Binaural Versus Monaural Listening in Young Adults in Competing Environments

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ABSTRACT

Binaural speech recognition abilities in a group of young adults with normal hearing were analyzed through dichotic listening and word recognition in noise tasks. Dichotic listening was tested under three conditions: free-recall, directed right, and directed left. Word recognition in noise was also tested under three conditions: binaural, monaural right, and monaural left. For the dichotic listening task, subjects exhibited a small right ear advantage (REA) under the free-recall condition, an even larger REA under the directed right condition, and a small left ear advantage (LEA) under the directed left condition. For the words in noise task, subjects exhibited similar scores for the binaural and monaural left conditions; monaural right scores were slightly worse. Results were compared to older adult data previously gathered for both dichotic listening (Roup et al., 2006) and word recognition in noise (Wilson, 2003) tasks. While the young adults exhibited a REA in the free-recall condition, the older adults exhibited an even greater REA. This suggests that there is an age related change in auditory processing that interferes with the ability to integrate the signals entering both ears in dichotic situations. For the words in noise task, both groups did worse as the signal-to-noise ratio decreased. However, young adults scored significantly better than the older adults overall. This suggests that younger adults are better able to separate a signal from background noise than older adults.

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Chapter 1

INTRODUCTION AND LITERATURE REVIEW

The use of both ears for hearing, or binaural listening, makes speech easier to understand and localize than with one ear alone. This is referred to as the binaural advantage. For example, when speech recognition is measured binaurally (i.e., both ears at the same time), listeners typically perform better than when speech recognition is measured in either ear alone (i.e., monaurally). However, this is untrue for some individuals, particularly older adults. It has been shown that some individuals experience binaural interference rather than a binaural advantage (Allen, Schwab, Cranford, & Carpenter, 2000; Jerger, Silman, Lew, & Chmiel, 1993). Binaural interference refers to the situation in which one ear actually interferes with recognition of speech from the other ear. In this case, speech recognition is best when listening with the better ear alone. Some researchers (e.g., Allen et al.) believe these individuals experience an auditory processing deficit, which causes this difficulty. The combination of binaural interference and a hearing loss may impact audiologic rehabilitation strategies. For instance, a traditional rehabilitation scheme involves binaural amplification to treat an individual's hearing loss. For an individual exhibiting binaural interference, monaural amplification may be of greater benefit.

Two ways to test a person's binaural versus monaural listening ability are through word recognition in noise tasks and in dichotic listening tasks. Word recognition in noise tasks use monaural and diotic listening (i.e., receiving the same signal in both ears at the same time) to assess speech understanding. Older adults with hearing loss often report much trouble understanding speech in noisy environments (e.g., a party), and word recognition in noise tasks closely mimic these situations. Testing involves examination of the left ear, the right ear, and both ears together (i.e., binaural) results. For most listeners with symmetric hearing loss, performance for binaural word recognition is superior to that of either ear alone. Further, performance for the two ears measured monaurally is typically the same. On the other hand, dichotic listening involves presenting two different stimuli at the same time to the left and right ears. When testing dichotic listening, a right ear advantage (REA) is observed for most listeners (Kimura, 1967). A REA consists of correctly recalling more of the stimuli presented to the right ear than to the left ear. As someone ages, the REA often becomes more pronounced and is more appropriately referred to as a left ear disadvantage (LED) (Jerger, Chmiel, Allen, & Wilson, 1994). A dichotic LED suggests a correlation between an increase in age and a binaural auditory processing breakdown.

The present study investigated the relationship between dichotic listening and left ear, right ear, and binaural word recognition in multitalker babble among the same group of young adult listeners. In addition, the results from the young adults were compared to already published older adult data collected on the same measures.

Binaural Listening

Individuals use both ears to listen to everyday sounds. Binaural listening allows someone the ability to perceive and localize the incoming signals through time and intensity differences between the two ears. As sounds reach the head, the interaural time and intensity differences, which are frequency dependent, allow the person to spatially separate, and therefore localize, each signal (Grose, 1996). Warren, Wagener, and Herman (1978) explain that the normal improvement one experiences from binaural listening, as opposed to monaural listening, comes from the auditory system's ability to use time and amplitude differences (i.e., binaural signal analysis) to localize sounds and to separate the intended signal from background noise. Binaural signal analysis helps filter speech signals based on their directional cues to perform binaural squelch, the suppression of interfering noises in order to focus on the intended signal. Another advantage to binaural listening is that it gives a 6-10 dB gain to the listener at suprathreshold levels (Haggard & Hall, 1982). Therefore, a sound's intensity is 6-10 dB softer when an individual is listening binaurally to perceive the signal as being equally loud as listening to that signal monaurally. According to Haggard and Hall, binaural listening helps a normal hearing listener distinguish lower frequency and intensity discrimination levels. This allows a listener using two ears to perceive smaller changes in pitch and loudness than someone listening monaurally.

Binaural Listening in Older Adults

Some older adults have a hard time listening to stimuli in the presence of background speech noise, due to their reduced ability to perform binaural signal analysis (Warren et al., 1978). Binaural signal analysis helps filter speech signals based on their directional cues. Therefore, these older adults have a difficult time finding where a signal is coming from and separating that signal from all the other speech noise. Warren et al. suggest there is "an age-related deficit in the binaural processing of speech signals" (p. 735). This deficit is one reason older adults may have trouble listening to speech in noisy environments.

Also, many older adults also have a deficit in their temporal processing (Warren et al, 1978). Grose (1996) tested both young adults' and older adults' abilities to localize the origin of pairs of clicks. He found that younger listeners, as a whole, performed better than the older listeners. This supports the notion that the older adults could not process the "time-of-arrival differences" (p. 169) as efficiently as the younger subjects, which suggests a breakdown in temporal processing.

Many older adults are affected by hearing loss. For example, presbycusis, the natural aging of the auditory system, can affect individuals' ability to understand speech in background noise. Warren et al. (1978) note that the hearing loss caused by presbycusis makes it hard for the individual to distinguish high frequency consonant sounds, especially in the presence of a background competitor. Also, Jerger et al. (1993) explain that older adults with asymmetrical hearing loss may not be able to integrate or separate two different speech signals, which causes problems with speech understanding. Allen et al. (2000) completed a study with a word recognition task comparing young and old listeners with normal hearing to groups of older listeners with hearing loss who were unaided or aided. Allen et al. tested word recognition in the right ear alone, the left ear alone, and both ears together for all subjects. Both groups of hearing impaired older adults, unaided and aided, exhibited their poorest word recognition scores (WRS) for the left ear alone. WRS for the right ear alone and WRS for both ears together did not differ. The group of older normal hearing adults showed little difference between the left ear WRS and right ear WRS. Therefore, the right ear appears to have an advantage over the left ear for the older hearing impaired adults. The older normal hearing group has better hearing sensitivity, but they did not exhibit the right ear advantage. This suggests that the group of older listeners with hearing loss, both aided and unaided, "may represent a physiologically older subset of the aging population than do their peers who have more normal peripheral sensitivity" (Allen et al., 2000, p. 500). The group of listeners with hearing loss may have, along with their cochlear dysfunction, an impairment in the transmission of speech information across the corpus callosum to the speech and language center contained in the left hemisphere, as discussed previously.

Therefore, the left ear may be interfering with the incoming signal, and this makes processing the signal more difficult (i.e., binaural interference). (Allen et al., 2000).

<u>Word Recognition in Noise</u>

Word recognition in noise tasks are similar to one of the most common complaints of older adults with poor hearing. Many of these individuals have a lot of trouble in situations with extensive background noise, such as a bar or restaurant (Brooks, 1984). In order to mimic these noisy environments, multitalker babble is introduced into the word recognition tasks so as to make them more challenging and more like what someone may hear in everyday life (Wilson, 2003). Multitalker babble is similar to the background noise an individual hears at a bar or restaurant because it is comprised of various speakers talking at the same time but with none of their conversations intelligible.

