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The effects of age on the perception of frequency in noise

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The Effects of Age on the Perception of Frequency in Noise

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ABSTRACT

Difficulty understanding speech in the presence of background noise is one of the most common complaints of older adults, both with and without hearing loss. One possible contributing factor is an age-related decline in neural synchrony (e.g., phase locking). Tones-in-noise were used in an attempt to disrupt rate-place coding of frequency and to encourage participants to use phase-locked, temporal representations of frequency during a behavioral frequency discrimination task. Fourteen adults participated in the study (five younger, aged 21-29; four middle aged, 41-50; and five older, aged 61-80). Participants had clinically normal hearing sensitivity (≤ 25 dB HL at octave frequencies 250 – 8000 Hz). Tone-in-noise detection thresholds and frequency discrimination limens (FDLs) were obtained at 500 and 1000 Hz, separately. FDLs were tested in quiet and noise conditions. The Words-in-Noise test was used to assess speech-in-noise understanding. Results indicated that tone-in-noise detection thresholds were not significantly different across age groups. Frequency discrimination limens were significantly poorer (larger) in the presence of noise; however, no significant age effects were found. Frequency discrimination results indicated that the presence of noise worsened FDLs, consistent with the effect expected with reduced neural coding strategies available in noise. Speech-in-noise understanding was not significantly different across age groups. It is believed that the presence of noise may reduce the effectiveness of some neural coding strategies available to listeners.

Chapter I

LITERATURE REVIEW

Introduction

It is well known that audiometric testing is not directly indicative of the real-world communication difficulties an individual is experiencing. Older adults with and without hearing loss report perceptual difficulties in everyday listening situations, such as speech understanding in the presence of background noise. Therefore, it can be hypothesized that these age-related declines in auditory perception are not solely a result of changes in the peripheral auditory system, but are also likely related to age-related changes in cognition and in the central nervous system (Ben-David et al., 2012; Frisna & Frisna, 1997). For example, a potential cause of these perceptual difficulties is age-related declines in neural synchrony (e.g., phase locking) and decreased populations of low spontaneous firing rate fibers in the auditory system (Schmidt et al., 1996).

Past studies have shown age-related declines by behavioral and physiological frequency representation in quiet (e.g. Clinard et al., 2010); however, previous studies have not yet used frequency discrimination in noise to disrupt rate-place coding, thus limiting subjects to use a temporal coding strategy (Costalupes, 1985). Therefore, past studies have not yet addressed the relevant problem of hearing in noise. This dissertation used a frequency discrimination in noise task to limit subjects to use temporal, phase-locked representation of frequency. This allowed the research to address whether declines in phase locking contributes to the perceptual difficulties older adults with normal hearing experience in noise.

Physiological Frequency Representation in Quiet

Frequency is coded in two different ways: rate-place coding and temporal coding (i.e. phase locking). Both rate-place and temporal coding are able to work in quiet to encode frequency. There are primarily two different VIII nerve populations: low spontaneous firing rate/high threshold fibers and high spontaneous firing rate/low threshold fibers. These populations were first described by Kiang et al. (1965) in cats and in more detail by Liberman (1978). Different VIII nerve populations represent different intensity ranges. This rate changes over a restricted range of sound intensities, which is accommodated by neurons graded thresholds, allowing a wide dynamic range of human hearing.

Rate-place coding can encode frequency in quiet across the audible human frequency range. This type of coding represents the spectral stimulus features in terms of the distribution of average discharge rate across fibers tuned to different characteristic frequencies. Shofner & Sachs (1986) examined the contributions of low to high spontaneous firing rate VIII nerve fiber populations to rate-place frequency coding, using low-frequency tones. They found that in quiet, rate-place coding in low and high spontaneous rate fibers is adequate to represent frequency. At high stimulus levels, rate-place representation of a low frequency tone is maintained in low spontaneous fibers and high spontaneous fibers saturate. This peak at high sound levels in the rate profile of the low spontaneous rate fibers reflects the higher threshold and wider dynamic range of these fibers relative to high spontaneous rate fibers. With frequency in noise, however, different frequency coding strategies are weighted differently.

Temporal coding can also represent frequencies. Temporal coding makes use of phase locking features of auditory neuron spikes by representing frequency by the timing between spikes (i.e. interspike intervals approximate the frequency's period). Unlike rate-place coding, phase locking is robust only for low frequencies, with weaker encoding at higher frequencies (Sinnot et al., 1985). Single-unit animal models have shown VIII nerve phase locking to be robust up to ~1000 – 2000 Hz and then declining (Palmer & Russel, 1986). Many studies have evaluated the respective roles of rate-place and temporal coding in behavioral frequency discrimination tasks (Clinard et al., 2010; Moore & Sek, 1996; Sinnott & Brown, 1993; Buss et al., 2004).

Age-Related Declines in Behavioral Frequency Discrimination

Two basic theories try to explain our ability to detect frequency change in a frequency discrimination task. The first theory is that frequency discrimination is based on changes in the cochlear place distribution of activity in the auditory system and does not depend on phase locking to the fine structure of sinusoids (Moore & Sek, 1994). The second theory is that frequency discrimination is based on information contained in the temporal patterns of firing in the auditory nerve (i.e. phase locking) (Dye & Hafter, 1980; Sek & Moore, 1995; Siebert, 1970; Sinnot & Brown, 1993).

