosexual, homosexual and bisexual males and females. The subjects consisted of 49 heterosexual females and 50 heterosexual males with normal hearing sensitivity. The results showed that basic substantial sex differences were present in the latency of wave V of the ABR and in the amplitude of Na of the middle latency response (MLR). Females have shorter latencies for wave V of the ABR and larger amplitude for Na of the MLR. Although not statistically significant there are slight differences in some of the other AEPs measured, such as the long latency response. These results indicate that significant sex differences do persist in the central auditory system.

Otoacoustic emissions (OAE), a cochlear phenomenon also exhibits a sex difference. OAEs are sounds produced by the outer hair cells of the cochlea either spontaneously or in response to acoustical stimulation (e.g. click-evoked OAES). There are more spontaneous OAEs (SOAE) in women than in men. Surveys show that 75% to 80% of females and only 45% to 65% of males have SOAEs in at least one ear (Talmadge, Long, Murphy, and Tubis, 1993). McFadden, Loehlin, and Pasanen (1996) found that females have 2 to 3 dB stronger click-evoked OAEs (CEOAE) than males do. There are more SOAEs and stronger CEOAEs in right ears than in left. These patterns of OAEs in humans highly resemble the hearing sensitivity patterns of humans (McFadden, 1998) discussed below.

Psychophysical differences have been found in hearing sensitivity, binaural tasks, and noise-induced hearing loss. Chung, Mason, Gannon, and Wilson (1983) found that

females on average are more sensitive to audiometric frequencies over 2000 Hz, by at least 3dB over males. Between 8000 and 20000 Hz, females were found to have a 4dB greater sensitivity than males (Stelmachowicz, Beauchaine, Kalberer, and Jesteadt 1998). Pearson, et al (1997) completed a longitudinal study of sex differences in age-associated hearing loss. Auditory thresholds were collected from 681 men and 416 women from 1965 to 1994. The results of this study showed that women have more sensitive hearing than men at frequencies above 1000 Hz; however, men have better sensitivity in the lower frequencies. Hearing sensitivity declines twice as fast in men as in women at most ages and frequencies, and longitudinal declines in hearing sensitivity are detectable at all frequencies among men by the age of 30, but the age of onset of decline is later for women. In a similar study, Dubno, Lee, Matthews, and Mills (1997) found that the average hearing sensitivity significantly declined with age for male subjects, and in females no significant changes with age were observed.

Hearing sensitivity can be reduced either permanently or temporarily following exposure to intense noise. From industrial noise-exposure databases, Royster, Royster, and Thomas (1980) reported that males have with more permanent threshold shifts than females. The reason for this is unknown, but it could be (1) that males are more susceptible to noise-induced hearing loss; (2) they are exposed to more noise and (3) for longer durations than woman.

Jerger, Rose, Stach, and Spretnjak (1993) reviewed large-scale surveys of hearing over the past 50 years and found a gender-reversal phenomenon in the average audiograms of the elderly. They found that above 1000 Hz males have a greater average loss than females, however below 1000 Hz females show a greater average loss than

males. Also, the study showed the effect increased with age and degree of hearing loss and the effect remained after those with significant noise exposures were excluded from the analysis.

Within binaural abilities of the auditory system, sex differences have been found. Langford (1994) showed that males are better at discriminating both small differences in interaural time and interaural intensity than are females. These results suggest that the male auditory system is able to encode more precisely the neural concomitants of the two cues for sound localization (McFadden, 1998). Tobias (1965) found that males have the ability to hear binaural beats up to 800 Hz to 1000 Hz, where women were unable to hear the binaural beats above 600 Hz. Chung et al. (1983) found that the right-ear advantage is greater in males than in females.

Explanations for the reported sex differences in the auditory system have included differences in hormone levels and hormone concentrations between males and females. Clinical studies have shown that the menstrual cycle has an effect on the auditory system, including changes in hearing sensitivity and the ABR. Baker and Weiler (1977) measured pure tone thresholds for 12 subjects between the ages of 18-28 years old. The 12 subjects were divided into 3 groups of 4 subjects including, (1) four women on oral contraceptives and who reported no abnormalities in hearing in or menstrual function, (2) four women who were not taking oral contraceptives and who reported no abnormalities in hearing or menstrual function, and (3) four men who reported no abnormalities in hearing. The female subjects were tested twice weekly until the onset of menses had occurred twice, while males were tested for one month at the same intervals. The mean thresholds for women using oral contraceptives were well below those of females not

using oral contraceptives or males. The normally cycling females showed systematic variation within the menstrual cycle, while males and females on the pill showed no systematic differences. Normally cycling women had lower thresholds at all frequencies tested (250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz) during the first half of their cycle than during the second half.