Sperry, Wiley, and Chial (1997) researched the effects various types of background noise can have on an individual's word recognition performance. They used three different background competitors: 1) a meaningful multitalker message consisting of three male and three female speakers; 2) the same multitalker message but recorded in reverse to eliminate meaning; and 3) "an amplitude-modulated speech-spectrum noise (SSN) having the same long-term average spectrum and amplitude fluctuations as the meaningful multitalker competing message" (p. 71). Sperry et al. found that the meaningful competitor caused significantly poorer word recognition performance than either non-meaningful competitor. This suggests that meaning in background noise for word recognition tasks produces worse performance than non-meaningful background noise. Therefore, using a meaningful speech competitor would make a word recognition task more difficult. Also, the non-meaningful speech competitor produced worse results than the SSN. Because both speech competitors, one with meaning and one without meaning, produced the poorest results, a background competitor without speech would produce the best performance on word recognition in noise tasks. In order to avoid both floor and ceiling effects, a background competitor of non-meaningful speech should be used to produce optimal results (Wilson, 2003).

A variety of stimuli can be used for speech recognition in noise tasks. Some, however, produce better results than others. For example, using sentences as the stimulus creates a variety of problems to the listener: "1) recognition versus recall; 2) recency and primacy effects [(i.e., the brain tends to remember items from the beginning and end of something but more easily forgets what is in the middle)]; 3) bottom-up versus top-down information processing; 4) the multiplicative effects of various degradations on recognition of the speech signal" (Wilson, 2003, p. 455). Using monosyllabic words, also more common in clinical practice (Wilson, 2003), avoids these issues.

Word recognition in noise tasks can be tested in the right and left ears alone (monaural) and the ears together (binaural). The binaural condition should produce the best results due to the binaural advantage. According to Haggard and Hall (1982), an individual's ability to use time and intensity differences between the ears to better analyze the incoming signal allows the binaural condition to produce the best scores. Wilson (2003) conducted a words in noise study comparing the differences between monaural and binaural scores in normal hearing adults and adults with hearing loss, both aided and unaided. He found that there was a significant 1 dB difference between the monaural scores and binaural scores. Normally in quiet, an individual's binaural threshold would be about 3 dB lower than his or her monaural threshold due to binaural summation. However, when background noise is added, both the signal and noise are summed together, and this alleviates the binaural advantage one finds in quiet. Wilson suggests the 1 dB advantage observed in his study is due to "the effects of the contralateral masking used with the monaural condition" (p. 468). Therefore, even though binaural summation has less of an effect when background noise is present, there is still a binaural advantage.

Dichotic Listening

Language Lateralization and the Right Ear Advantage

Dichotic listening involves simultaneously presenting different stimuli to each ear (i.e., one stimuli to the left ear and a different stimuli to the right ear). In order to learn about the connection between dichotic listening and language lateralization, Kimura (1961a) tested 71 subjects who experienced epileptic seizures, and the subjects were grouped according to the location of their brain abnormality. A dichotic digits test was given to each subject. Subjects with lesions on their left hemisphere performed more poorly overall than subjects with lesions on their right hemisphere. However, the subjects with lesions on their left hemisphere performed better than the subjects with lesions on their right hemisphere on dichotic tasks consisting of non-verbal stimuli. This suggests the left hemisphere is "specialized for the recognition of verbal material […] and that it is particularly important in the analysis of verbal material coming from more than one source" (p. 162). For most people, the left hemisphere appears to be the center for processing and comprehension of speech and language.

Some of the subjects in Kimura's study (1961a) had brain operations to remove the damaged tissue causing the epileptic seizures. These patients, regardless of the location of the surgery (i.e., the left hemisphere versus the right hemisphere), showed an impairment in the recognition of digits presented to the ear opposite the hemisphere of the tissue removal. This data suggests, as stated in Kimura's 1961b research article, the contralateral pathway (i.e., a signal going in one ear connects to the opposite hemisphere of the brain) is more important and stronger than the ipsilateral pathway (i.e., the signal going in one ear connects to the hemisphere of the brain on the same side of the head) during dichotic speech perception. In a similar study, Kimura (1961b) once again tested subjects with epileptic brain lesions. Some subjects had a dominant left hemisphere for the processing and comprehension of speech and language while others had a dominant right hemisphere for the processing and comprehension of speech and language, as determined by a sodium amytal procedure. All subjects were presented with dichotic digits, and Kimura found that the stimuli that "[arrived] at the ear opposite the dominant hemisphere [were] more efficiently recognized" (169). Again, this reinforces the idea that the crossed auditory pathways are "more efficient" (169) than the uncrossed pathways, and the dominant hemisphere is more important than the non-dominant hemisphere in the perception of verbal dichotic material. Not only does the central auditory processing center receive more fibers from the contralateral pathway but the contralateral pathway actually suppresses the ipsilateral pathway during dichotic listening (Kimura, 1967). At the point where the contralateral pathway overlaps with the ipsilateral pathway, the contralateral pathway actually occludes impulses from the ipsilateral pathway. The quantity of auditory fibers and the suppression of the ipsilateral pathway make the contralateral pathway stronger than the ipsilateral pathway.

Because the contralateral pathway is strongest and because most people have their language center in their left hemisphere, sounds entering the right ear have a more direct pathway to the speech center than sounds entering the left ear. During dichotic listening, an auditory signal entering the left ear would initially be conducted to the right hemisphere of the brain and transferred to the left hemisphere through the corpus callosum in order to reach the speech and language center. This extra step causes a loss of energy in the transmission of the auditory signal between brain hemispheres (Kimura, 1967). Kimura (1961b) explains that stimuli presented to the right ear will send more impulses to the left hemisphere than to the right hemisphere, and the individual will therefore be able to correctly identify more of the stimuli presented to their right ear. The ability to recall more stimuli from the right ear is the REA. Using a dichotic digits task to test an epileptic group of subjects, each participant with a dominant left hemisphere, Kimura (1961b) recorded higher scores for the right ear as opposed to the left ear for all subjects, regardless of the site of lesion. She found similar results for a group of normal subjects. The subjects' ability to recall more digits presented to their right ear is the basis of the REA concept. Similarly, in concurrence with the notion of an ear advantage, Kimura's subjects who had the speech center in their right hemisphere, a more infrequent occurrence, were able to correctly identify more stimuli presented to their left ear as opposed to their right ear (i.e., a left ear advantage) when tested on dichotic digits tasks (Kimura, 1961b). This supports the theories that the contralateral pathway is stronger than the ipsilateral pathway and that one hemisphere of an individual's brain is more dominant for speech perception.

Kimura (1967) completed a study where she asked normal hearing subjects to listen to dichotic monosyllabic words and repeat only the words from a pre-determined ear. Subjects repeated the words they heard only in their left ear or only in their right ear but not both. The same list of words was then presented monaurally with no competing stimuli. The list was presented only to the pre-determined ear from the first portion of the test. Under the dichotic condition, subjects who repeated words from their right ear had higher scores than the subjects who repeated words from their left ear. Under the monaural condition, no advantage was found for either ear. Even though both conditions require the subject to only listen to one ear and both conditions contain the same word list, the results between the dichotic condition and monaural condition are different. The difference between conditions suggests that in the dichotic condition, there is a competition between stimuli. The competition between stimuli creates a noticeable difference between the right ear performance and left ear performance. In the dichotic condition, more correct responses were recorded from the subjects responding to the message in their right ear, and this is the basis for the REA. Another way to test language lateralization is through the use of nonsense syllables instead of digits, words, or any other meaningful stimuli (Kimura 1967). Nonsense syllables are verbal stimuli, but they lack the meaning that digits, monosyllabic words, and sentences have. When tested similarly to other dichotic measures, nonsense syllables also evoke a REA. This strengthens the argument that the left hemisphere is usually where the processing of speech occurs, and the contralateral connection between the right ear and left hemisphere is strongest.