Research by Moore & Sek (1996) used young normal-hearing adults to try and address the temporal vs rate-place coding issue. They tested the effect of amplitude modulation on frequency modulation detection limens. Their research suggests that both temporal and rate-place coding mechanisms contribute to frequency modulation detection, however, the amount of contribution varies depending on the carrier frequency and the modulation rate. They found that at carrier frequencies below 4000 Hz and modulation frequencies below 10 Hz temporal cues were more dominant, suggesting that temporal mechanisms primarily operate below 4000 Hz, whereas rate-place coding primarily dominates above 4000 Hz.

Frequency discrimination studies have consistently reported age-related deficits that are more prevalent at lower frequencies (i.e. 500 and 1000 Hz) then at higher frequencies (i.e. 2000 and 4000 Hz) (He et al., 1998). This trend has been shown in multiple studies (Clinard et al.; 2010, He et al., 1998; Abel et al., 1990). Since it is thought that frequency discrimination limens (FDLs) at lower frequencies depend more on phase locking (e.g. Hienz et al., 2001) than on temporal coding, it is believed that age-related declines in phase locking may contribute to this age-related frequency effect since frequency coding ≤ 1000 Hz is thought to be robustly represented by phase locking (Palmer & Russel, 1986).

He et al. (1998) studied frequency discrimination for aged and young normal-hearing adults. Consistent with past studies, they observed a frequency-dependent difference in frequency discrimination abilities between young and older adults, with significant differences at low frequencies. The largest significant difference was at 500 Hz. As frequency increased, the age-related differences became smaller and not significant. This suggests that even with closely matched audiograms, older subjects demonstrate poorer discrimination abilities then their younger counterparts. Their study also revealed larger intersubject variability in frequency discrimination in older subjects. This trend has been shown in past literature (Moore & Peters, 1992) and suggests that heterogeneity is characteristic of older adults and cannot be explained by their detection thresholds in quiet (He et al., 1998).

Overall, age-related declines in behavioral frequency discrimination and frequency modulation detection limens are consistent with corresponding age-related declines in the quality of phase-locked neural activity. At higher frequencies (i.e. > 1000 Hz), where frequency discrimination performance is predicted better by rate-place coding, age differences are minimal-to-absent. Even though past studies have evaluated age-related changes in frequency discrimination in quiet, little is known about the effects of age and noise on frequency discrimination.

Physiological Frequency Representation in Noise

Effects of background noise on perception of pure tones provides information on understanding the mechanisms that underlie auditory perception (Costolupes, 1983). By controlling the stimulus parameters researchers can target certain coding populations of auditory nerve fibers. For example, by introducing noise into the frequency discrimination task, it potentially forces an individual to use low spontaneous fibers and limit them to use phase locking. This is because high spontaneous firing rate fibers saturate in noise, whereas low spontaneous fibers do not.

Rate-place coding works well in quiet and it can work in certain noise conditions as well (Shofner & Sachs, 1986). However, rate-place coding is more susceptible to noise then temporal coding (Winslow & Sachs, 1988). At high noise levels, low spontaneous fibers carry most of the information that is encoded in the rate response of the auditory nerve fibers (Young & Barta, 1986); high spontaneous rate fibers saturate at high noise levels and do not adequately represent the frequency in noise via rate-place coding. Differences between the rate response in noise of low and high spontaneous rate fibers probably arises from the differences in their thresholds and in the widths of their dynamic ranges. Low spontaneous fibers have higher thresholds than high spontaneous rate fibers, and therefore, are driven less strongly at any given noise level. Temporal coding, however, can be intact when rate-place does not work. At higher stimulus levels, and at lower signal-to-noise ratios, even rate-place coding can break down in low spontaneous firing rate fibers.

Age-related Declines in Physiological Frequency Representation

Past studies have shown age-related declines in behavioral and neural representation of tones in quiet, however, they have not shown any significant relationship between perceptual FDLs and physiological representation of tones in quiet, as reflected in the frequency following response (FFR). Past studies have evaluated age-related declines in phase locking using FFRs (Clinard et al., 2010). Clinard et al. (2010) found that FFRs (temporal coding) did not predict behavioral FDLs at 500 and 1000 Hz. FDLs, however, were measured with tones in quiet, so both temporal and rate-place coding were available. It is hypothesized that if the FDL task focused on temporal coding, and limited the subjects to use phase locking we might be able to better link temporal coding with perceptual measures.

Behavioral Frequency Discrimination in Noise

Frequency discrimination in noise has been used to explore frequency encoding mechanisms. Studies have shown that frequency discrimination at low frequencies is consistent with temporal coding, and frequency discrimination at higher frequencies is consistent with rate-place coding. Dye & Hafter (1980) examined behavioral frequency discrimination in noise by varying experimental parameters. By measuring how FDLs changed as intensity changed, they found that tone level had differential effect on low and high frequencies. Their research showed that as intensity of tones in noise increased, frequency discrimination limens in noise at 2000 and 4000 Hz became poorer. However, as intensity of the tones increased, FDLs in noise at 500 and 1000 Hz became better. Using mathematical models to fit the frequency discrimination data across level, Dye & Hafter (1980) showed that FDL data at 2000 and 4000 Hz were consistent with rate-place model predictions, whereas FDL data at 500 and 1000 Hz were consistent with temporal model predictions. Other studies have shown this trend as well (Sinnot & Brown, 1993). Sinnot & Brown hypothesized that as research continues in this field it may be found that the rate-place code is most likely active via the efferent system, which has ways of overcoming saturation effects, especially in the presence of noise.