Miller and Gould (1967) reported case studies of two women whose complaint was a fluctuating hearing loss occurring in relation to the menstrual cycle. The first patient was a 38-year-old woman who reported her hearing dropped around day 17 of her cycle and then improved with the onset of menses. The second patient was a 29-year-old who reported her hearing dropped as early as 10 days before menstruation and improved with the onset of menses. Hearing was tested twice; once post menstruation, when hearing was reported as "good", and again approximately 2 weeks before menstruation, when hearing was worse. For both patients, hearing thresholds within the speech frequencies (750-4000 Hz) were affected and the drop was of sensorineural type. Site-of-lesion tests including recruitment findings, positive SISI scores, minimal tone decay, and type II Bekesy tracings pointed to the cochlea as the site affected by cycle time.

The use of oral contraceptives has also been found to have an effect on temporary threshold shift. Dengerink et al. (1984) evaluated gender and oral contraceptive effects on temporary threshold shifts. In the first experiment, they examined threshold at 4000 and 8000 Hz and the threshold of octave masking at 4000 Hz before and after noise. The second experiment examined threshold and the loudness discrimination index at 4000 Hz before and after noise. Results indicated that females who were taking oral contraceptives did evidence more temporary threshold shift than both males and normally

cycling females. Implications of these results include, gender differences in noise susceptibility may be mediated by hormonal differences, and also that gender differences in noise effects may be dependent upon menstrual cycle variations within the female group. Furthermore, gender differences in noise effects may vary depending on the phase of the female subjects' cycle. Finally, the differences observed indicate that the mechanism or process by which noise alters hearing acuity is modified in some fashion by progesterone.

Research has also shown an effect of the menstrual cycle in physiological aspects of the auditory system such as in the ABRs test and in OAEs. Data suggest that the brainstem auditory neural pathways are sensitive to fluctuations in follicular estradiol (E2) levels during the menstrual cycle (Hirsch, Stoner, Stach, and Jerger 1992). In their study they compared the ABRs of 9 normally-cycling women (ages 23-40 years) at four different phases in the same menstrual cycle. A control group of 9 women (ages 23-40 years) using oral contraceptives were also tested at the same intervals. There was a significant increase in the latency of wave III and wave V peak latencies and in the I-V interpeak latencies during the high estrogen state at the mid-cycle phase. The latencies of wave I varied little with the monthly cycle, suggesting that the source of latency change appears to be in the central auditory neural pathways rather than in the auditory periphery. No significant change during the monthly cycle was observed in the control group of women using an oral contraceptive. McFadden (2000) studied the masculinizing effects on OAEs and auditory evoked potentials (AEPs) in women using oral contraceptives. Although this study's results were not statistically significant, they indicate a trend towards a weak-masculinizing effect on some structures of the auditory

system. OEAs and AEPs were measured in normally-cycling women, women using oral contraceptives, and males. In the results every difference was in the direction of weaker values for women (more male-like responses) using oral contraceptives, meaning invariably they were shifted away from normal cycling women.

The effects of menstruation and oral contraceptives on the auditory system, are of value and should not be over looked in future research. These effects need to be controlled for in research to avoid a confounding influence on data. In this study, any sex differences in acceptable noise level will be documented.

Acceptable Noise Level (ANL)

Nabelek (A), Tucker, and Letowski (1991) developed a procedure to assess the maximum amount of background noise that individuals are willing to accept while listening to speech. In this procedure subjects adjust running speech to their "most comfortable level" (MCL). Next the subjects adjust background noise to the maximum level that they would be willing to accept while listening to and following the words of the speech. The difference in decibels between the MCL for speech and the accepted background noise has been termed the Acceptable Noise Level (ANL) by Nabelek and Burchfield (2000) and previous studies have explored this phenomenon.