Handedness and Ear Advantage

The majority of people, regardless of handedness, will show a REA because of the speech center's location in the left brain hemisphere for most individuals. However, there is discrepancy between scores from right-handed subjects and left-handed subjects. Upon review of 18 various studies investigating the relationship between dichotic listening and handedness, Bryden (1988) found that overall 82% of the right-handed subjects and 64% of the left-handed subjects showed a REA on dichotic listening tasks. Even though both groups displayed a REA, the difference was significant enough to cause one to pay attention to handedness during subject criteria selection. Wilson and Leigh (1996) tested 24 right-handed subjects and 24 left-handed subjects on a dichotic nonsense syllable task. They found that both groups of subjects expressed a REA, but the right-handed subjects, as a whole, had a more pronounced REA than the left-handed subjects. Wilson and Leigh found the "average ear difference between groups (the mean from the right-handed group minus the mean from the left-handed group)" (p. 5) for both the right ear and left ear. For the right ear, it was 10.4%. For the left ear, it was 0.8%. Therefore, on average, the right-handed group correctly repeated back 10.4% more of the stimuli presented to the right ear and 0.8% of the stimuli presented to the left ear than the left-handed group. Consequently, handedness has a stronger relationship with the scores for the right ear and a weaker relationship to the scores for the left ear, which illuminates the notion that right-handed people have a greater REA than left-handed people.

While 90% of right-handed people contain the speech and language processing center in the left hemisphere of their brain, only 60% of left-handed people contain their speech and language processing center on the left half of their brain as well (Branch, Milner, & Rasmussen, 1964). Fewer left-handed people experience language lateralization in their left hemisphere because they must constantly adapt to a world that is predominately right-handed. Because of this adaptation, their brain hemispheres tend to be less lateralized altogether. In order to reduce variability among subjects and to control for handedness when measuring dichotic listening, only right-handed subjects should be used. By doing this, it narrows the possibility of having a subject with language lateralization toward the right brain hemisphere as opposed to the usual left hemisphere.

Response Condition and the Ear Advantage

Dichotic listening is measured using three response conditions: free-recall, directed-recall right, and directed-recall left. The free-recall response condition involves having the subject repeat both stimuli in any order. The directed-recall right condition involves having the subject repeat the stimulus heard in their right ear followed by the stimulus heard in their left ear. The directed-recall left condition involves having the subject repeat the stimulus heard in their left ear followed by the stimulus heard in their right ear. In both directed-recall conditions, the subject is prompted to which ear to first respond to prior to hearing the actual stimuli. The prompting of the subject helps relieve much of the cognitive and memory demands placed on him or her in the free-recall condition. In the free-recall condition, a REA is often seen because of the left hemisphere language lateralization commonly seen in right-handed individuals, as discussed previously. In the directed-recall right condition, an even greater REA should be noticed. The prompting allows the brain to prepare for and focus on the incoming stimulus in the right ear. Because the subject's anatomy already predisposes him or her to a REA, the added focus from the directed-recall in this condition increases the number of correct responses, which also increases the REA. The directed-recall left condition should produce a slight left ear advantage. Again, the prompting allows the brain to prepare for and focus on the stimuli coming into the left ear. However, due to language lateralization to the left hemisphere, the left ear advantage seen is not as great as the REA noticed for both of the other conditions.

Stimuli for Dichotic Speech Recognition

Dichotic listening tasks use words, digits, sentences, or consonant vowels (CVs), also called nonsense syllables, as stimuli. These stimuli can differ in two ways: in meaning and in length. As the stimuli have less meaning to an individual, the dichotic listening task increases in difficulty. Inversely, as the stimuli have more meaning to an individual, the dichotic listening task decreases in difficulty. As Noffsinger, Martinez, and Andrews (1996) note, CV tasks are challenging because the individual does not already have those stimuli present in their internal vocabulary. Without a place in one's internal vocabulary, the syllables lack meaning, which makes the dichotic listening task harder. Noffsinger et al. explain that digits and sentences are more common in everyday life. Because of this, they have more meaning, and the dichotic listening task is easier. CVs are difficult not only due to their lack of meaning to a subject but also because of their short duration. Noffsinger et al. state that the use of CVs makes a task very difficult because the stimuli occur for the same duration and only differ in a few characteristics. In Wilson and Jaffe's (1996) research using digits as stimuli, they found that as the stimuli increased in complexity and length from 1-pair digits to 4-pair digits, there was a decrease in correct recognition performance. The dichotic listening task became more difficult as the length of the stimuli increased. Also, as the stimuli became longer and more complex, the REA increased. Differences in difficulty of the stimuli, in both meaning and length, will create differences in subject performance. Subject performance affects the magnitude of the REA. Therefore, the magnitude of the REA is dependent on the complexity and difficulty of the stimuli and listening task (Wilson & Jaffe, 1996).

While words, digits, sentences, or CVs could be used as stimuli for a dichotic listening task, the use of words (i.e., digits, monosyllabic PB words, and spondees) has its advantages. The most commonly used stimuli for dichotic listening tasks are digits. However, monosyllabic words are very practical for dichotic presentation for many reasons. Roup, Wiley, and Wilson (2006) explain that monosyllabic words give these advantages: 1) monosyllabic words are meaningful to the subject and limit syntactical cues; 2) lists of pre-recorded monosyllabic words are readily available, already standardized, and in common use clinically; 3) norms have been previously created for various age groups, for normal hearing and hearing impaired individuals, and for both quiet and competing message environments; 4) monosyllabic words have an open stimulus set. Therefore, words may represent a stimulus that is complex enough but not too complicated for a wide range of subjects.

Age Effects on the Ear Advantage

The phenomenon of a REA has been studied in various ways under different conditions. Researchers have wondered how changes in age affect the REA. Wilson and Jaffe (1996) did a dichotic listening study with two groups: a <30 years old group and a 60-75 year old group. They found that the <30 years group had significantly better overall recognition performance than the 60-75 years group. They noticed that increasing the complexity of the stimuli had a larger detrimental effect on the older adults as opposed to the younger adults. While both groups expressed a REA, the 60-75 years group exhibited a larger one. Even though both groups had similar right ear scores, the 60-75 year olds had worse left ear scores. This is called a left ear disadvantage (LED) (Jerger et al., 1994). Wilson and Jaffe demonstrate the connection between a decline in left ear performance with an increase in age.

Noffsinger et al. (1996) conducted a study with older adults (58-85 years old with an average age of 70). They found that the scores on dichotic digits for the right ear (98%) and for the left ear (95%) were comparable to the scores of younger adults collected in a separate study but with the same test. Scores were best for this condition because dichotic digits are least challenging since they have meaning to the listener and are short in duration (Noffsinger et al.;

Wilson & Jaffe, 1996). The scores for older adults on dichotic sentences were good but not as good as the scores compiled for younger adults. The older adults did 11.8% better on average in their right ears as opposed to their left ears. The older adults did poorest on the nonsense syllables task. The average recognition performance for the right ear was 58.4% while it was only 41.6% for the left ear. These results are considerably poorer than those collected for the younger adults. This data supports the conclusion that there is a correlation between an increase in age and an increase in poorer dichotic listening scores.

Jerger et al. (1994) conducted a study with 356 individuals ranging in age from 9-91 years old. The study was comprised of both free-recall and directed-recall tasks with dichotic sentences. In general, an overall decline in performance was observed for both ears as age increased. In the free-recall condition, all age groups exhibited a REA, but the magnitude of the REA increased as age increased. In the directed-recall condition, a REA was seen for all age groups. Again, as age increased, the left ear performed poorer than the right ear, which creates a larger REA. This is the left ear disadvantage. This data is in support of other research that suggests an association between an increase in age with a left ear deficit. As the left ear deficit increases, the REA increases.