In young adults, rate-place coding by low spontaneous rate fibers may still be effective in noise. However, it is believed that in older adults rate-place coding by low spontaneous rate fibers is less likely to be effective in noise since the survival rate of low spontaneous fibers in aged auditory systems is lower (Schmidt et al., 1996). Using aged gerbils, Schmidt et al. (1996) found that there was a paucity of low spontaneous rate fibers with high characteristic frequencies, unlike their younger counterparts. Furthermore, in aged auditory systems there is a decrease in neural inhibition which may lead to more overall excitement (Caspery et al., 2005). This may contribute to poorer phase locking and rate-place coding.

Summary

Research has shown age-related declines in frequency discrimination in quiet (Clinard et al., 2010), however, there is a lack of studies on the effects of age on frequency discrimination in noise. Further research needs to be done to investigate this topic. This study used tones-in noise to disrupt rate-place coding and encourage subjects to use temporal, phase-locked representations in frequency.

This dissertation evaluated the relationship between age-related declines in frequency discrimination in noise and speech perception in noise within the same individuals. This dissertation looked to clarify the following hypotheses:

1. Thresholds for tone-in-noise detection will be significantly higher (poorer) in older adults than in their younger counterparts.
2. Younger adults will demonstrate lower (better) frequency discrimination limens in noise than older adults.
3. Younger adults will have lower (better) signal-to-noise thresholds on the Words-in-Noise test.

Chapter II

METHODS

Materials and Methods

Data collection consisted of three behavioral measures: tone-in-noise detection, frequency discrimination in quiet and noise, and the Words-in Noise test. The test order and the order of conditions for each test were randomized. Data for each subject were collected during one test session. A typical test session lasted approximately four hours.

Subjects

Fourteen subjects participated in this study. Subjects were divided into three groups: young adults (n = 5, ages 21-22, mean age = 22), middle-aged adults (n = 4, ages 43-53, mean age=48), and older adults (n = 5, ages 61-66, mean age = 63). All subjects had hearing within normal limits defined as ≤ 25 dB HL at octave frequencies 250 – 8000 Hz, with the exception of one older participant, age 63, who had an 8000 Hz threshold of 45 dB HL in the right ear and 65 dB HL in the left ear. All subjects had normal tympanograms at the time of testing, suggesting normal middle ear function. All subjects were monolingual native English speakers, had no medical history of otological or neurological disorders, and were not taking any interfering prescriptions. One 23 year old participant was excluded from the study due to their inability to attend to the behavioral tasks.

Subjects were predominantly recruited from James Madison University through campus posted flyers and word-of-mouth. All procedures were passed through the James

Madison University review board. 13 of the 14 participants were compensated $10 an hour for participation.

Stimuli

The output of the computer used for testing was routed through Tucker-Davis Technologies (Alachua, FL) System II sound attenuators (PA4) and a headphone buffer (HB6), and the stimulus was delivered to the subject's right ear through ER3-A insert earphones. Tonebursts of 250 ms in duration (including rise/fall time of 15 ms, Hanning window) were used. Two frequencies were tested: 500 and 1000 Hz. For each frequency octave-wide noise was used, centered on the test frequency (i.e., 500 Hz or 1000 Hz). Subjects were seated in a double-walled, sound-attenuating sound booth during testing.

Tone-in-Noise Detection

For tone-in-noise detection, a method of constant stimuli was used with a single-interval, yes/no paradigm. The tone level was fixed at 60 dB SPL and the octave-band noise was varied to adjust the signal-to-noise ratios (SNR). The SNRs were calculated using the spectrum level of the noise rather than dB SPL (see fig. 1) (Dye & Hafter, 1980; Hienz, Sachs, & Aleszcyk, 1992). Fourteen SNRs were presented ranging from - 6 to 20 dB in 4 dB steps. Twenty trials were completed at each SNR; ten trials had tones-in-noise (signal + noise), and ten had only noise present (catch trials). A logistic fit was calculated on the Proportion Correct [P(C)] from each SNR. Training conditions were performed until a stable psychometric function was obtained. Threshold was determined to be the SNR corresponding to 0.91 P(C) point. Individual data from a younger and older subject are shown in Figure 2.

