The Effects of Stimulus Type and Response Condition on Dichotic Speech Recognition

Honors Research Thesis

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Abstract

Dichotic listening refers to a binaural competing auditory recognition task in which listeners are asked to identify one or both stimuli. Most listeners exhibit a right ear advantage (REA) in which they can better identify stimuli presented to the right ear than the left ear. Dichotic speech recognition is included in test batteries assessing auditory processing in both children and adults. Recognition performance on dichotic listening tasks, however, varies according to the stimulus type, response condition and age of the listener. Determination of normal versus abnormal performance on a dichotic listening task is therefore dependent upon how it was measured and in what population. The purpose of the present study was to measure dichotic speech recognition using four common stimulus types and three common response conditions in the same group of listeners. Two groups participated: ten young adults with normal hearing (21-22 years) and seven older adults with bilateral sensorineural hearing loss (67-80 years). Four types of speech stimuli were used: (1) consonant-vowel syllables (CVs), (2) sentences, (3) digits, and (4) monosyllabic words. For each task listeners were asked to respond under three response conditions: (1) free recall, (2) directed-right, and (3) directed-left. Results revealed that the young adults exhibited smaller REA’s and better overall performance on all stimulus types relative to older adults. Poorer overall performance for older adults is unsurprising given the presence of hearing loss; however, larger REA’s likely reflect age-related deficits in auditory processing. In addition, recognition performance varied substantially across stimulus types for both age groups. Both young and older adults performed best for sentences and poorest for CV’s. By measuring dichotic speech recognition across stimulus types in the same group of subjects, this study may prove
clinically significant by providing easily comparable data for testing methods used in current auditory processing test batteries.
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Chapter 1

Introduction and Literature Review

Dichotic listening is a binaural competing auditory recognition task using either speech or tonal stimuli and has been shown to be useful for determining central auditory pathologies. Specifically, for dichotic speech tasks listeners are asked to listen to two competing stimuli presented simultaneously to each ear and then to identify one or both stimuli. The nature of dichotic listening tasks forces the central auditory system to work differently than it would under ordinary listening conditions. By challenging the auditory system, dichotic listening tasks have been used to determine the presence of disease or damage (such as brain lesions) along the auditory pathway, as well as a more generalized auditory processing deficit (Sparks & Geschwind, 1968). Jerger and Martin (2006) have shown that brain lesions can have an effect on dichotic listening scores, firmly linking deficits in dichotic listening tasks and Auditory Processing Disorders (APDs) with brain abnormalities.

Dichotic listening tasks were pioneered by Broadbent (1954) who had listeners listen to and repeat back differing messages of 3-pair digits presented simultaneously to both ears, and found they could do so quite successfully. Broadbent also noted that his group of listeners recalled the digits from one ear first, then the other – not the temporal order of presentation. Kimura (1961) further investigated dichotic listening tasks, and found that they could be used as a noninvasive way to test hemispheric laterality of speech perception in healthy persons. That is, people whose language was lateralized to the left hemisphere had better right ear performance for dichotic speech tasks and those with right hemisphere language lateralization had a better left ear performance.
The nature of dichotic listening tasks results in processing differences between the two ears. It has been established that dichotic stimuli are processed by the contralateral auditory pathways while the ipsilateral auditory pathways are suppressed (Kimura, 1961, 1967). It has also been established that speech signals are primarily processed in the left hemisphere. The suppression of ipsilateral auditory pathways during dichotic tasks requires incoming auditory information from the left ear to first travel contralaterally to the right hemisphere, then cross over via the corpus collosum to the left hemisphere to be processed. Auditory information from the right ear travels contralaterally directly to the left hemisphere. Therefore, the suppression of the ipsilateral pathways during dichotic listening results in superior recognition performance for the right compared to the left ear for the majority of listeners. This has been referred to as the right ear advantage (REA) (Kimura, 1967).

Theories of Dichotic Listening

Historically there are two theoretical models of dichotic listening used to explain the presence of an REA: the structural model (Kimura, 1961) and the attentional model (Kinsbourne, 1970).

The Structural Model

The structural model explains the presence of an REA through examining differences in anatomical structure and function during dichotic listening tasks. During normal listening conditions, both ears hear the same stimulus which is processed through both the ipsilateral and contralateral pathways. As previously stated, during dichotic listening tasks the ipsilateral pathways are suppressed. Specifically, Kimura’s (1961) structural model of dichotic listening hypothesized that contralateral auditory pathways
are stronger than ipsilateral, and the listener’s dominant hemisphere is more important for perceiving speech than the non-dominant one. The structural model of dichotic listening is a ‘bottom-up’ approach that views ear performance differences as a result of anatomical structures beginning with what is presented to each ear and working up to the hemispheric processing. Jerger and Martin (2006, p. 26) further explain this by outlining the following steps along the central auditory nervous system that result in an REA:

1) information to each ear is better represented in the opposite hemisphere via the dominant contralateral auditory pathways; 2) right-ear linguistic input, therefore, has a stronger connection to the linguistic processor in the left hemisphere; 3) information carried in the ipsilateral auditory pathways during dichotic stimulation is suppressed by uncorrelated information in the contralateral pathways; and 4) left-ear linguistic input is subject to delay as it crosses from the right hemisphere to the left hemisphere via the corpus callosum.