The presence of a LED as a function of increasing age could potentially be due to a breakdown in cognitive factors (e.g., memory or information processing). Jerger et al. (1994) believe this is not what causes the left ear deficit. They found similar results for both the free-recall and directed-recall conditions. The free-recall condition requires greater cognitive skills and should therefore produce poorer results as age increases. However, the results were the same for both the free-recall and the directed-recall tasks. This rules out the hypothesis that a breakdown in cognitive factors contributes to the left ear deficit. Instead, Jerger et al. (1994)

believe it is due to a breakdown in the auditory structures or pathways. This could be explained by two different hypotheses. First, there could be a greater decline in "neural processes and neural efficiency associated with aging" (Carter, Noe, & Wilson, 2001, p. 266). This would affect the input to the left ear more because it is believed there may be a greater decline in the function of the right hemisphere, as opposed to the left hemisphere, as one ages (Goldstein & Shelly, 1981). Second, the corpus callosum may not be as efficient in interhemispheric transmission of the auditory signal from the right hemisphere to the left hemisphere, where the speech processing center is located. Therefore, sounds entering the left ear traveling contralaterally to the right hemisphere are at a disadvantage because they must pass through a less efficient corpus callosum.

Clinical Implications

Most hearing aid users are fit with two hearing aids at their initial hearing aid fitting. This is done because of the added benefits of improved localization, elimination of the head shadow effect (i.e., the head blocking a sound wave resulting in reduced intensity of the signal), binaural summation (i.e., a perceived greater loudness due to the combination of both the left and right ears), and binaural squelch (i.e., the ability of the auditory system to suppress background noise interfering with the intended message) (Carter et al., 2001). Also, the audiologist wants to prevent auditory deprivation in one ear (i.e., when an ear lacks auditory stimulation over time, the function of that ear eventually diminishes) (Allen et al., 2000). The benefit a patient gets from amplification is usually measured through the testing of speech discrimination for both the pre-hearing aid fitting and the post-hearing aid fitting and by comparison of pure tone thresholds with the hearing aids in and with the hearing aids out (Brooks, 1984). While many adults score very well on these tests with binaural amplification, there is a group of older adults who may score well in the sound booth but will not actually have as much benefit from being binaurally aided in their environment. Much of the problem these older adults face with binaural aids occurs in noisy situations where the brain cannot separate background noise from the intended signal (Warren et al., 1978). Jerger et al. (1993) present cases in which subjects' binaural performance is worse than their monaural performance on either aided speech recognition scores, a behavioral test, or their middle-latency responses, an electrophysiologic test. They explain this phenomenon as a binaural interference effect, where the poorer ear interferes with the response of the better ear. All of the subjects studied in their report experienced a poorer response when both ears were stimulated rather than when only the better ear was stimulated. This suggests some sort of interference from the poorer ear.

Carter et al. (2001) studied a group of four individuals who were initially fit with binaural amplification after exhibiting symmetric audiometric thresholds and found the binaural hearing aids to be unsatisfactory. These patients experienced the most difficulty in situations with a lot of background noise, and they found that they could hear better when only using one hearing aid as opposed to both. Carter et al. conducted a dichotic digits task using both free-recall and directed-recall stimuli as well as a word recognition in noise task under various amplification conditions. The results showed all four patients expressed a left ear deficit for both free-recall and directed-recall dichotic listening tasks that could not be explained by a hearing loss or any cognitive-based deficit. Each subject showed a drop in word recognition scores once a competing babble was introduced, which is consistent with their trouble with speech comprehension in noisy environments. The four subjects had worse monaural left scores compared to their monaural right scores for word recognition. The subjects experienced better performance when monaurally aided in their right as opposed to being binaurally aided when all amplification strategies were tested, excluding the FM system. Carter et al. suggest the improved signal-to-noise ratio found with FM systems enhances the left ear performance enough in order to not interfere with the right ear. Also, there was no significant difference between aided and unaided binaural word recognition scores. This shows the lack of benefit the subjects received from their hearing aids when background noise was present. In another study, Brooks (1980) collected reports from patients who have worn both monaural and binaural amplification. Most preferred being binaurally aided in quiet situations, but over half preferred being monaurally aided in noisy environments. Therefore, the need to identify patients who benefit from being monaurally aided, as opposed to the typical rehabilitation scheme involving binaural amplification, is essential in order to ensure their optimal success.

A typical rehabilitation scheme for those with a bilateral hearing loss is to binaurally aid the patient (Haggard & Hall, 1982). While this often works well for many individuals, there is a small group of people who find being monaurally aided more beneficial. Jerger et al. (1993) estimate this group to be about 8%-10% of elderly hearing aid users. Even though this is not close to a majority, a monaural hearing aid fitting could positively impact the quality of their lives. A binaural hearing aid fitting for someone who fits into this minority group could be a reason he or she may return their hearing aids (Allen et al., 2000). One goal of an audiologist is to assist their patients in obtaining the best hearing possible. Having a patient return their hearing aids is not optimal, especially for something that can be altered and improved.

One of the main complaints of hearing aid users who experience binaural interference is that it is very difficult to hear in noisy situations. Hearing aids help amplify the intended signal, but they also amplify the background noise. The hearing aid cannot differentiate between the speech signal and speech as background noise (Warren et al., 1978). For someone with binaural interference, the addition of amplified background noise adds to the confusion. Monaural aiding in this situation can give the individual the amplification they need to pick up the intended signal while avoiding the binaural interference complications they would receive from being binaurally aided.

One way to test an individual to see if he or she may be a candidate for monaural aiding is through dichotic listening tasks (Carter et al., 2001) and word recognition in noise tasks. Currently, these are not always standard procedures during a hearing evaluation. While some clinicians may complete brief word recognition in noise tests, they often do not complete them both monaurally and binaurally. The time involved to test these processes is minimal, and the potential benefits are great (Allen et al., 2000).

As Wilson (2003) points out, the typical audiologic evaluation does not address "the distortion component of hearing loss" (p. 454). In addition to the processes already tested in the evaluation, the audiologist should also test for hearing loss for speech in noise to help the patient choose the appropriate hearing aid strategy and shape appropriate amplification expectations (Wilson, 2003).

Present Study

The present study compared the results of free-recall and directed- recall dichotic listening tasks to monaural left, monaural right, and binaural word recognition in multitalker babble tasks. These data were compared to previously published data for the same tasks for older adults. The data from younger adults serves as a norm in order to compare the older adults' scores. The younger adults should exhibit a slight REA for the dichotic listening tasks and a binaural advantage in the word recognition in multitalker babble tasks. Comparing these results to the older subjects' results will show how much aging has affected the auditory system's ability to analyze incoming sounds in various competing environments. This will help define more specific dichotic listening scores and word recognition in noise scores to better identify those individuals who may benefit from monaural amplification instead of the more common binaural amplification.

The questions I intend to answer through my research are:

1. What is the correlation between dichotic listening and left ear, right ear, and binaural word recognition in noise in younger listeners?
2. How do the results from this research compare to already published data collected on older adults under the same testing conditions?

Chapter 2

METHODS

Subjects

Ten young adults (3 male and 7 female) with normal hearing were recruited for the present study. The subjects ranged in age from years 18 - 22 (mean = 20.9). Normal hearing was defined by pure tone thresholds ≤ 20 dB HL for 250 – 8000 Hz. Bone conduction thresholds were within 10 dB HL of air conduction thresholds for 500 – 4000 Hz. All subjects were right-handed as determined by a score of ≤ 20 on the Edinburgh Handedness Inventory (Oldfield, 1971). The questionnaire consists of ten tasks in which the subject must rate their "preference in the use of hands" (see Appendix A). Only right-handed subjects were recruited for the present study in order to limit the variability in dichotic performance associated with left-handedness (Wilson & Leigh, 1996). Additional inclusion criteria include: 1) normal ear canal and tympanic membrane status determined by otoscopy; 2) normal middle-ear function determined by tympanometry (Roup et al., 1998); and 3) native speakers of American English. Subjects were recruited from the student population at The Ohio State University and from the surrounding community of Columbus, Ohio.