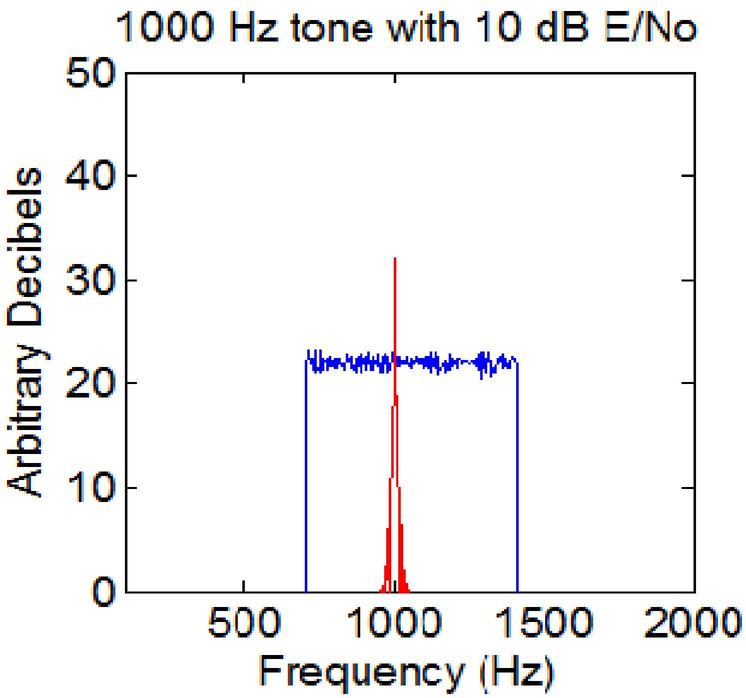

Figure 1. Fast Fourier Transform (FFT) of a representative stimulus. Signal-to-noise ratios were calibrated using spectrum level of noise rather than RMS dB SPL.

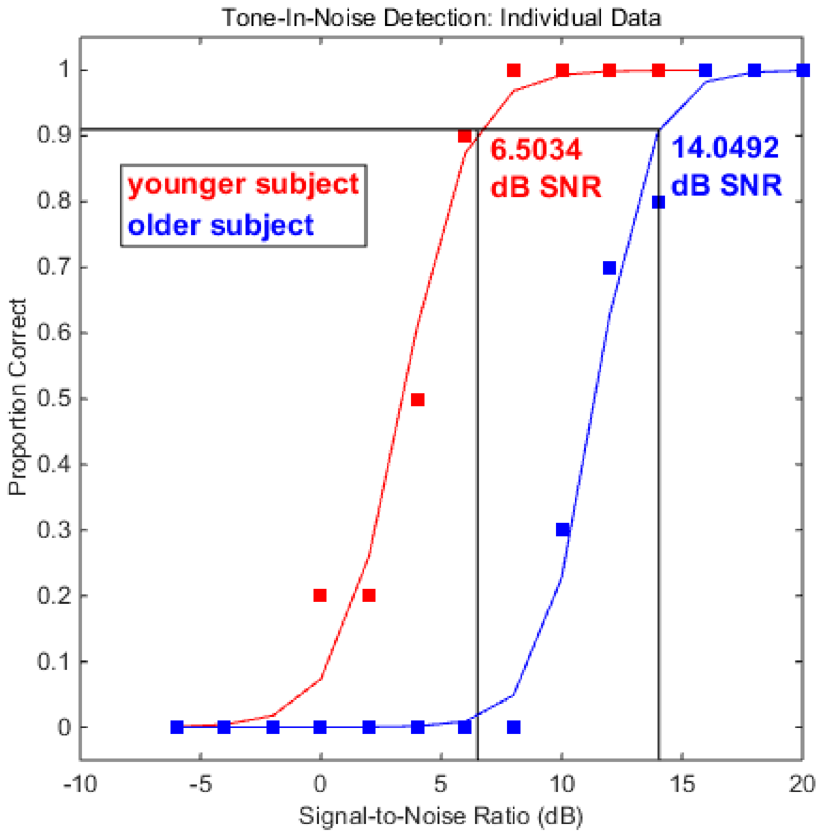

Figure 2. Individual tone-in-noise detection data (squares) and logistic fits (solid lines) from a younger (age 22) and a middle-aged subject (age 53). Detection of the signal improved as SNR increased. The horizontal line indicates the 0.91 P(C) point on the psychometric function, with a vertical line extending to the corresponding SNR(s).

Frequency Discrimination Limens

Frequency discrimination was tested separately for each of the two test frequencies (500 Hz and 1000 Hz), and each of the three signal-to-noise levels (Quiet, + 5, and +10 dB), using an adaptive two-interval forced choice procedure with a two-down, one-up adaptive rule. The +5 and +10 dB conditions had their acoustic SNRs based on the individual's tone-in-noise detection threshold. For example, if an individual's tone-in-noise detection threshold at 500 Hz was 7 dB, they were tested at 12 dB for the +5 dB

(7 + 5 = 12) condition and 17 at the +10 dB (7 + 10 = 17) condition. This approach is common to the frequency discrimination in noise literature (e.g., Dye and Hafter, 1984).

In each of the trials, a blue light flashed when each tone was played. Each pair of tones consisted of the test frequency (i.e. 500 Hz or 1000 Hz) and another tone that was always lower than the test frequency by a given amount, Δf. The order of these tones were randomized, with an inter-stimulus interval of 300 ms. Each subject was instructed to use a mouse to select the button on the computer monitor that corresponded to the tone that was higher in pitch. After the subject selected the tone, they were given visual feedback to indicate whether they had chosen the correct or incorrect tone. If the correct answer was chosen, Δf decreased by half its previous value. If the incorrect answer was chosen, Δf doubled. This procedure continued until there were 12 reversals. The frequency discrimination threshold was computed using the mean of the last 10 reversals. A minimum of two runs for each stimulus (500 Hz or 1000 Hz) was collected. The mean frequency discrimination threshold for each of the stimuli was calculated and used to obtain the frequency discrimination limen (FDL), which is defined as Δf/f.