Nabelek et al (1991) examined the relationship between hearing aid use and the ANL in five groups of subjects. Each group contained 15 subjects. Groups one and two contained young subjects with normal hearing (mean age=22 years) and elderly subjects (mean age=71 years) with normal hearing respectively. Groups 3, 4, and 5 contained elderly subjects with sensorineural hearing loss fitted previously with hearing aids. These groups were selected on the basis of their hearing aid use: full-time users, part-time

users, and nonusers. The subjects listened through earphones that were filtered and distorted to approximate listening with hearing aids. Several background noises were used including speech babble, speech spectrum, traffic, music, and a drill. The results revealed significant interaction between the groups and the background noises. Full-time hearing-aid users accepted significantly higher levels of speech spectrum and music than part-time and nonusers. ANL results for the subjects with normal hearing were not related to age or hearing loss.

Lytle (1994) compared acceptance of background noise and amplification use in elderly individuals with hearing-impairment. Twenty subjects were divided into two audiometrically matched groups that differed in their use of amplification. One group, the "successful" hearing-aid users, wore their hearing aids full time. The members of the other group rarely or never used their hearing aids and were referred to as "unsuccessful" users. Testing was conducted in sound field with and without the subject's personal hearing aids. Speech spectrum and speech babble were used for background noise. The successful hearing-aid users accepted significantly more background noise than unsuccessful hearing aid users. This difference was present with and without the subject's personal hearing aids. These findings suggest that acceptance of background noise is related to amplification use. Also, it may be possible to predict use before hearing aids are actually tried.

Crowley (1994) explored the acceptance of background noise as well as several other factors, which might predict hearing-aid performance, usage, and satisfaction rating before hearing aids are purchased. Data was collected on 46 subjects (31 males and 15 females), based on 16 unaided variables including pure-tone average, slope of hearing

loss, the Speech Perception in Noise (SPIN) test (Kalikow, Stevens and Elliott, 1977), dynamic range, comfortable loudness level, tolerated signal-to-noise level for babble and speech spectrum noise, the difference between actual gain and target based upon the National Acoustic Laboratories' prescription formula, age, sex, percentage of employment, years of education, number of medications taken, Personal Adjustment and Communication Strategies scores of the Communication Profile for the Hearing Impaired (Demorest and Erdman, 1987), and motivation for pursuing hearing aid use. Aided performance was represented by the Profile of Hearing Aid Performance, (PHAP, Cox and Gilmore, 1990). Regression analysis showed poor predictive values for most of the variables explored. However, regression analysis for noise acceptance (referred to as "tolerance" in this study) resulted in predicted values that matched actual scores within about 12% for 75% of the subjects. This confirms Lytle's (1994) findings that successful hearing-aid use is related to noise tolerance and indicates the predictive value of the variable.

Fisher, Nabelek (A), and Burchfield, (2000) investigated the reliability of the ANL and the relationship between the ANL and preference for background noise in 12 young subjects with normal hearing. The ANL was measured for each subject using both speech spectrum noise and multitalker speech babble noise during three experimental sessions separated by one week. The subjects responded consistently over the three-week period, yielding a strong positive correlation and indicating high test-retest reliability. The comparison between the ANL and the reported preference for background noise, for both the speech spectrum and speech babble background noise,

resulted in a weak correlation, which suggests that the acceptance of background noise and preference for background noise are different perceptual events.

The comparison between data collected in this study from young normal-hearing subjects and data collected by Nabelek et al. (1991) in elderly normal-hearing subjects were remarkably similar although not identical (Table 1). This similarity indicates that ANL may be independent of age for normal-hearing individuals.

Franklin, Burchfield, and Nabelek (2001) compared ANL and uncomfortable levels (UCL). Twenty-three adults between the ages of 18-25 served as experimental subjects. Each subject reported 3 measures of their MCL, 3 judgments of the maximum acceptable noise level while listening to speech, and 3 judgments of their UCL. The average of the 3 MCL measures, the average of the 3 acceptable levels of background noise, and the average of the 3 UCL measures were analyzed. The results showed that the ANL values and the UCL values are not related and that the acceptable level of speech babble background noise is different based on whether the babble is the competing signal or the primary signal. It seems that speech babble presented as the primary signal would be

Table 1. Comparison of data between Nabelek et. al (1991) and Fisher (2001)

Study		Speech Babble Noise	Speech Spectrum Noise
Nabelek (1991)	M	11.73	12.73
	Range	0-27	2-23
	SD	7.57	8.10
Fisher (2001)	M	12.5	14
	Range	5-22	5.29
	SD	4.61	2.47

given more attention than when it is presented as a competing stimulus. Therefore, individuals process speech babble noise at different levels within the central auditory nervous system when the babble is a competing signal as compared to how the babble is processed as the primary stimulus.