In summary, the signal presented to the left ear must travel first contralaterally to the right hemisphere then cross via the corpus collosum to the left hemisphere to be processed, while the signal presented to the right ear is carried contralaterally directly to the listener’s dominant left hemisphere. The delay in processing due to the interhemispheric transfer of the left ear signal leads to the right ear signal being processed more quickly and a subsequent REA.

The Attentional Model

Another explanation of dichotic speech listening tasks resulting in an REA is the attentional model. The attentional model was proposed by Kinsbourne (1970) and builds upon Kimura’s (1961) idea of the REA as a result of the anatomical structure of the central auditory pathway. Kinsbourne disagreed with the idea that a robust REA could be due to Kimura’s structural model alone, suggesting that if incoming stimuli to the right ear is processed by a shorter, more efficient pathway it should result in much more robust
asymmetries in performance. Specifically, the interhemispheric transfer of information from the left ear adds about 4 milliseconds to the total processing time, yet differences in listener response are much greater (Buffery, 1970). He proposed instead a ‘top-down’ attentional model.

Kinsbourne notes that no matter how structured an experiment is to control for variables, humans are capable of a wide range of spontaneous information processing that cannot always be regulated. Specifically, Kinsbourne proposed that it is impossible to fully eliminate attentional factors during dichotic listening. The attentional model takes ingrained attentional factors into account and is based on the left hemisphere as the primary place for speech processing. Therefore, the left hemisphere is ‘primed’ for verbal input. When a listener is expecting verbal stimuli, the left hemisphere is prepared for activation. This left hemispheric preparation then biases the listeners’ attention slightly to the right ear. When stimuli are presented to the right ear, they can be processed somewhat quicker and more efficiently since the listener’s focus was already slightly shifted to the right side. The stimulus presented to the left side of the listener requires the listener to shift attention from the right to the left side and is therefore processed more slowly. Kinsbourne also predicted right-handed persons would be more capable of focusing attention to the right and would therefore have even better right ear performance.

Ear Advantage and Aging

The REA for dichotic listening tasks, in which subjects are more accurate at identifying stimuli presented to their right ear, is exhibited by most listeners (Bryden, 1988; Kimura, 1961). The difference in performance between the right and left ears in
dichotic listening tasks is generally small for normal hearing listeners, particularly for easier tasks with a lower linguistic workload. However, differences in performance become more pronounced with age, with older adults exhibiting increasingly larger REAs than younger listeners. This exaggerated REA is more appropriately termed a left ear disadvantage (LED) for older adults, as the performance for the left ear grows progressively weaker as a function of increasing age at a disproportionate rate to the right ear (Jerger et al., 1994). The decline in left ear performance as a function of age due to either structural or cognitive deficits can result in difficulty comprehending information in difficult listening environments.

Decreased performance on dichotic listening tasks for older adults can partially be explained by the tendency for greater peripheral hearing loss to occur with age, but this does not entirely explain the increased performance deficit for stimuli presented to the left ear (Roup et al., 2006). Specifically, the decline in left ear performance for older adults may in part be due to the weakened efficiency of the transfer of auditory information between the two hemispheres via the corpus callosum (Jerger et al., 1995). As the function of the corpus callosum declines as a function of age this results in a greater LED since information coming into the left ear must travel contralaterally to the right hemisphere before crossing the corpus callosum the be processed in the left hemisphere. Meanwhile, the right ear has direct access to the left hemisphere and is unaffected by degenerating corpus callosum function that may result in a loss of neural information (Greenwald & Jerger, 2001). Bellis and Wilbur (2001) studied the integrity of interhemispheric transfer and the corpus callosum specifically in right-handed individuals ages 20-75. Bellis and Wilbur used dichotic tasks, auditory temporal
patterning, and visualmotor temporal indices of interhemispheric function to examine the
transfer of information between hemispheres. They suggested that as adults age, their
interhemispheric function declines and the magnitude of a dichotic REA increases.
Specifically, they found that listeners did worse on all tasks beginning between the ages
of 40 and 55, but performance did not continue to decline with age.

The decline in performance on tasks related to interhemispheric function noted
by Bellis and Wilbur (2001) has implications for older adults in difficult listening
situations. Competing speech stimuli presented to both ears suppresses ipsilateral
auditory pathways and requires information presented to the left ear to first be processed
contralaterally to the right hemisphere and then cross the corpus collosus to the left
hemisphere. Therefore, due to the decline in interhemispheric information transfer as a
function of age, Bellis and Wilbur suggest that older persons will have increased
difficulty with speech-in-noise and binaural processing tasks in which speech recognition
occurs in a competitive listening environment.

In addition, the prevalence of central auditory processing deficits increases with
age, leading to difficulty with tasks involving memory or information-processing skills,
such as those used in dichotic listening (Jerger & Jordan, 1992). Hallgren et al. (2001)
found that for dichotic tasks that focus attention on the left ear, efficient memory abilities
were important to accurately perceive, recall, and report stimuli presented to the left ear.
Their study of hearing-impaired subjects between the ages of 42 and 84 found a
correlation between poorer scores on reaction time and working memory tests and a
greater LED. They suggest that attending to the left ear requires a higher level of
cognitive ability that deteriorates as a function of age, resulting in poorer left ear
performance among elderly listeners. The decrease in cognitive abilities found in older adult listeners also contributes to speech recognition difficulties in competitive listening environments.