Speech Perception in Noise

The Words-in-Noise test (WIN; Wilson, 2003) was administered to participants to quantify their ability to understand monosyllabic words in a background noise of multi talker babble. The WIN test was performed by routing the output of a CD-player through the Tucker Davis System II Rack. Two WIN lists (randomized order) were used. The level of the multi-talker babble was fixed at 80 dB SPL and five monosyllabic words were presented at each of the seven signal-to-noise ratios from +24 to 0 dB SNR, in 4 dB increments. The signal-to-babble ratio (SBR) corresponding to the 50% correct point was used as the individual's WIN threshold.

The subject was told to listen for a female voice reading words in the presence of background noise. They were instructed to verbally repeat the words they heard, even when the female voice got quieter and more difficult to understand. They were told to take a guess even if they thought they heard the word. At the end, the participant's responses were scored as correct or incorrect and a total raw score (out of a maximum of 35 points) was calculated. The 50% point threshold was obtained by using a chart of norms located on the WIN score sheet, and using the participant's raw score, their SNR loss was determined to be normal (< 6 dB SBR), mild (6.8 – 10 dB SBR), moderate (10.8 – 14.8 dB SBR), severe (15.6 – 19.6 dB SBR) or profound (20.4 – 26 dB SBR).

Chapter III

RESULTS

Tone-in-Noise Detection

A 3 x 2 repeated-measures ANOVA with one between-subjects factors of group (young, middle-aged, and older adults), and one within-subject factor of frequency (500 Hz and 1000 Hz), was performed to assess differences in tone-in-noise detection thresholds. The ANOVA revealed a significant main effect of frequency [$F_{(1,11)} = 9.549$, $p = 0.010$, partial $\eta^2 = 0.465$], with detection thresholds for 1000 Hz being poorer (higher) than for 500 Hz. The main effect of group was not significant [$F_{(2,11)} = 2.028$, $p = 0.178$]. There was no significant interaction between group and frequency ($p > 0.05$). Although the main effect of group was not significant, in general, detection thresholds were generally poorer (higher) in middle-aged and older adults then younger adults' detection thresholds. Figure 3 shows the tone-in-noise detection threshold data of the young, middle, and older aged groups.

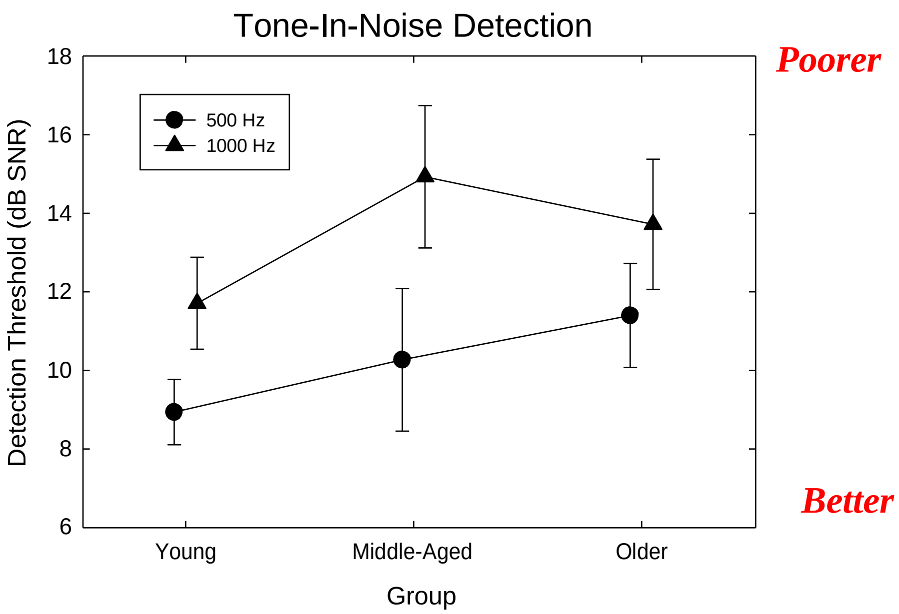

Figure 3. Tone-in-noise detection threshold by frequency (500 Hz = black circles, 1000 Hz = black triangles) for young, middle age, and older adults. Error bars represent the Standard Error of the Mean. Data points have been slightly shifted along the abscissa to minimize overlap.

Frequency Discrimination

A 3 x 3 x 2 repeated measures ANOVA was conducted on FDLs. Factors were group (young, middle-aged, and older adults), noise (Quiet, +5, and +10), and frequency (500 Hz and 1000Hz). The main effect of noise was significant [$F_{(2,22)} = 11.116$, $p <$ 0.001, partial $\eta^2 = 0.503$], consistent with poorer performance in the presence of noise (Figure 4). Main effects were not significant for frequency [$F_{(1,11)} = 3.124$, $p = 0.105$], or for group [$F_{(1,11)} = 1.283$, $p = 0.316$]. Figure 4 illustrates the FDL data which shows that the FDLs were poorer in the presence of noise for all groups at 500 Hz and 1000 Hz.