Rationale for Present Study

As reported, there are differences between males and females in numerous auditory measures. These measures have been documented within the physical, physiological, and psychophysical areas of the auditory system. Differences have been documented in ABR, middle and long latency response measures. Also, differences have been found in psychophysical measures of hearing sensitivity, binaural beats and noise induced hearing loss.

The most consistent finding of the previous ANL studies has been the large between subject variability. This variability is not explained by age, hearing loss, preference for background noise, or UCL. Sex differences within ANL have only been investigated in one previous study, however the number of males and females differed significantly and no statistical difference was found. There have been no systematic, large-scale investigations of sex differences in the auditory system producing the large between subject variability in ANL scores. Therefore the possibility of sex differences within ANL scores does exist.

The present study will investigate if a significant difference in ANL exists between males and females. The subjects will be asked to set the maximum amount of acceptable background noise while following or listening to the words of a story. This method is intended to imitate a real-life situation. This task is a direct measure of

acceptable background noise, which may or may not be related to speech discrimination ability.

Chapter III

Method

Subjects

Fifty adults (25 male, 25 female) from the University of Tennessee Knoxville between the ages of 19-25 years served as the experimental subjects. All subjects had hearing thresholds of at least 15 dB HL across a frequency range of 250 to 8000 Hz, with no conductive component to their hearing. All subjects had normal middle-ear function, type A, AS, or AD tympanograms. No subject had a history of significant noise exposure, auditory pathology, such as recent otitis media or ear surgery, or is on any otoxic medications. All female subjects were using oral contraceptives.

Subjects were evaluated in one thirty-minute experimental session. During this session the subject reported one judgment of their MCL to speech and 3 judgments of their maximum acceptable level of background noise while listening to the speech at MCL. The ANL was calculated by subtracting the average of the 3 judgments of the background noise from their MCL judgment.

Apparatus and Test Materials

The apparatus and test materials for MCL and background noise measures were based on the A. Nabelek et al. (1991) procedure. Both the MCL and background noise measures were used to calculate ANL. The speech and speech-babble stimuli were delivered via two compact disc players through an audiometer to a loudspeaker that is located at zero-azimuth one meter from the subject in an audiometric booth. A recording of running male speech was used as the primary stimulus. First the subject's MCL was

determined. Then, speech babble was added as the competing stimulus and a maximum level of acceptable background noise was determined. Both the MCL and the maximum amount of background noise were determined using a method of adjustment and bracketing procedure. The subjects were given two hand-held buttons, which signaled to the examiner to adjust the volume of the speech and speech babble either up or down. The volume was then adjusted in 2-dB steps either up or down until reaching the subject's MCL and the level of acceptable background noise. The subject gave a verbal confirmation when the appropriate level has been reached.

Procedure

Prior to testing each subjected signed a consent form and filled out a case history form. Following completion of the paperwork tympanograms were completed on each subject and hearing was screened at 15 dB. Prior to testing, each subject was given verbal and written instructions describing the experiment and his/her task. Following the instruction, each subject was given the opportunity to practice adjusting the level of the background noise.

Following practice of adjusting the background noise, the subject adjusted the level of the story to his/her MCL. The story started at 0 dB and increased in steps of 10 dB until the subject told the experimenter to reduce the intensity. Then, the level of the story was adjusted in 2-dB steps. The subject went below his/her MCL and then raised the volume to his/her MCL.

The verbal and written instructions for measuring MCL are as follows:

You will be listening to speech. After you listen for a few moments you will be asked to adjust the loudness to a level that is most comfortable to you. You will

be given two hand-held buttons that will allow you to adjust the volume of the speaker louder or softer, in small increments. In order to obtain a reference level, please adjust the loudness up to a level that is too loud and then down to a level that is too soft. Then, adjust the loudness of the story to a level that is most comfortable to you. Tell me when you have reached your most comfortable level.