*Response Conditions (Strategy Effects)*

Jerger and Martin (2006) outlined two response conditions used to elicit responses from subjects during testing: divided attention and directed attention. Divided attention tasks, also called “free recall”, requires the listener to identify and report back all stimuli heard in both ears in no particular order. Some potential drawbacks for this type of response condition is that both stimuli must be stored in the subject’s short-term memory, introducing subject variability based on memory and speed of mental processing. For directed attention, the subject is pre-cued to attend to either the stimulus presented to the right or the left ear and ignore what is heard on the non-cued side. Therefore, directed-right requires the listener to recall only what is presented to the right ear, and directed-left requires the listener to recall only what is presented in the left ear. This type of response condition minimizes possible effects of memory and speed of processing (Jerger & Martin, 2006). Essentially, directed recall tasks gives subjects a listening strategy by directing them to one ear, minimizing the cognitive load. In free recall, where the subject is offered no strategy, the task is more challenging. Free recall dichotic tasks are also more challenging for the listener due to the increased cognitive demands of remembering two stimuli rather than only one.

Jerger et al. (1990) proposed that the use of both directed and free recall can differentiate between two possible factors having an effect on subjects’ dichotic recognition performance: 1) an auditory/structural factor involving the auditory pathway
and 2) a task-related/cognitive factor based on cognitive demands put on memory and speed of processing (unrelated to auditory abilities). Since free recall is more cognitively demanding, if dichotic performance is poor for the free recall task but improves with directed recall, the deficit was due to a task or cognitive factor. However, if dichotic performance remains poor for both divided and directed attention response conditions (that is, performance did not improve by lessening cognitive demands), the poor performance is attributed to auditory factors.

The effect that directed and free recall can have on a listener’s performance becomes more important when testing older adults who may have diminished cognitive capacity due to age. Jerger and Martin (2006) note that for older adults in particular, dichotic listening tasks should be administered in both the divided and directed attention modes. They found that comparison of performance between the two response conditions could be used to differentiate between cognitive and auditory causes of dichotic deficits. Specifically, they tested older adults who showed an LED for free recall conditions, but both ears were within normal limits for directed recall (interpreted as a primarily cognitive affect). However, when older adults showed an LED for both free and directed recall, it was interpreted as auditory-structural in origin. This indicates a decline in function along the central auditory pathway.

Strouse and Wilson (1999) found similar advantages to including both free and directed recall in their study of older listeners between the ages of 60 and 79 using dichotic digits. They found that 52% of their subjects responded within normal limits for both ears during both response conditions, 42% had a performance deficit during the free recall condition that improved with directed recall, and only 7% responded poorly for
both response conditions. They attributed the group with poor performance during the free recall task only as resulting from a cognitive deficit due to age, especially due to the high demands of recalling one, two, three, and four pair sets of digits. The 7% of elderly listeners with deficits during both response conditions would then be considered to have an auditory specific deficit.

By including a directed recall response condition to both the left and right ear in addition to the free recall response condition, the clinician can be sure a resultant LED is indeed due to auditory processing deficits. Jerger and Martin (2006) also hypothesized that including both response conditions is especially important when administering dichotic stimuli tasks with high cognitive demands to older adults.

Stimulus Effects

Previous studies and clinical diagnostic testing employ a variety of stimuli in dichotic listening tasks. The four main categories of dichotic speech stimuli include: digits, sentences, non-rhyming monosyllabic words (consonant-vowel-consonant, or CVCs) and nonsense syllables (consonant-vowels, or CVs). Each stimulus type affects listener performance and the presence of an REA when used in dichotic listening tasks.

Digits

As indicated by Strouse and Wilson (1999), dichotic digit tasks can be useful for evaluation of older adult listeners since digits are unaffected by cochlear hearing loss and consistently demonstrate good intertest reliability for young and older adults (Strouse & Hall, 1995; Humes et al., 1996). For dichotic digit tasks, the number of digit pairs the listener is required to listen to and repeat influences the difficulty of the task, listener performance and the presence of an REA. The difficulty of the task for the listener also
influences the usefulness of the task for determining central auditory processing pathologies.

A study done by Noffsinger et al. (1994) used the nine monosyllabic digits one through ten (excluding seven because it is disyllabic). Each digit was paired to have the same onset time with a differing digit than itself and presented dichotically to the listener. Younger adults with normal hearing scored at 94% or better for each of three presentation levels (50, 60, and 70 dB HL). These near perfect scores were expected due to the relative low cognitive load of remembering and repeating back one-digit pairs of stimuli. Noffsinger et al. suggested a 90% cut-off score for normal population response. On the same task for older adults, performance was above the 90% cut-off mark for all listeners except for the scores for two left ears and one right ear which were slightly below 90% (Noffsinger et al., 1996). Due to the relative ease of a one-digit pair dichotic task for both younger and older adults, its effectiveness as a clinical dichotic test for processing disorders is limited.