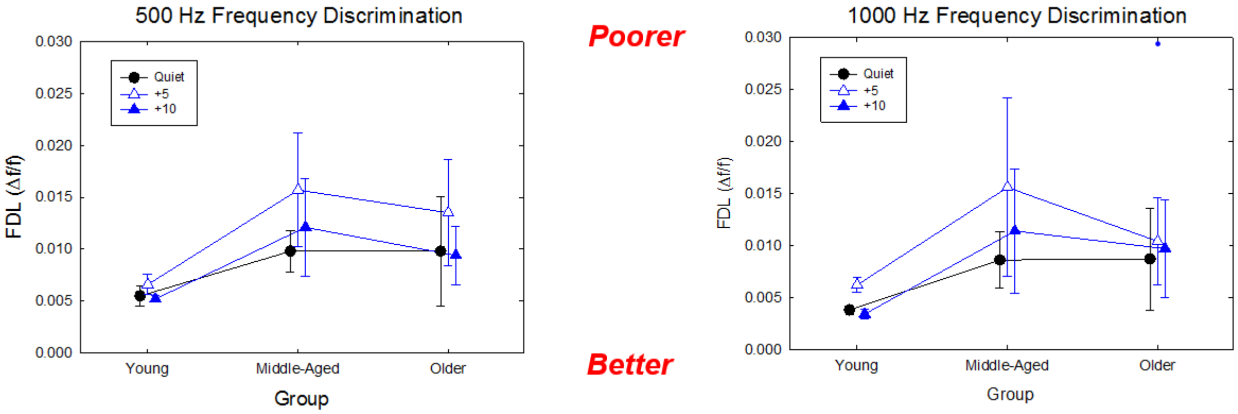

Figure 4. FDLs are shown by frequency, group, and noise condition. Error bars represent the Standard Error of the Mean. Data points have been slightly shifted along the abscissa to minimize overlap.

Words-in-Noise

A one-way ANOVA was performed to examine differences in the performance of listeners by group (young, middle-aged, and older adults). The ANOVA revealed that the main effect of group was not significant [$F_{(2,7)} = 0.205$, $p = 0.819$], indicating no significant difference in performance based on age. Figure 5 illustrates the performance of the three groups for the WIN test.

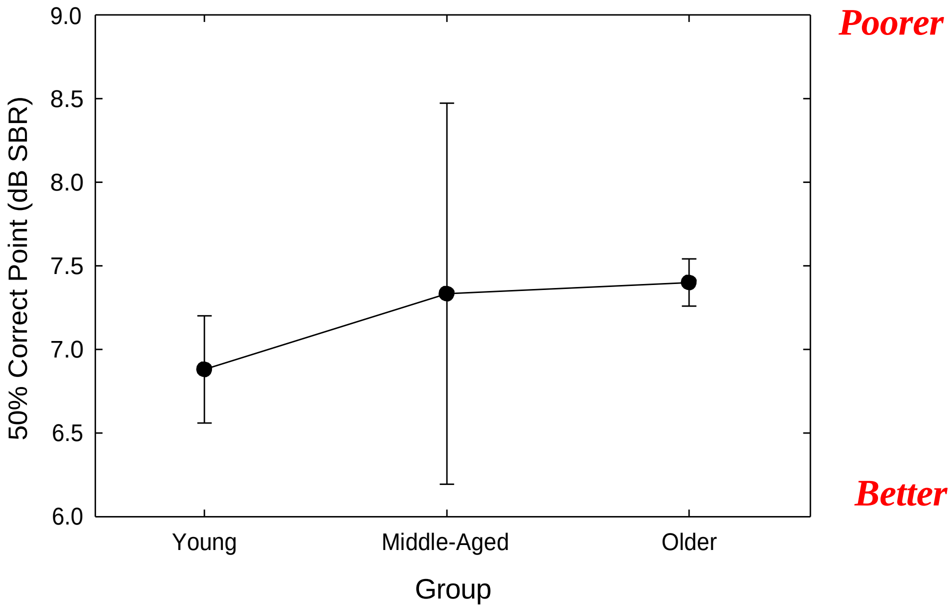

Figure 5. WIN performance for each group. The signal-to-babble ratio (SBR) corresponding to the 50% correct point on the WIN is represented on the y-axis. Error bars represent the Standard Error of the Mean. Middle-aged subjects had considerable variability in their performance.

Chapter IV

DISCUSSION

This dissertation examined the effects of age on behavioral measures of tone-in-noise detection, frequency discrimination, and speech-in-noise understanding. The hypotheses were 1) that older adults would demonstrate significantly higher (poorer) tone-in-noise detection thresholds than younger adults; 2) that younger adults would demonstrate significantly lower (better) frequency discrimination limens than older adults; and 3) that younger adults would have lower (better) signal-to-noise thresholds on the Words-in-Noise test. Lower (better) frequency discrimination limens were expected to be associated with lower (better) signal-to-noise thresholds, and vice versa. Statistical analysis of the data revealed that tone-in-noise detection thresholds were significantly poorer at 1000 Hz than at 500 Hz, however, no significant age effect was observed. Additionally, frequency discrimination limens were poorer (larger) in noise conditions, but no significant age effect was found. These were disappointing results as it was hypothesized that there would be age related declines in all behavioral test measures.

Effect of Age on Frequency Discrimination Limens

There were no significant differences between older and younger subjects' performance on behavioral frequency discrimination measures. It was hypothesized that the younger adults would have better (lower) FDLs than older adults. The results from this study are inconsistent with past studies, which have shown age-related declines in

FDLs beginning as early as middle-age (Clinard et al., 2010). This result, however, is potentially due to the small sample size used for the current study.