Once the subject's MCL was established, the speech continued at that level while the background noise was added. The background noise started at 0 dB and was increased in 10-dB steps until the patient signaled the experimenter to decrease the volume of the background noise. Then, the background noise was adjusted in 2-dB steps either up or down until the individual reached his/her maximum amount of accepted background noise. The procedure to establish the maximum amount of background noise was completed three times and the average of the three was used in the calculation of ANL. The verbal and written directions for measuring the acceptance level of background noise were as follow:

You will be listening to speech at your most comfortable level, which you have established. Then background noises, which sound like several people talking, will be added. You will be asked to adjust the level of background noise to a level, which would be deemed acceptable while listening to speech without becoming tense or tired while following the words of the story. To establish a reference please adjust the level of the background noise up to an unacceptable level, and then down to a level that is softer and then back up to the maximum amount of acceptable background noise. The amount of attention you give to the

story is completely up to you. Please give the same amount of attention to the story each time the procedure is completed.

The ANL was calculated by subtracting the maximum amount of background noise deemed acceptable from the subject's most comfortable level.

Data Analysis

A one-factor multivariate analysis of variance (MANOVA) was computed on the data. The factor was sex (two levels) and the three dependent variables were (1) MCL, (2) accepted background noise level, and (3) ANL. To explore significance found in the MANOVA, post hoc analyses were conducted. Three one-factor ANOVAs were conducted; one for MCL, one for average background noise levels and one for ANL.

Chapter IV

Results

MCLs, average background noise levels, and ANLs were established for 50 normal-hearing young adults (25 males, 25 females). Means, ranges and standard deviations for these measures are shown in Table 2 and Figure 1. A one-factor repeated measures MANOVA was conducted. The factor was sex (two levels) and dependent variables were MCL, average background noise levels and ANL. Significance was found for the main effect of sex ($F_{2, 47}$=690.373, p= .001) and the interaction of sex with the dependent variables ($F_{2, 47}$= 4.354, p=.018). In order to explore the significant interaction found with the MANOVA, post hoc analyses were conducted. Three one-factor ANOVAs were conducted; one for MCL, one for average background noise levels, and one for ANL (Table 3). The factor was sex (2 levels). A significant interaction was obtained between sex and MCLs ($F_{1, 48}$=7.44, p<.009), indicating that males have significantly higher MCLs than females. Also, a significant interaction was found between sex and average background noise levels ($F_{1, 48}$=7.99, p<.007), indicating that males accepted a higher intensity of background noise than females. No significant interaction was found between sex and ANLs ($F_{1, 48}$=.087, p<.769), indicating that males and females accepted approximately the same amount of background noise.

Table 2: Means, ranges (minimum to maximum) and standard deviations (S.D.) for most comfortable levels (MCL), accepted background noise and acceptable noise levels (ANL) for females (F), males (M) and for all subjects.

Group		MCL	Accepted Background Noise	ANL
	M	36.24	24.83	11.01
F (25)	Range	24-54	7.3-38.7	0-24.7
	S.D.	6.31	8.28	7.70
	M	42.08	31.68	10.41
M (25)	Range	28-58	11.3-46.7	0-24
	S.D.	8.65	8.84	6.64
ALL (50)	M	39.16	28.25	10.71
	Range	24-58	7.3-46.7	0-24.7
	S.D.	8.05	9.16	7.12

Table 3: Results of post hoc one-factor ANOVAs on MCL, average background noise levels (AvBNL) and ANL. Sex is the factor.

Dependent Variable	Degrees of Freedom	Error Degrees of Freedom	Mean Square	Total Sum of Squares	F	Significance
MCL	1	48	426.32	79852.0	7.44	.009
AvBNL	1	48	587.10	44022.67	8.0	.007
ANL	1	48	4.5	8219.5	.087	.769