Strouse and Wilson (1999) sought to increase the cognitive load, and therefore the difficulty, of the dichotic digits task by changing the number of digit pairs and the level of uncertainty for the listener. Introducing an uncertainty variable, that is randomly interspersing one, two, three, and four digit pairs throughout the task so the listener does not know what stimulus pair length will be next, reduces overall performance and enhances the REA.

For one-pair digits, Strouse and Wilson found that listeners less than 30 years old were able to report back one-pair dichotic digits with over 99% accuracy in both the right and left ears and listeners aged 60-75 years were responded correctly 85.2% and 91.8%
of the time for the left and right ears respectively. Therefore, recalling one-pair dichotic digits was relatively easy and there were no significant ear effects for young adults with a slightly decreased left ear performance for older adults. When the task becomes more difficult, such as repeating back three pair digits, the difference in performance between ears becomes more pronounced. Specifically, for three-pair digits, younger listeners recalled 83.8% correct in the left ear and 91.6% correct for the right ear (i.e. a 7.8% REA). The older adult group recalled 58.9% of the digits correctly in the left ear and 76.3% in the right (i.e. a 17.4% REA). Strouse and Wilson also suggest that four digit pairs are not useful for evaluating dichotic performance due to the higher reported difficulty of the task, increased strain on memory and cognitive abilities, and general unpleasantness of the task.

Words:

Monosyllabic words offer advantages as dichotic tasks since they are used widely, provide an abundant open-set of stimuli, and are easily comparable. Roup et al. (2006) used pairs of monosyllabic words from the NU-6 word list that were preceded by the carrier phrase ‘say the word.’ The words were presented to three different groups of listeners: listeners aged 19-30 years, listeners aged 60-69 years, and listeners aged 70-79 years in three different response conditions: free recall, directed right, and directed left. Roup et al. found that there was a significant decrease in performance on the dichotic word task by the two older groups in relation to the younger group, as well as an increase in an REA with age. Specifically, during free recall for the right and left ears respectively, the youngest group averaged 86.9% and 84.4% correct, the 60-69 year old group averaged 65.2% and 49.9% correct and the oldest group averaged 48.3% and
36.1% correct. When performance was collapsed across ear and response condition for the two older groups, differences were not found to be statistically significant. The presence of an REA also increased with age with the younger adults having a small average REA of 2.5% increasing to an average REA of 15.3% for the 60-69 group and 12.3% for the 70-79 group.

To determine how lexical content and cognitive load influences listener performance, Strouse-Carter and Wilson (2001) studied the lexical difficulty of dichotic words deemed either ‘easy’ or ‘hard’ presented to young and older adults. They found similar results to Roup et al. (2006) in that older adults performed significantly worse on the dichotic task than younger adults and older adults also exhibited a more enhanced REA. Interestingly, while younger adults performed better on the easy words than the hard words for both ears, for older adults performance was better for the words presented to the right ear than words presented to the left ear regardless of the difficulty of the word. Strouse-Carter and Wilson suggest that the right hemisphere decreases in its ability to process either easy or hard words as a function of age, leading to slower and less accurate processing for words presented to the left ear and the enhanced REA. In addition, they note that lexical difficulty within the same type of stimulus task (i.e. words) does not have as great of an effect on performance as dichotic task difficulty between different types of stimulus materials (such as sentences and nonsense syllables). Therefore, results from dichotic speech tasks using monosyllabic meaningful words can be easily compared to other dichotic word tests.
Sentences

The Dichotic Sentence Identification (DSI) test was developed to be an effective dichotic listening test for subjects with mild to moderate hearing loss that would provide an appropriate level of difficulty while remaining sensitive to dichotic performance differences. As it is difficult to separate peripheral from central auditory components for a subject's hearing loss, the DSI sentences have a pivotal frequency of approximately 725 Hz, compared to monosyllabic and single word stimuli which rely on acoustical information at 1000 Hz and above (Fifer et al., 1983). For older adults with high-frequency sloping hearing loss, Fifer et al. (1983) proposed that using sentences in dichotic tasks provides the subject with more meaning at lower frequencies, helping to separate peripheral from central factors and more accurately testing for central auditory processing disorders. Fifer et al. (1983) created ten third-order synthetic sentences composed of strings of meaningful words put together to create a grammatically correct but meaningless sentence. Sentences were paired to have the same start time, and the same sentence was never paired with itself.

Noffsinger et al. (1994) and Noffsinger et al. (1996) used six of the ten third-order sentences as described by Fifer et al. (1983) randomly combined for 30 possible pairings. Subjects were given a closed set of six possible responses to choose from. Noffsinger et al. (1994) found that for 40 young adult listeners, performance was 90% accurate or better for each of three presentation levels (50, 60, and 70 dB HL). Noffsinger et al. (1996) found overall older adult listener performance was slightly worse: of 19 subjects, 6 right-ear scores and 10 left-ear scores were below the 90% accuracy cut-off mark as suggested by the young adult performance. There was also an increased LED with the
right ear performing 11.8% better than the left ear. Jerger et al. (1994) found a more substantial increase in LED ranging from a 1.5% difference in listeners aged 9-19 to 34.3% difference for the oldest age group which was 80-89 years old.