FDL results showed that performance on the 1000 Hz FDL task was significantly better than that of 500 Hz for all age groups. This is consistent with past studies (He et al., 1998; Sinnott & Brown, 1993). Furthermore, it was expected that FDLs would be best in quiet and worst at the +5 dB SNR condition. Results showed this trend among all groups. Past studies have suggested that age-related declines in phase locking and neural synchrony may contribute to poor frequency discrimination in older adults. Therefore, it was anticipated that older adults these age related declines would be more apparent in older adults, however, no significant group effects were found.

It is possible that different testing parameters in this study resulted in findings that were not consistent with past research studies. First, this study was done in noise, whereas other studies were performed in quiet. Noise may have impacted the performance of all age groups more than originally anticipated. Additionally, this study used the .91 P(C) point whereas past studies used a .76 P(C) point (Sinnott & Brown, 1993). Therefore, the current study measured threshold where the participant performed very well and where they were more likely to detect the tone-in-noise. It is possible that if the current study used a lower value such as .71 P(C), results may have revealed more significant age effects since the task would have been more difficult. Additionally, past studies, such as Dye & Hafter (1980), used a lower stimulus level (i.e. 45 dB SPL) then the current study. This may have had a similar effect on participant performance. Using a higher level, as the current study did, may have made the task easier for participants than if it a lower level stimulus level was used. In turn, this could have resulted in data more consistent with past studies.

Age and Speech-in-Noise

Even though speech in noise difficulty is one of the most common complaints heard in audiology clinics, the standard measure of hearing, the audiogram, does not effectively evaluate this complaint. Although there are current clinical test measures that can be used to evaluate speech-in-noise difficulties, they do not always accurately identify the actual difficulty an individual experiences. Since there are many available speech-in-noise test measures that can be used, research should focus on which test measure would most accurately identify the difficulty an individual is experiencing.

Currently, research regarding age and speech-in-noise measures reveal inconsistencies in the performance of younger vs. older adults. This variable findings of significant age effects in speech-in-noise measures may be attributed to different methodological approaches, as well as cognitive and hearing loss considerations. One study by Moore et al. (2014) used the digit triplets test to evaluate speech-in-noise performance of normal hearing adults. They found that speech-in-noise declined with age in adults' ≥ 50 years of age. Other studies (Dubno et al. 1984; Gordon Salant 1987; Kim et al. 2006) found similar results. This present study failed to reveal significant age-effects. This study, however, used the WIN test, whereas other studies that revealed significant age-effects used different test measures such as the speech-in-noise test (Dubno et al. (1984; Gordon-Salant, 1987) and the hearing-in-noise test (Kim et al., 2006). Therefore, the different methodological protocols and considerations used among these studies may contribute to the conflicting results. Additionally, the number of participants may have also influenced the results. Frisna & Frisna (1997), for example, used 50 participants, 10 of which were considered elderly with normal hearing, whereas this dissertation only was able to analyze the speech-in-noise test results of 3 elderly subjects with normal hearing.

Methodological Issues

Some of the methodological issues to consider in the current study are the number of subjects who participated and equipment issues. For this study, five participants were selected for each age group. It is possible that more, or larger, group differences may have been found if there were more participants in each age group. Nevertheless, in this study the rationale for selection criteria was based on time restraints. Furthermore, the number of participants used in this study was further reduced from 15 to 14 due to sound card issues. The sound card used for this study began to act erratically while running the last participant. This caused data collection to end, resulting in data for only four middle-aged participants to be statistically analyzed.

Clinical Implications

Difficulty understanding speech in the presence of background noise is one of the most common complaints of older adults. Research that has been done over the past 8 years is beginning to suggest that noise exposure may contribute to these difficulties (Kujawa & Liberman, 2009). Recent animal studies suggest that noise exposure can cause selective loss of high-threshold auditory nerve fibers without affecting the individual’s absolute threshold permanently. This is referred to as “hidden hearing loss,” as it is not detectable in audiometric test measures. It is possible that this “hidden hearing loss” is associated with individual’s speech discrimination and temporal processing abilities (Plack et al., 2014). Currently, however, there is no proven behavioral or physiological measure in detecting hidden hearing loss in humans. Therefore, there is no way of ruling out this possible variable in this current behavioral study or any other study.

Conclusions

(1) Tone-in-noise detection thresholds were significantly poorer at 1000 Hz than at 500 Hz. However, no significant age effects were found

(2) Frequency discrimination limens were poorer (larger) in noise conditions.

(3) No age-related differences were observed on the Words-in-Noise task.

REFERENCES

Abel, S. M., Krever, E. M., Alberti, P. W. (1990). Auditory detection, discrimination, and speech processing in ageing, noise sensitive and hearing-impaired listeners. *Scandinavian Audiology, 19*(1), 43-54.

Ben-David, B.M., Tse, V.Y.Y. & Schneider, B.A. (2012). Does it take older adults longer than younger adults to perceptually segregate a speech target from a background masker? *Hearing Research, 290*, 55-63.

Buss, E., Hall, III, J. W., Grose, J. H. (2004). Temporal fine-structure cues to speech and pure tone modulation in observers with sensorineural hearing loss. *Ear and Hearing, 25*, 242-250.

Caspary, D. M., Schatteman, T. A., & Hughes, L. F. (2005). Age-related in the inhibitory response properties of dorsal cochlear nucleus output neurons: Role of inhibitory inputs. *The Journal of Neuroscience, 24*(47), 10952-10959.