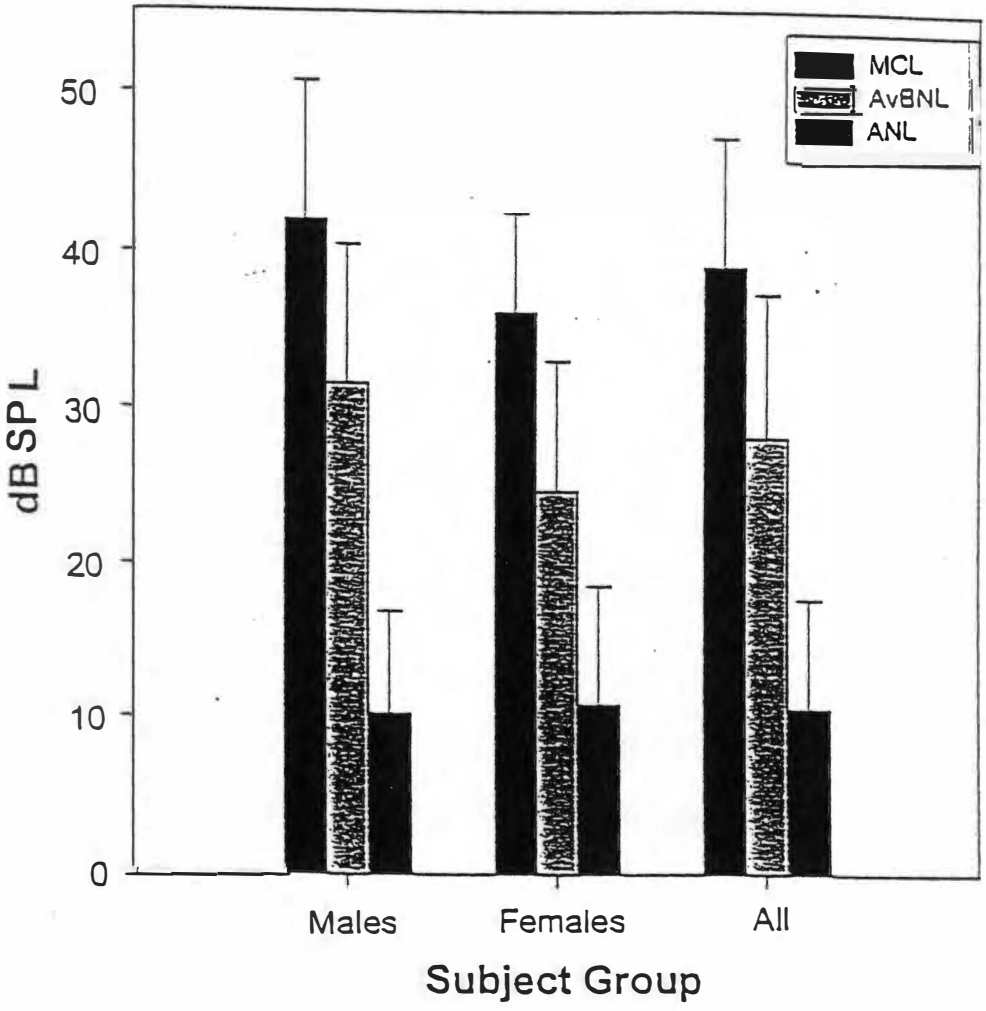


Figure One. Mean MCL, average accepted background noise level (AvBNL), and ANL for males, females, and all subjects. Error bars denote one standard deviation from the mean.

Chapter V

Discussion

Sex Differences in ANL

The ANL has been defined as the difference, in decibels, between the MCL for speech and the accepted background noise (Burchfield and Nabelek, 2000). It has been documented that ANL is not predictable by age, hearing loss, preference for background noise, or UCL. However, it has been shown that ANL is related to hearing aid use and is stable over time. One consistent finding of ANL studies is the broad range of variability among individuals. This study attempted to determine if the differences in ANL across listeners is due to the listeners' sex.

Sex differences in ANL would not be surprising. Previous studies have documented differences between males and females in many aspects of the auditory system including, physical, physiological and psychophysical areas. However, the results of the present study showed that no significant difference in ANL exist between males and females. Statistical significance was found between the sex of the listener and MCL, as well as the accepted background noise level. Male listeners had a higher MCL than females, with approximately a 6 dB difference between the groups. Further, males accepted a higher intensity of background noise, by approximately 7 dB, than females. Even though, MCL and background noise levels were different in males and females, ANL levels were within 0.6 dB of each other. This was because average MCL and the average acceptable background noise levels (values used to calculate ANL) were different by a consistent amount and direction and, thus, resulted similar ANLs between the two groups.

The results of the present study are consistent with the past findings for ANL of Nabelek et al. (1991) and Crowley (1994). Nabelek et al. (1991) was not specifically looking at sex differences in ANL, however, in a retrospective analysis the ANLs of normal-hearing elderly males and females showed no significant difference. Similarly, Crowley (1994) found no significant difference between ANLs measured from males and females. In that study an uneven number of males (31) and females (15) were used as subjects; males had approximately a 2 dB lower ANL than females. However, in a retrospective analysis of this data using an even number of males (15) and females (15), no significant difference was found between the two groups. A comparison of means and ranges of these three studies can be found in Table 4.