Experimental Stimuli

All dichotic listening and words in noise tasks were completed using the Northwestern University Test Number 6 (NU-6) monosyllabic words spoken by a female speaker from the Department of Veterans Affairs compact disc (CD) *Speech Recognition and Identification Materials 1.1* (VA Medical Center, Long Beach, CA, 1991). The NU-6 test is a list of phonetically balanced words commonly used to measure speech understanding in clinical audiology. For the dichotic listening paradigm, two-hundred NU-6 words were used to create a CD recording of 100 dichotic word pairs in order to measure dichotic word recognition (Roup et al., 2006). For details on how the word pairs were created, see Roup et al. (2006). Seven randomizations of the 100 word pairs were recorded on CD, and each randomization was broken into four lists of 25 word pairs. A 4.5s interstimulus interval (ISI) was inserted between each stimulus. Each pair of words was preceded by the carrier phrase "say the word" (Roup et al., 2006).

The Words in Noise (WIN) test was used to measure word recognition in multitalker babble (Wilson, 2003). The words chosen for the WIN were based on a series of pilot studies that produced psychometric functions of 150 monosyllabic words from the NU-6 test list from both normal hearing listeners and listeners with a hearing loss in order to produce target performances for each word. From the original 150 word list, 102 words met the selection criteria (i.e., 30% correct at 0 dB signal to babble ratio [S/B], 50% at 4 dB S/B, 70% at 8 dB S/B, 90% at 12 dB S/B, and $95\%^{+}$ at 16, 20, and 24 dB S/Bs with a ±5% range for each target percentage) at one or more of the signal to babble ratios. Primary selection criterion was performance from subjects with normal hearing, but performance from listeners with hearing loss was considered. In order to narrow down the word list from 102 words to 70 words, the words with the poorest recognition performance at 0 and 4 dB S/Bs were eliminated. At all other S/Bs, words were eliminated on a fairly arbitrary basis with some consideration for performance by the listeners with hearing loss (Wilson, 2003). The end result is that the WIN test consists of 70 monosyllabic words, 10 words at each of the 7 signal-to-babble ratios (i.e., from 0 dB to 24 dB split in 4 dB increments). The multitalker babble consists of three female and three male speakers who are simultaneously talking about various topics, all of which are unintelligible.

Throughout the test, in order to mimic the real world, the level of the multitalker babbles stays constant while the intensity of the speech signal varies (Wilson, 2003).

Procedure

Subjects participated in one 2-hour session that included the verification of inclusion criteria and the testing of the experimental conditions: dichotic word recognition and word recognition in multitalker babble. Dichotic word recognition was measured in 3 response conditions: 1) free-recall (report both words regardless of order); 2) directed-recall right (report the word from the right ear first followed by the word from the left ear); and 3) directed-recall left (report the word from the left ear first followed by the word from the right ear). Free-recall was always presented first followed by either directed-recall right or directed-recall left. The order in which directed-recall right and directed-recall left were presented was counterbalanced across subjects. Word recognition in multitalker babble was also measured in 3 response conditions: 1) monaural right; 2) monaural left; and 3) binaural (i.e., diotic). The order in which monaural right, monaural left, and binaural conditions were presented was counterbalanced across subjects. The order in which dichotic listening tasks and word recognition in noise tasks were presented was also counterbalanced across subjects. Each listener was given up to 10 practice items per experimental condition to ensure familiarity with the experimental tasks. The participants were required to respond verbally and correct responses were scored in percent correct. All subjects were paid $10 per hour upon completion of all testing procedures.

All testing was completed in a sound-attenuating booth. The speech stimuli were routed from a CD player (Sony CE375) through a diagnostic audiometer (Grason Stadler, Model 61) to insert earphones (Etymotic ER-3A) and presented to each participant at 50 dB HL. Audiologic testing equipment (audiometer and tympanometer) was calibrated according to the appropriate standards as given by the American National Standards Institute (ANSI, 2004; 1987) at the beginning of the study and at 6-month intervals thereafter. Daily biologic checks were performed to ensure that the equipment was functioning properly.

Chapter 3

RESULTS

Descriptive statistics including means and standard deviations for the WIN test are presented in Table 1. As can be seen in Table 1, average overall recognition performance was essentially equal for the left ear and binaural conditions (79.0% and 79.4%, respectively). Overall recognition performance for the right ear was slightly poorer (75.6%) than performance of the left ear or binaural condition. Therefore, there was no binaural advantage for overall recognition performance since the binaural condition was not better than both monaural conditions (i.e., the right and left ears). This is not surprising due to the subjects' normal hearing status and consistent performance across all conditions. In addition to overall percent correct, the WIN test determines the 50%-correct threshold signal-to-babble ratio (S/B). The binaural condition resulted in an average 50%-correct threshold of 3.6 dB S/B, which was slightly lower than the 50%-correct threshold of 3.8 dB S/B for the left ear. The right ear had the highest average 50%-correct threshold (4.6 dB). Across all conditions, the mean 50%-correct thresholds were within normal limits relative to published norms (Wilson, 2003).

Table 2 shows the mean dichotic word recognition (DWR) scores (in percent correct) and standard deviations for each response condition (i.e., free-recall, directed right, and directed left). Data is presented for the right ear (RE), left ear (LE), and ear advantage (RE-LE). Average recognition performance is fairly consistent across the three response conditions. Figure 1 displays the mean ear advantages for each response condition. As can be seen, the free recall condition produced a right ear advantage (REA) of 4.4%. The directed right condition produced a REA of 9.0%, which is more than twice the REA observed in the free recall condition. The directed left condition produced a small left ear advantage (LEA) of 2.4%. As expected, there

Table 1. Means (and standard deviations) for WIN recognition performance and 50%-correct S/B thresholds across three response conditions: right ear, left ear, and binaural.

	Recognition Performance (% Correct)	50%-Correct Threshold (dB S/B)
Right Ear		
Mean	75.6	4.6
SD	3.9	1.2
Left Ear		
Mean	79.0	3.8
SD	2.6	0.6
Binaural		
Mean	79.4	3.6
SD	4.0	1.1

Table 2. Means (and standard deviations) for dichotic word recognition performance across the three response conditions: free recall, directed right, and directed left.

	Right Ear (%)	Left Ear (%)	RE – LE (%)
Free Recall			
Mean	85.2	80.8	4.4
SD	6.6	5.2	5.9
Directed Right			
Mean	87.2	78.2	9.0
SD	5.0	8.0	7.1
Directed Left			
Mean	84.8	87.2	-2.4
SD	6.1	4.8	7.2