Clinard, C.G., Tremblay, K., & Krishnan, A. (2010). Aging alters the perception and physiological representation of frequency: Evidence from human FFR recordings. *Hearing Research, 264*, 48-55.

Costalupes, J.A. (1983). Broadband masking noise and behavioral pure tone thresholds in cats. *Journal of the Acoustical Society of America, 74*, 758-764.

Costalupes, J.A. (1985). Representation of tones in noise in the response of auditory nerve fibers in cats. *The Journal of Neuroscience, 5*(12), 3261-3269.

Dubno, J. R., Dirks, D. D., & Morgan, E. E. (1984). Effects of age and mild hearing loss on speech recognition in noise. *Journal of Acoustic Society of America*, *76,* 87-96.

Dye, J. R. H., Hafter, E. R. (1980). Just-noticeable differences of frequency for masked tones. *Journal of the Acoustical Society of America, 76*, 87-96.

Frisna, D. R., & Frisna, R. D. (1997). Speech recognition in noise and presbycusis: Relations to possible neural mechanisms. *Hearing Research, 106*(1-2), 95-104.

Gordon-Salant, S. (1987). Age-related differences in speech recognition performance as a function of test format and paradigm. *Ear and Hearing, 8*, 277-282.

He, N., Mills, J. H., Dubno, J. R. (1998). Frequency and intensity discrimination measured in a maximum-likelihood procedure from young and aged normal-hearing subjects. *Journal of Acoustical Society of America, 103,* 553-565.

Hienz, R. D., Sachs, M. B., Aleszczyk, C. M. (1993). Frequency discrimination in noise: Comparison of cat performance with auditory-nerve models. *Journal of Acoustical Society of America, 93,* 462-469.

Kiang, N. Y. S., Watanabe, T., Thomas, E. C., & Clark, L. F.(1965). Discharge patterns of single fibers in the cat's auditory nerve. MIT, Cambridge, MA.

Kim, S., Frisna, R. D., Mapes, F. M., Hickman, E. D., & Frisna, D. R. (2004). Effect of age on binaural speech intelligibility in normal hearing adults. *Speech Communication, 48*, 591-597.

Kujawa, S. G., & Liberman, C. M. (2009). Adding insult to injury: Cochlear nerve degeneration after "temporary" noise-induced hearing loss. *The Journal of Neuroscience (29)*45, 14077-14085.

Liberman, M. C. (1978). Auditory-nervy response from cats raised in a low-noise chamber. *The Journal of the Acoustical Society of America, 63*(2), 442-455.

Moore, D. R., Edmondson-Jones, M., Dawes, P., Fortnum, H., McCormack, A., Pierzycki, R. H., & Munro, K. J. (2014). Relation between speech-in-noise threshold, hearing loss and cognition from 40-69 years of age. *PLOS ONE, 9*(9), 1-10.

Moore, B. C., & Sek, A. (1994). Effects of carrier frequency and background noise on the detection of mixed modulations. *Journal of Acoustical Society of America, 96,* 741-751.

Moore, B. C. & Sek, A. (1995). Effects of carrier frequency, modulation rate and modulation waveform on the detection of modulation and the discrimination of modulation type (AM vs FM). *Journal of Acoustical Society of America, 97*(4), 468-2478.

Moore, B. C. & Sek, A. (1996). Detection of frequency modulation at low modulation rates: Evidence for a mechanism based on phase locking. *Journal of Acoustical Society of America, 100*(4), 2320-2331.

Palmer, A. R. & Russel, I. J. (1986). Phase-locking in the cochlear nerve of the guinea-pig and its relation to the receptor potential of the inner hair-cells. *Hearing Research, 24,* 1-15.

Plack, C. J., Barker, D., & Prenergast, G. (2014). Perceptual consequences of “hidden” hearing loss. *Trend in Hearing, 18,* 1-11.

Schalk, T. B., & Sachs, M. B. (1980). Nonlinearities in auditory-nerve representation of vowels in background noise. Journal of Neurophysiology, 50, 27-45.

Sek, A., & Moore, B. C. (1995). Frequency discrimination as a function of frequency, measured in several ways. *The Journal of the Acoustical Society of America, 97(*4), 2479-2486.

Siebery, W. M. (1970). Frequency discrimination in the auditory system: place or periodicity mechanisms. *Proceedings of the IEEE, 58*, 723-730.

Schmiedt, R. A., Mills, J. H., & Boettcher, F. A. (1996). Age-related loss of activity of auditory nerve fibers. *Journal of Neurophysiology, 76, 2799-2803*.

Shofner, W. P, & Sachs, M. B. (1986). Representation of a low-frequency tone in the discharge rate of populations of auditory nerve fibers. *Hearing Research, 21*, 91-95.

Sinnot, J. M., & Brown, C.H. (1992). Effects of varying signal and noise levels on pure-tone frequency discrimination in humans and monkeys. *Journal of the Acoustical Society of America, 93*(3), 1535-1540.

Winslow, R. L. & Sachs, M. B. (1988). Single-tone intensity discrimination based on auditory-nerve rate responses in backgrounds of quiet, noise, and with stimulation of the crossed olivocochlear bundle. *Hearing Research, 35*(2-3), 165-189.

Young, E. D. & Barta, P. E. (1986). Rate responses of auditory nerve fibers to tones in noise near masked threshold. *Journal of Acoustical Society of America*, *79*(2), 426-442.