The results of the present study show that males and females are judging background noise similarly. Despite the fact that no significant difference was found between males and females within ANL in the current or previous studies, there was a significant difference within the MCLs and average background noise levels of males and females in this study and others.

Sex differences in MCL

Statistical significance was found between the MCLs of males and females. Males on average had a 6 dB higher MCL than females. These results were consistent with the previous findings of Decker (1978) and Hochberg (1975). Hochberg (1975) found that when young (18 to 26 year olds) normal hearing males (14) and females (16) found that when young (18 to 26 year olds) normal hearing males (14) and females (16) listened to a message for intelligibility that male subjects had a 5 dB higher MCL than the female subjects. Decker (1978) obtained similar results with young (21 to 32 year olds)

Table 4: Comparison of means and ranges of ANL, of the present study, Nabelek (1991) and Crowley (1994).

Study		Males	Females	Difference
Present	Mean	10.41	11.01	.6
	Range	0-24	0-24.7	
Nabelek	Mean	11.4	11.0	.4
	Range	2-20	5-19	
Crowley	Mean	7.8	8.7	.9
	Range	0-21.5	1-24	

normal hearing males and females (15 each). In these results males had a 5.5 dB higher MCL than females for the informative condition; this condition involved speech that contained a message versus non-meaningful speech.

The lower MCLs measured from females versus males may be due, in part, to the overall differences in the sensitivity of their auditory systems. Females, on average, have better hearing thresholds than males at frequencies above 2000 Hz (Chung et al., 1983) indicating better auditory sensitivity. Consistent with this behavioral finding, OAEs differ in females versus males. Female cochleae produce more SOAEs (Talmadge et al., 1994) and stronger CEOEAs than male cochleae (McFadden et al., 1996). These results indicate that the cochleae of females are more sensitive for low to moderate level acoustic stimulation. Another example of the sensitivity of the female auditory system can be found in the amplitude and latency of wave V of the ABR (Don et al., 1993). Shorter latencies and larger amplitudes of wave V would indicate that the female auditory system has a slightly more robust response to stimulation than the male auditory system.

The majority of speech sounds are produced within the frequency range of 500-4000 Hz. The lower frequencies provide 95% of speech power, whereas the high frequencies provide 95% of speech intelligibility (Hodgson, 1977). Therefore, it is possible that males, who have poorer hearing in the higher frequencies, would need a higher intensity of speech in order to fully understand the speech signal. Also, it may be more difficult for males to extract speech from out of the low frequency environmental noise. Females, who detect high frequencies approximately 3 dB better than males, may therefore require a lower level of speech to understand it and, thus, lower MCLs as reported in this study.

Sex Differences in Accepted Level of Background Noise

The frequency spectrum of the speech babble used as the competing signal in this study mirrors that of speech, such that lower frequencies are more dominant than higher frequencies. The composition of speech babble is similar to that of speech noise, which is white noise, filtered at 12 dB per octave above 1000 Hz and 3 dB per octave below 1000Hz (Martin, 1997). Pearson et al. (1997) found that males have more sensitive hearing below 1000 Hz than females do. It would seem that since males have slightly better hearing in the lower frequencies than females, they would prefer a lower intensity level of background noise. However, the results of this study show just the opposite. Males accepted a higher level of background noise than females.

Other psychological factors that have been reported between males and females may help explain the results of this study. Jamner et al. (1998) found that males have a higher tolerance for pain than females do. The results of that study showed that females had lower thresholds for pain, a lower discomfort level and a lower tolerance for pain, which may be analogous to the lower auditory thresholds and lower acceptance levels of background noise for females found in this study. Knott (1984) found that females show more distractability when an auditory task requires cognitive effort than when the task does not. Therefore, it is possible that, in this study, a higher-level background noise caused the female subjects to become more easily distracted and therefore they preferred a lower level of background noise when listening to the story than males. In a review article of sex differences in the auditory system, McFadden (1998) reported several differences between males and females involving complex masking tasks. Neff et al. (1996) found that males as a group were able to detect a common signal in the presence

of an array of maskers at a lower intensity than females. Wright (1994) found more lateral suppression in males than in females; this indicates that inhibition is stronger in males versus females. Since background noise can serve as a masker in many circumstances, it seems that males are able to accept a higher intensity of background noise and still be able to distinguish the signal or message.

ANL and S/N Ratio

Even though the male subjects had a higher MCL and accepted a higher intensity of background noise than females, the ANL was the same. This indicates that both males and females prefer a similar signal-to-noise (S/N) ratio.