Jerger and Martin (2006) bring up conflicting arguments regarding the level of cognitive demand level present in the DSI. Since the DSI involves various linguistic processing dimensions and requires better memory function to remember a full sentence (versus a single syllable), it can be argued that these high cognitive demands may result in greater discrepancies between divided and directed attention response conditions. Furthermore, the sentences themselves are presented outside of a contextual background and with no semantic meaning. This presents a task that requires a great deal of cognitive functioning, which often decreases with age since older adults (especially those with hearing loss) are more prone to rely on the context of the situation to identify the message. Gates et al. (2008) found that the DSI is particularly sensitive to the presence of memory impairment in older adults. Strouse and Wilson (1999) speculate that for older adults in particular, the task the DSI asks of subjects is more complicated than those associated with dichotic digits. Therefore, the DSI presents a more difficult task for older adults than younger adults, and in terms of stimulus differences, a more difficult task for older adults than the dichotic digits.

However, since the listener is given a closed set of six items to choose from during each stimulus set, a counter-argument is presented that this actually reduces the cognitive load, memory and retrieval processes. Fifer et al. (1983) found that the performance of normal subjects on the DSI was 94.2% and 93.5% correct for the right and left ears respectively. Jerger et al. (1994) also had normal listeners between 9-29
score above 90% correct, which is consistent with the Noffsinger et al. (1994) study previously discussed. Therefore, near perfect performance for younger adults on the DSI is a reasonable expectation, given that they are not affected by age-related cognitive deficits.

**Syllables:**

Nonsense consonant-vowel (CV) syllables have much lower lexical content than the three other stimuli previously discussed, resulting in lower dichotic performance rates for both younger and older adults. As a result of lower and more variable rates of performance, syllables may not be as useful for determining the presence of APD. In their study of CVC words and CVC nonsense syllables, Findlen and Roup (2011) found that overall performance on tasks using the CVC syllables was poorer than those using CVC words. This suggests that listeners use lexical cues during complex listening situations requiring speech processing; therefore, lexical content impacts performance for dichotic speech tasks. However, not all subjects demonstrated a significant ear advantage and showed greater variability in performance, suggesting that decreased lexical content affects listeners differently.

Noffsinger et al.’s (1994) study of young adults and performance on dichotic syllable tasks also found decreased rates of performance compared to other stimuli. Noffsinger et al. used thirty possible pairings of six syllables (pa, ka, ta, ba, da, and ga) from the VA-CD with simultaneous onset. Their subjects included 40 young adult subjects who identified 74% and 76% of the syllables correctly for the right and left ears respectively on average, considerably lower than the scores for digits and sentences from the same subjects. However, Noffsinger et al. also reported large variability for listeners’
responses for syllable stimuli. Interestingly, their subjects did not show the 6%-8% REA as reported in Noffsinger’s (1985) previous study of dichotic CV tasks, which the authors were unable to explain. Noffsinger (1985) tested 75 normal hearing listeners using simultaneous-onset dichotic nonsense syllables and found an average of 7% ear advantage. However, Noffsinger notes that the responses were variable over repeated trials and among numerous subjects. Specifically, at times no REA was present or even a left ear advantage may occur, but over repeated trials with a high test population, listeners have shown a consistent REA (Speaks & Niccum, 1977).

Noffsinger et al. (1996) studied 19 older adults who also performed significantly poorer and more variably on the syllables task than the digits and sentences. The older adult group averaged 58.4% correct for the right ear and 41.6% correct for the left. Average scores for older adults with a presentation level of 80 dB HL were 19% poorer for the right and 38% poorer for the left ears than younger adults. Sixteen of the 19 subjects were retested after a 3-month period, this time with presentation levels of 90 dB HL. Fourteen subjects performed within 10% of their original scores, while two subjects actually performed worse, indicating additional acoustic cues from a higher presentation level does not influence performance. Noffsinger et al. (1996) raise concerns that these scores are low enough to question how useful dichotic syllable listening tasks are for clinical testing. For this task, only two listeners had right ear performance below 43%, indicating these scores should be considered uncommon. But, nine left ears scored below 43% on the dichotic syllable task, and seven of the nine were between 23% and 33%, making it extremely difficult to determine distinctions between common and uncommon scores. Since it becomes difficult to determine a cut-off point for what is a normal versus
disordered rate of performance for dichotic syllable tasks, their usefulness may be limited.

In summary, the level of dichotic performance differs among the four types of dichotic test stimuli based on their levels of difficulty and amount of lexical content. Both young and older listeners perform well on sentence identification as this is a relatively easy task, and performance should be much poorer on the more difficult nonsense syllables task (Noffsinger et al., 1994, 1996). The correct responses for randomized digits should fall between the two extremes of the nonsense syllables and sentence identification tasks (Strouse & Wilson, 1999). In general digits, sentences, and CVC words are all easier to identify than CV syllables due to their higher lexical content (Findlen & Roup, 2011).

Roup et al. (2006) note that monosyllabic word tasks present a middle ground by being neither too easy nor too difficult, yet remaining sensitive to auditory processing differences present between varying age groups and between the right and left ears. Specifically, Roup et al. note that unlike dichotic digits tasks in which there is a well-known closed set of digits, monosyllabic words present an open set of meaningful stimuli.