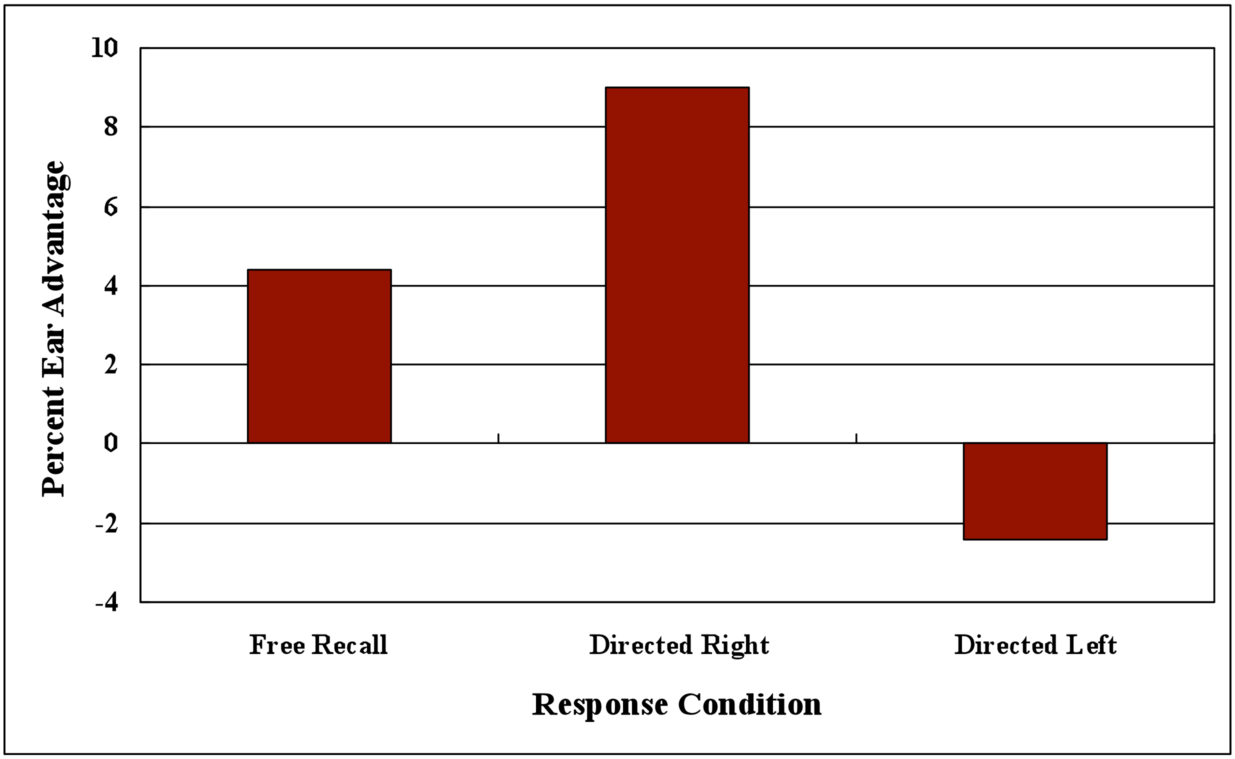

Figure 1. Mean ear advantages (in percent) for the three dichotic word recognition response conditions: free recall, directed right and directed left.

was a right ear advantage in the free-recall condition, but as attention shifted to the right ear (i.e., the directed right condition), the right ear advantage increased. When attention was focused on the left ear, the direction of the ear advantage shifted and a small left ear advantage was seen. The DWR results indicate normal dichotic recognition performance for right-handed young adults with normal hearing.

Figure 2 displays the individual data as bivariate plots for each of the response conditions with percent correct recognition for the words presented to the right ear on the abscissa and percent correct recognition for the words presented to the left ear on the ordinate. The diagonal line signifies equal performance on recognition of stimuli presented to both the right ear and the left ear. Data points falling below the line indicate that a subject correctly responded to more stimuli presented to the right ear versus the left ear (i.e., a REA). Data points above the line indicate that a subject correctly responded to more stimuli presented to the left ear versus the right ear (i.e., a LEA). As can be seen in Figure 2, the free recall plot (upper) has data points clustered around the line but with more slightly below the line (i.e., a REA). The directed right plot (lower left) has all but one data points below the line indicating that the majority of subjects exhibited a REA. And the directed left plot (lower right) has most of the data points above the line (i.e., a LEA).

Prior to statistical analysis, the scores from both the WIN test and dichotic word recognition were transformed to rationalized arcsine units (rau's) in order to correct for the error variance associated with percentage data (Studebaker, 1985). The transformed WIN recognition data were examined using an one-way repeated measures analysis of variance (ANOVA). The ANOVA revealed a significant main effect of WIN overall recognition performance ($F_{2, 18} = 7.8$; $p < .05$).

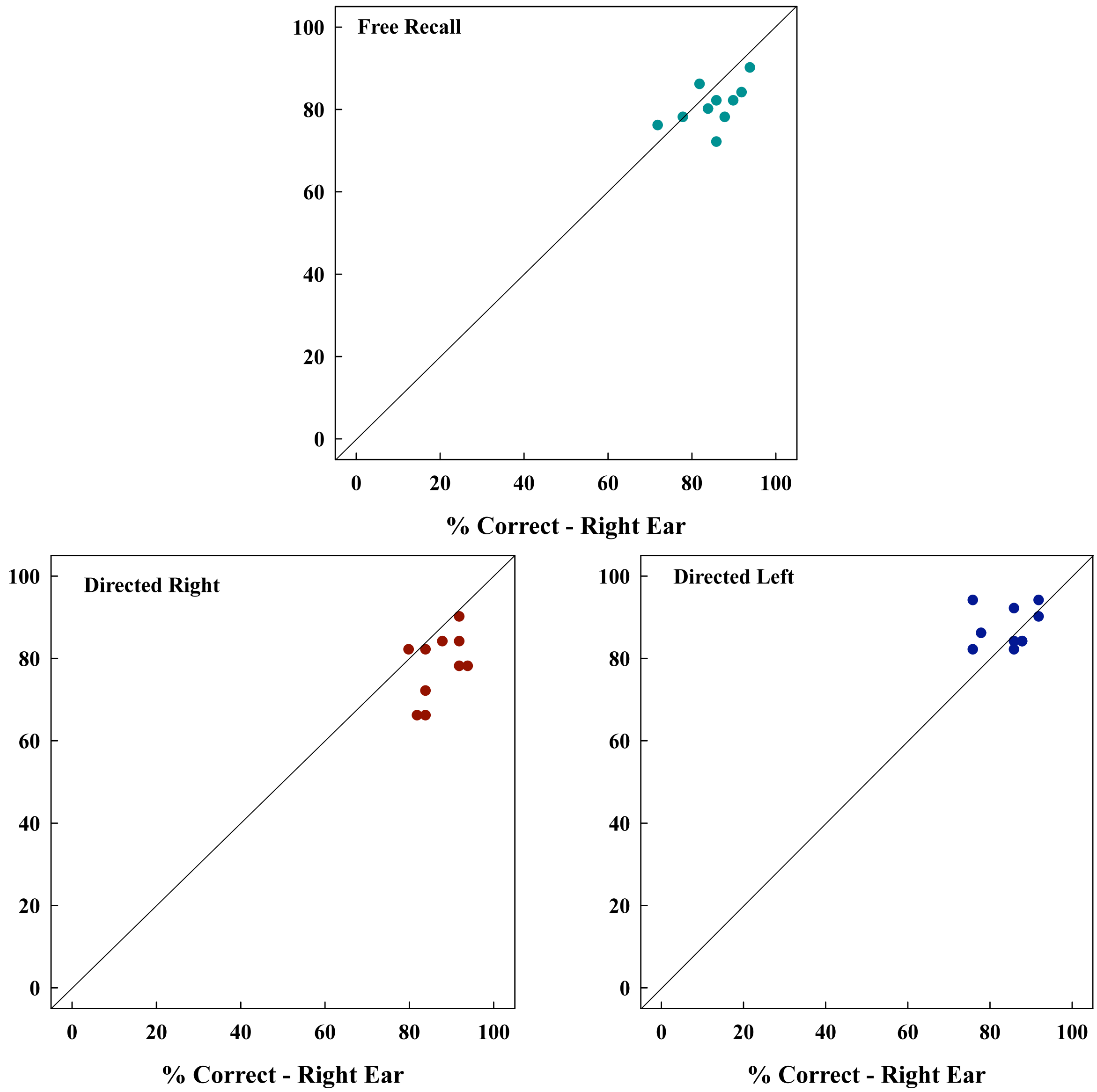

Figure 2. Individual dichotic word data presented as bivariate plots of percent correct recognition for the right ear (abscissa) and for the left ear (ordinate) for the three dichotic response conditions: free recall (upper plot), directed right (lower left plot), and directed left (lower right plot). The diagonal line indicates equal performance between the two ears. Data points below the line indicate better right ear performance, whereas data points above the line indicate better left ear performance.