The S/N ratio is the difference in decibels between a signal and a noise when presented to the same or both ears (Martin, 1997). ANL and S/N ratio are fundamentally different measures. This is because S/N ratio implies that perception of speech is being measured where as ANL is not related to speech perception but to acceptance of noise. Studies evaluating ANL and S/N ratios have found variability among individuals. In this study individuals on average wanted approximately an 11dB difference between the speech signal and the competing background noise. ANL is designed to stimulate a real life situation, in which a S/N ratio is created between the speech signal and background noise, however speech perception is not being measured.

There are numerous situations that require an individual to extract a speech signal from background noise. Pearson, Bennett and Fidell (1976) reported S/N relationships for conversational, social, and environmental situations. They reported that, in the majority of conversations the S/N ratio is between +5 to +8 dB, meaning the speech is about 5 to 8 dB louder than the background noise. In a social situation such as a

"cocktail party" the S/N ratio can be reduced as low as + 1 dB. In many environmental situations, for example traffic, the S/N ratio can be 0 dB or even worse. The results of the present study show that individuals preferred about an 11 dB ANL. This ANL may be due to the fact that, while individuals are used to listening at a S/N ratio of 5 to 8 dB in most conversational settings (Pearson et al., 1976), they may be experiencing a slight difficulty extracting the signal from the background noise. Therefore, even though individuals can and do communicate often in a poorer S/N ratio of 5 to 8 dB, they may actually prefer a larger difference between the signal and the background noise, as measured by the ANL of 11 dB reported in this study.

Individual Variability in S/N Ratio and ANL

There is variation among individuals in the amount of background noise that they can tolerate and still understand speech. Extracting speech from background noises may be an easy task for one person and therefore he/she can tolerate a poorer S/N ratio and still decipher speech. Studies evaluating ANL have also have found variability among individuals (Nabelek et al., 1991; Lytle, 1994; Crowley, 1994; Fisher et al., 2001; Franklin et al., 2001). Consistent with previously reported individual variability, ANL ranged from 0 to 24.7 dB in this study and could not be explained by accounting for the listeners' sex. There was a higher variability of ANL in females (S.D.=7.70) than in males (S.D.=6.64). This was the only difference in ANL scores between the sexes (table 3). This suggests that there will be less predictability in ANL based on MCL for females versus males, a finding with some clinical implications. This increased variability in females is consistent with the findings of Wright (1994), which found a greater range of detectability of signals in simultaneous-onset maskers for females than males.

Clinical Implications

In a clinical setting, one of the most common problems expressed by patients is difficulty in the presence of background noise. This problem is common among all patients, and is not sex specific. Based on the results of the present study, it does not appear that preferred background noise levels while listening to speech (ANLs) are sex specific either. As reported by, Dirks et al (1982) hearing-impaired listeners need a larger S/N ratio than normal-hearing individuals. Individuals are willing to accept different levels of background noise for different periods of time. Nabelek et al (1991) and Lytle (1994), in small subject groups, found that individuals who accepted a higher level of background noise were usually more successful with their hearing aids. These individuals were able to accept higher levels of background noise, thus requiring a reduced S/N ratio. Knowing how much background noise an individual is willing to accept may objectively predict the success of hearing aid use. This prediction would be able to provide the clinician with a valuable counseling and rehabilitation tool.

The most consistent finding among prior ANL studies is between subject variability. Results of the present study show that this variability is not related to listener sex differences. Future research with ANL needs to address other possible causes of this variability.

Conclusions

Due to the numerous sex differences previously reported within the auditory system, it would seem possible for sex differences to be seen between males and females in ANL scores. The large between subject variability seen in previous ANL studies is

also seen in this data. However, the results of the present study showed that no significant difference in ANL exist between males and females. Statistical significance was found between the sex of the listener and MCL, as well as the accepted background noise level. MCL represents a listening level that a subject indicates is most desirable for a long period of time and the accepted background noise level is the maximum amount of background noise an individual can put up with before it becomes a distraction from listening to the speaker. Male listeners had a higher MCL and accepted a higher intensity of background noise than females. Both the MCL and accepted background noise level are used to calculate the ANL. The differences between MCL and accepted background noise levels were different by a consistent amount and direction, which created similar ANLs between the two groups. These results indicate that males and females are judging background noise levels similarly and prefer the same ANLs.

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