**Handedness Effects**

Kimura (1961) attempted to define the relationship between hemispheric speech dominance and handedness. However, she found that the ear opposite the dominant hemisphere (the hemisphere more strongly lateralized for speech) operated more efficiently, regardless of which hand was dominant. Therefore, she concluded that handedness played no role in ear effects during dichotic listening tasks.
However, Bryden (1988) pointed out that a re-examination of Kimura’s data indicates that for subjects with speech lateralized to the right hemisphere, right-handers have smaller left ear advantages than do left-handers; meanwhile, for those with left hemisphere speech lateralization, left-handers have a smaller REA than right-handers. It becomes unclear whether these results would disappear with stronger controls for response condition, or if there is indeed a handedness effect. Bryden analyzed 18 studies that tested both left and right handed subjects. He found that of the 10 that showed a significant handedness effect, there was a trend for left-handed persons to show a reduced laterality effect and a smaller proportion of left-handers, compared to right-handers, show a robust REA. He found that only 64% of the left-handers showed a REA, compared to 82% of right-handers. Bryden concludes that there is strong enough evidence for a handedness effect for verbal dichotic listening tasks, supporting the idea that the REA is due to cerebral language lateralization.

Nevertheless, McKeever et al. (1984) point out that many studies do not show a significant difference between handedness. Concerns have been raised that variability between studies is further compounded by inaccurate classifications of handedness, due to the unreliability of self-reports. However, Strouse and Wilson (1999) maintain that virtually all dichotic studies show a trend for at least a reduced laterality effect for left-handed subjects. Their analysis of 20 left handed young adults and 20 right handed young adults found that both groups exhibited an REA, although the effect was reduced for left-handers and more variable. In order to control for variability and ensure more robust REA scores, left-handed individuals are generally excluded from dichotic listening studies.
Sex Differences

Bryden (1988) suggest that males tend to have stronger right-ear-to-left-hemisphere specialization for verbal materials than women. A study performed by Jerger et al. (1994) using the Dichotic Sentence Identification found the possibility of gender differences having an effect on age differences for dichotic speech listening tasks. Their study of 44 men and 34 women ages 50-91 years found that older women had poorer performance for the right ear when compared with older men but few performance deficits for the left ear. This yielded a much greater REA in men among much older adults as the left ear performance was worse than for women. Specifically, for both free and directed response conditions, the average ear advantage was about 30% for men and 10% for women.

Bellis and Wilbur (2001) found that men and women perform differently on dichotic tasks at different stages in life, due to the changing structure of the aging corpus callosum. Men begin showing difficulty for dichotic listening tasks between the ages of 35-40, while for women it is postponed until age 55-60. However, no differences in performance on dichotic speech tasks were found between men and women for age groups of 20-25 and 70-75. This variability in performance based on ages can account for the variability in previous research on dichotic listening tasks and gender.

Present Study

The goal of the present study was to examine variability of a) performance and b) ear advantage across four stimulus types for two groups of listeners. Specifically, four different stimuli were used: 1) sentences, 2) digits, 3) words, and 4) nonsense syllables for two subject groups: 1) young adults with normal hearing and 2) older adults with
bilateral sensorineural hearing loss. Between groups, younger adults were hypothesized to have better overall dichotic recognition performance for all stimuli than older adults. Older adults were also expected to have a more pronounced ear advantage than younger adults. Across stimuli, digits and sentences were hypothesized to be the easiest of the four stimuli with words being moderately difficult and syllables being the most difficult. Finally, the ear advantage was expected to be largest for the syllables and smaller for digits and sentences, with words falling somewhere in the middle.

By measuring dichotic speech recognition across stimulus types in the same group of listeners, this study may prove significant for clinical applications by providing easily comparable data for a variety of testing methods used in current auditory processing test batteries.
Chapter 2

Methods

Subjects

For this study there were two subject groups: (1) a young adult group comprised of 10 participants between the ages of 21 and 22 years with normal hearing (5 males and 5 females), and (2) an older adult group comprised of 7 participants between the ages of 67 and 80 years with mild sloping to moderate bilateral sensorineural hearing loss (3 males and 4 females). Normal hearing was defined as pure tone thresholds of $\leq 20$ dB HL for frequencies 250-8000 Hz with bone conduction thresholds within $\pm 10$ dB HL of air conduction thresholds for frequencies between 500 and 4000 Hz. Hearing loss for older adults was bilateral, symmetric, sloping sensorineural hearing loss, meaning air conduction thresholds were within $\pm 10$ dB HL for both ears at frequencies of 500-4000 Hz. Subjects’ ear canal, tympanic membrane, and middle ear function were within normal limits (no drainage, impacted cerumen, etc.), ascertained through tympanometry and otoscopy. Subjects were also asked about their medical history to determine no history of ear infections, no history of ototoxic medications, and to ensure good overall health. All subjects were native speakers of American English. All older adults scored $\geq 25$ on the Mini-Mental State Examination to verify normal cognitive function (Folstein et al., 1975). To minimize variability, all subjects were right-handed as determined by the Edinburgh Handedness Inventory, on which subjects rate their hand preference for ten familiar tasks (Oldfield, 1971). Subjects were recruited from the student, faculty, and staff population at The Ohio State University as well as The Ohio State University.
Hearing Clinic and the surrounding community of Columbus, OH. More subjects were screened using the above inclusion criteria than the 17 total that qualified for the study.