Post-hoc *t*-tests revealed a significant difference ($p < .05$ divided by 3 contrasts) between the right ear overall WIN recognition performance and binaural overall WIN recognition performance ($t_8 = -3.9$; $p < .017$). The post-hoc *t*-test showed that all other paired samples (i.e., right ear versus left ear overall WIN recognition performance and left ear versus binaural overall WIN recognition performance) were not significantly different. Similarly, the transformed WIN 50%-correct threshold data were examined using an one-way repeated measures ANOVA. The ANOVA revealed a significant main effect of WIN threshold ($F_{2, 18} = 5.7$; $p < .05$). A post-hoc *t*-test revealed a significant difference ($p < .05$ divided by 3 contrasts) between the right ear WIN threshold and the binaural WIN threshold ($t_8 = 3.3$; $p < .017$). The post-hoc *t*-test showed all other paired samples (i.e., right ear versus left ear WIN threshold and left ear versus binaural WIN threshold) were not significantly different. Because there was not a significant difference between the binaural overall WIN recognition performance and the left ear overall WIN recognition performance ($t_8 = -0.51$; $p > .017$) or the binaural WIN threshold and the left ear WIN threshold ($t_8 = 0.61$; $p > .017$), the binaural condition does not have an overall advantage over the monaural conditions.

The transformed dichotic word recognition data were examined using a two-way repeated measures ANOVA with *response condition* and *ear* as within-subjects factors. Significant main effects were present for the within-subject factor of *ear* ($F_{1, 9} = 14.9$; $p < .05$) but not for *response condition* ($F_{2, 18} = 2.9$; $p > .05$). Significant main effects were also present between *ear* and *response condition* ($F_{2, 18} = 6.1$; $p < .05$). A post-hoc *t*-test revealed a significant difference ($p < .05$ divided by 5 contrasts) between the directed right, right ear condition and the directed right, left ear condition ($t_8 = 4.2$; $p < .01$). All other within-subject factors showed no significant differences. This exemplifies the increased right ear advantage as attention is directed to the right ear. There was no significant difference between the free response, right ear condition and free response, left ear condition ($t_8 = 2.6$; $p > .01$), but as attention shifted to the right ear, a significant difference occurred.

The secondary purpose of this study was to compare the results from the young adults to already published data on older adults with hearing loss on the same measures. As can be seen in Figure 3, the young adult WIN data at each S/B ratio is compared to older adult data from Wilson (2003). In Wilson's study, the WIN was given at the same seven S/B ratios from 0 dB to 24 dB. However, the stimuli were presented at 70 dB SPL instead of at the 50 dB HL used in this study. The young adults scored better overall than the older adults at every S/B ratio. Also, in Figure 3, one can see that the older adults have more separation between the binaural and monaural scores than the young adults. This is particularly noticeable at 8 dB S/B and 12 dB S/B. Both a floor effect (from 0 to 4 dB S/B) and a ceiling effect (from 16 to 24 dB S/B) can be seen for the older adults. However, in the young adults only a ceiling effect is exhibited (from 12 to 24 dB S/B).

Figure 4 displays a comparison between the young adult data and older adult data (Roup et al., 2006) on the dichotic listening task. Roup et al. tested older adults on the same response conditions (free-recall, directed-right, and directed-left), but stimuli were presented at 80 dB HL instead of 50 dB HL. As can be seen from Figure 4, the young adults scored better overall than the older adults. Also, the figure shows that the young adults exhibited a small REA (4.4%) in the free-recall condition. However, the older adults exhibited an even larger REA (13.8%) in the free-recall condition. There is a 9.4% difference in REA between the young adults and older adults.

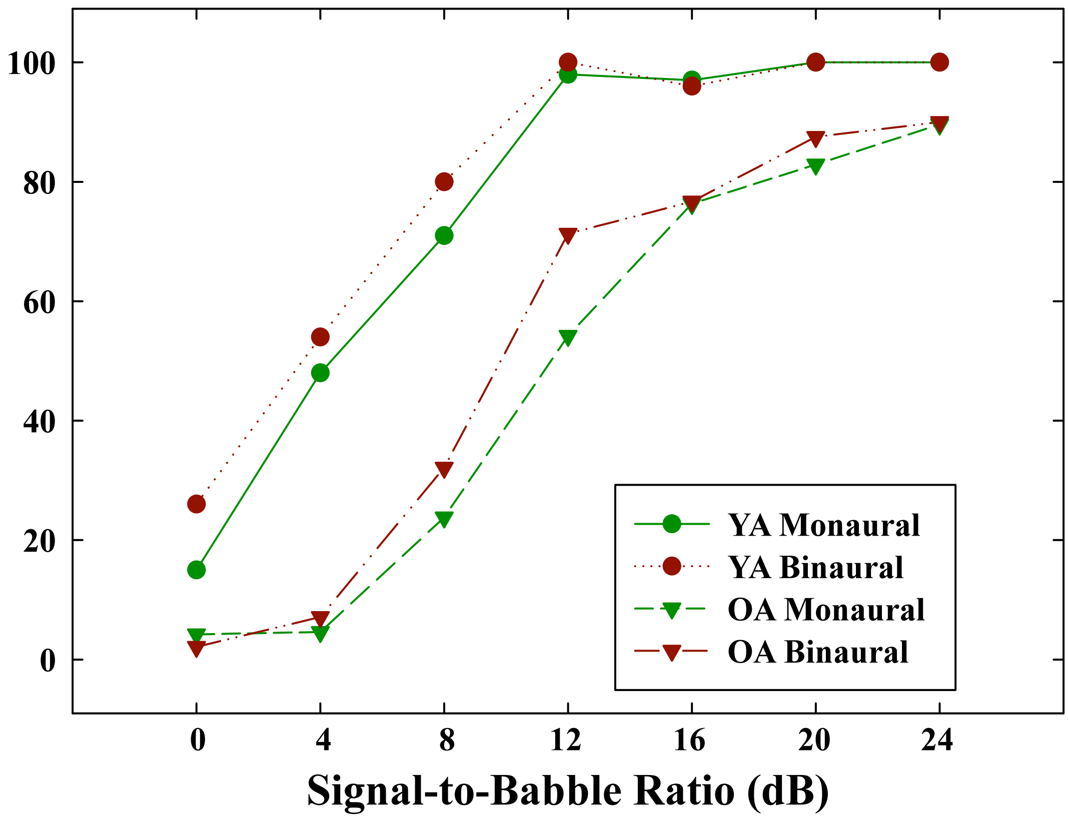

Figure 3. Mean overall WIN recognition performance of monaural and binaural conditions for S/B ratios between 0 and 24 dB measured in % correct for young adults and older adults (Wilson, 2003).