**Stimuli**

Each of the test stimuli were commonly used in audiometric test batteries to test for auditory processing disorders. The stimuli consisted of differing speech signals presented dichotically. Four different speech stimuli were used to test stimuli effects during dichotic listening tasks including: (1) nonsense syllables, (2) sentences, (3) digits, and (4) monosyllabic words.

The nonsense syllables were taken from the VA-CD Tonal and Speech Materials for Auditory Perceptual Assessment. Syllables consisted of a consonant followed by the vowel (pa, ta, ga, ba, da, ka) and two different syllables with the same onset time were presented to the listener. An interstimulus interval of five seconds was used in order for subjects to recall and respond with what was heard. Subjects were given a written closed set of the six possible responses from which to choose their responses.

The sentence stimuli were from the Dichotic Sentence Identification Test (Fifer et al., 1983). Sentences consisted of a string of meaningful words that made up a meaningless sentence. The test used thirty randomizations of the six sentences, all aligned to have the same onset time and each pair consisted of two different sentences. An interstimulus interval of seven seconds followed presentation. Listeners were given a written closed set of the six sentences to choose from.

Digits from the Randomized Dichotic Digits test (Strouse & Wilson, 1999) were used and consisted of the monosyllabic numbers from one through ten (all numbers except seven which is disyllabic). Digits were grouped into one, two, and three pair sets.
The same digit was never repeated within a stimulus set and the number of paired digits was randomized across the 54 stimulus trials. Digits presented to each ear were aligned to have the same onset time. One-pair digits were followed by a five second silent interstimulus interval and two and three pair digits were followed by a six second interstimulus interval.

Finally, meaningful monosyllabic words (Findlen & Roup, 2011; Boothroyd & Nittrouer, 1988) with high lexical context and phonemic contrast were used. A total of 100 different words were split into 50 word pairs with no repeating words. Three randomizations of the 50 word pairs were created. Words were preceded by the carrier phrase ‘say the word’ and followed by an interstimulus interval of 5 seconds.

All stimuli contain pairings presented simultaneously to both channels. Three randomizations for each stimulus set in addition to the original trial were generated in order to allow for multiple trials (free-recall, directed-right and directed-left) and a set of practice items and were recorded on a two-channel CD. All stimuli are spoken by a male talker. Score sheets were created for each stimulus containing correct responses for each of the response conditions to keep track of participants’ incorrect responses.

**Procedures**

Each subject participated in a 2-hour test session which included the four stimulus tasks: syllables, sentences, digits, and words, counterbalanced across subjects. Subjects responded under three response conditions: free recall (the subject responded by repeating both stimuli in any order) and directed-left (the subject repeated back only the stimulus heard in the left ear) and directed-right (the subject repeated back only the stimulus heard in the right ear). Free recall was always presented first for each subject,
followed by directed-left and directed-right, counterbalanced across subjects. All participants also received a minimum of five practice items in order to familiarize the listener with the response task.

All testing will took place within a sound-attenuating booth. The stimuli were be routed from a CD player (Sony CE375) through a 2-channel diagnostic audiometer (Grason Stadler, Model 61) and presented to the subject through insert earphones (Etymotic ER-3A). For all stimuli, presentation levels were 50 dB HL for young adults and 80 dB HL for older adults. All testing equipment was calibrated according to the appropriate American National Standards Institute standards (ANSI, 2004; 1987).
Chapter 3

Results

Descriptive Analysis

Table 1 shows group means and standard deviations for young adults for free and directed response conditions across all stimulus types. Table 2 shows group means and standard deviations for older adults for free and directed response conditions all stimulus types. Figures 1-4 illustrates mean dichotic recognition performance for young and older adults for right and left ears across all stimulus types for both free and directed recall.

As expected, young adults (Table 1) had near perfect performance for sentences, performed poorer for digits, even poorer for words and exhibited the poorest rates of performance for CVs. Young adult performance for sentences, digits, and words improved from the free recall response condition to the directed recall response condition. However, for CVs young adult performance actually decreased from the free recall to the directed recall response condition. Specifically, mean performance for the right and left ears decreased by 4.34% and 8.77% respectively.

Similarly, for older adults (Table 2) performance was also best on sentences followed by digits, words, and CVs. Older adults performed surprisingly well on sentences with free recall right and left ear scores of 96.67% and 82.86% respectively and directed recall scores approaching ceiling levels. Older adults also exhibited an improvement in dichotic performance from the free recall to the directed recall response condition for sentences, digits, and words. Unexpectedly, for CVs performance for the right ear increased by 2.86% from free to directed recall but performance for the left ear decreased by 3.33% from free to directed recall.
Table 1: Mean dichotic recognition performance (in percent) and standard deviations for young adults for free and directed recall across all four stimulus types: sentences, digits, words, and CVs.