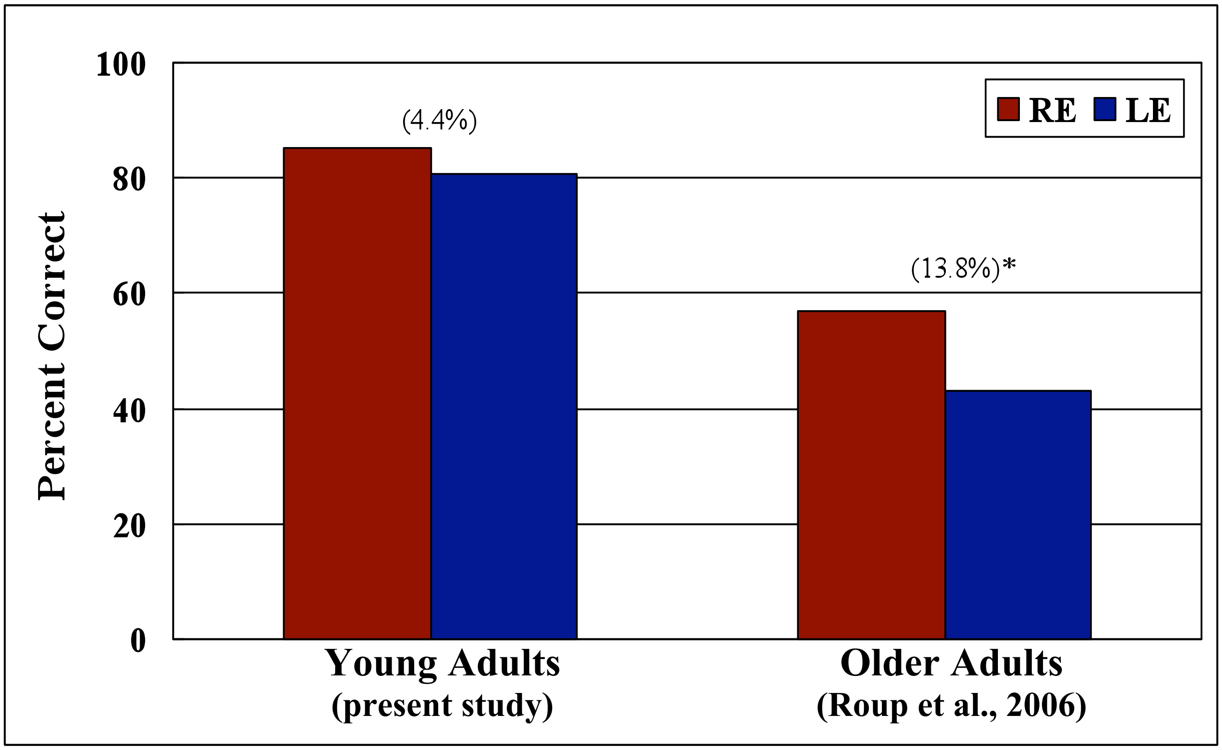

Figure 4. Mean dichotic word recognition performance (in % correct) for the right and left ears of young adults and older adult data (Roup et al., 2006).

Chapter 4

DISCUSSION

The purpose of the present study was to compare the results of dichotic listening and word recognition in noise in the same group of young adults with normal hearing. A secondary purpose was to compare the young adult data to that of published older adult data on the same measures. In the WIN, the binaural condition (mean overall percent correct = 79.4%) was not significantly better than the left monaural condition (mean left ear overall percent correct = 79.0%). Therefore, no binaural advantage was exhibited because the binaural condition was not better than both monaural conditions. However, because all subjects had normal hearing and because all performed consistently across all conditions, this is not surprising. The task was not difficult enough, and all subjects could therefore perform well overall resulting in no binaural advantage.

In comparison of the young adult WIN data to that of the older adult WIN data (Wilson, 2003), the young adults performed better than the older adults overall across all S/B ratios. This can be attributed to the effects of hearing loss in the older adults. Also, the larger separation between the binaural and monaural scores in older adults, rather than in the young adults, shows the effect of aging on someone's binaural listening ability. The young adults had either no separation or a small separation between their binaural versus monaural listening abilities. However, the older adults had a larger separation between their binaural and monaural scores (i.e., a larger binaural advantage). This data suggests that as someone ages, the difference between their binaural versus monaural listening ability becomes greater, especially in the mid-part of the function (i.e., 8 dB S/B and 12 dB S/B). Because the older adults exhibited both a ceiling effect and floor effect, they experienced a part of the test that was too easy (i.e., the ceiling effect) and too difficult (i.e., the floor effect). The area in between the ceiling effect and floor effect is where one can see the binaural advantage. For the young adults, part of the test was too easy (i.e., the ceiling effect), but the test never became so difficult that a floor effect was seen. Even though these results show how aging affects someone's binaural versus monaural listening ability, the results from the older adults do not show an auditory processing deficit. Someone with an auditory processing deficit would likely exhibit better monaural scores than binaural scores.

On the dichotic test, subjects exhibited typical results with a small REA in the free-recall condition (4.4%), a greater REA in the directed-right condition (9.0%), and a LEA in the directed-left condition (2.4%). As attention shifted to the right ear, the REA increased. As attention shifted to the left ear, a LEA was seen. The results are what one would expect to find from a dichotic speech recognition task and are a reflection of the anatomical configuration of the connection between the brain and ears. Because the left hemisphere contains the speech and language center in most people and because the contralateral auditory pathways are stronger than the ipsilateral auditory pathways, the right ear has a more direct connection to the speech and language center (Kimura, 1967a; Kimura, 1967b). Therefore, in the free-recall condition, one would expect to find a REA, as was seen in this study. As attention shifts to the right ear, the added focus to that ear creates an even larger REA, as exhibited in this study. Lastly, as attention shifts to the left ear, the added focus on that ear produces either a very small REA or a small LEA. The directed-left condition showed a small LEA in this study.

The comparison of the young adult data to the older adult data (Roup et al., 2006) shows that overall, similar to the WIN scores, young adults scored better overall than the older adults. Again, this can be attributed to hearing loss affecting the older adults (Roup et al., 2006). More interesting, though, is the comparison of the right ear advantage found in both groups of adults. The young adults exhibited a small REA (4.4%) in the free-recall condition, but the older adults exhibited an even larger REA (13.8%) in this condition. The 9.4% difference in REA is thought to reflect deficits in auditory processing abilities in the older adults. While right ear performance stays about the same, the left ear performance gets considerably worse. Therefore, a larger REA is exhibited, but it is more appropriately called a left ear disadvantage. This left ear disadvantage suggests a breakdown in auditory processing due to a decline in the efficiency of the corpus callosum (Jerger et al., 1994). Because speech entering the left ear during dichotic listening first travels to the right hemisphere, it must cross the corpus callosum in order to get to the left hemisphere where the speech and language center is usually found. If the corpus callosum is impaired, some of the information from the signal may not reach the left hemisphere, which results in decreased recognition. Therefore, older adults who exhibit a large REA (i.e., an auditory processing deficit) may have a hard time understanding in noisy situations, and they may benefit from a monaural rather than a binaural amplification strategy (Carter, Noe & Wilson, 2001; Chmiel et al., 1997).

Clinical Implications

The results of the current study highlight the effect of aging on an individual's speech processing abilities. Because the young adult data serves as a norm, one can see that aging has an effect on some adults' binaural versus monaural listening abilities. Those adults with an auditory processing deficit will often show better monaural rather than binaural scores. Because of this, they may benefit from a monaural amplification strategy. However, a typical rehabilitation scheme consists of a binaural amplification strategy. Also, individuals with an auditory processing deficit may experience a lot of trouble understanding speech in noise. This especially becomes troublesome when fit with bilateral hearing aids. Because all signals are amplified in both ears with a binaural amplification scheme, the auditory processing deficit interferes with the individual's ability to separate the background noise from the intended signal (Warren et al., 1978). However, a monaural hearing aid fitting would help someone bypass the auditory processing deficit and be better able to separate the signal from the background noise in a noisy environment. In fact, Carter et al. (2001) found that in a group of four older adults who had been previously fit with bilateral hearing aids but found them to be unhelpful, binaural aided and unaided scores were the same on binaural word recognition in noise tests. The lack of improvement with hearing aids shows that a different rehabilitation scheme is needed for these individuals.

Jerger et al. (1993) estimate that 8%-10% of older adults with hearing aids have a binaural processing deficit. These individuals would most likely exhibit better monaural rather than binaural scores on the WIN and a large REA on dichotic listening tasks. Because word recognition in noise tests and dichotic listening tests are not standard tests to give in a hearing aid evaluation, many older adults with an auditory processing deficit go unrecognized. Implementing a quick and easy way to test word recognition in noise and dichotic listening in a typical audiological evaluation would help identify those individuals who may benefit from monaural rather than binaural amplification. This would reduce the amount of time these people would experience the lack of maximal benefit they likely receive from having bilateral hearing aids.

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Appendix A

Handedness Inventory

Please indicate your preferences in the use of hands in the following activities by checking the appropriate column.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	LEFT	RIGHT
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking Match (match)		
10. Opening Box (lid)		