<table>
<thead>
<tr>
<th></th>
<th>Right Ear (RE)</th>
<th>Left Ear (LE)</th>
<th>RE-LE</th>
<th></th>
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<tbody>
<tr>
<td><strong>Sentences</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free Recall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>99.67</td>
<td>100.00</td>
<td>-0.30</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.05</td>
<td>0.00</td>
<td>0.95</td>
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<tr>
<td>Directed Recall</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>100.00</td>
<td>99.37</td>
<td>0.63</td>
<td></td>
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<tr>
<td>SD</td>
<td>0.00</td>
<td>1.34</td>
<td>1.26</td>
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<tr>
<td><strong>Digits</strong></td>
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<td></td>
</tr>
<tr>
<td>Free Recall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>95.18</td>
<td>92.22</td>
<td>2.96</td>
<td></td>
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<tr>
<td>SD</td>
<td>3.72</td>
<td>4.99</td>
<td>6.25</td>
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<tr>
<td>Directed Recall</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>99.62</td>
<td>97.78</td>
<td>1.85</td>
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<tr>
<td>SD</td>
<td>0.78</td>
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<tr>
<td><strong>Words</strong></td>
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<tr>
<td>Free Recall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>91.20</td>
<td>83.40</td>
<td>7.80</td>
<td></td>
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<tr>
<td>SD</td>
<td>4.44</td>
<td>6.19</td>
<td>5.20</td>
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<tr>
<td>Directed Recall</td>
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</tr>
<tr>
<td>Mean</td>
<td>96.40</td>
<td>90.00</td>
<td>6.20</td>
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<tr>
<td>SD</td>
<td>2.46</td>
<td>6.03</td>
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<td><strong>CVs</strong></td>
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<tr>
<td>Free Recall</td>
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<td></td>
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<tr>
<td>Mean</td>
<td>66.00</td>
<td>51.00</td>
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<tr>
<td>SD</td>
<td>65.20</td>
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<tr>
<td>Mean</td>
<td>61.66</td>
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<tr>
<td>SD</td>
<td>13.54</td>
<td>19.75</td>
<td>22.88</td>
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Table 2: Mean dichotic recognition performance (in percent) and standard deviations for older adults for free and directed recall across all four stimulus types: sentences, digits, words, and CVs.

<table>
<thead>
<tr>
<th>Stimulus Type</th>
<th>Right Ear (RE)</th>
<th>Left Ear (LE)</th>
<th>RE-LE</th>
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<tbody>
<tr>
<td><strong>Sentences</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free Recall</td>
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<td></td>
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<tr>
<td>Mean</td>
<td>96.67</td>
<td>82.86</td>
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<td>SD</td>
<td>6.38</td>
<td>24.45</td>
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<tr>
<td>Directed Recall</td>
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<tr>
<td>Mean</td>
<td>100.00</td>
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<tr>
<td>SD</td>
<td>0.00</td>
<td>3.78</td>
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<tr>
<td><strong>Digits</strong></td>
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<tr>
<td>Free Recall</td>
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<td></td>
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<tr>
<td>Mean</td>
<td>84.39</td>
<td>76.46</td>
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<tr>
<td>SD</td>
<td>8.48</td>
<td>15.81</td>
<td>16.24</td>
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<tr>
<td>Directed Recall</td>
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<tr>
<td>Mean</td>
<td>97.35</td>
<td>94.18</td>
<td>3.17</td>
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<tr>
<td>SD</td>
<td>5.54</td>
<td>9.47</td>
<td>6.65</td>
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<tr>
<td><strong>Words</strong></td>
<td></td>
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<td>Free Recall</td>
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<tr>
<td>Mean</td>
<td>69.71</td>
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<td>Mean</td>
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<tr>
<td>SD</td>
<td>5.89</td>
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<td><strong>CVs</strong></td>
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<tr>
<td>Free Recall</td>
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<td></td>
<td></td>
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<tr>
<td>Mean</td>
<td>53.81</td>
<td>44.76</td>
<td>9.05</td>
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<tr>
<td>SD</td>
<td>10.40</td>
<td>16.40</td>
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<td>Directed Recall</td>
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<tr>
<td>Mean</td>
<td>56.67</td>
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<td>SD</td>
<td>18.60</td>
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<td>23.90</td>
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</table>
Figures 1-4: Mean dichotic recognition performance (in percent) for young and older adults for free and directed recall across sentences, digits, words, and CVs.

Figure 1: Sentences

![Bar chart showing mean dichotic recognition performance for young adults (YA) and older adults (OA) for free and directed recall of sentences. The chart illustrates that older adults have lower performance compared to young adults, with a drop in performance from free to directed recall.]

Figure 2: Digits

![Bar chart showing mean dichotic recognition performance for young adults (YA) and older adults (OA) for free and directed recall of digits. The chart illustrates a similar pattern to sentences, with older adults showing lower performance and a drop in performance from free to directed recall.]

Effects of Stimulus Type and Response Condition
Figure 3: Words

![Bar chart showing the comparison between Right Ear and Left Ear for Free Recall and Directed Recall.]

Figure 4: Sentences

![Bar chart showing the comparison between Right Ear and Left Ear for Free Recall and Directed Recall.]

Free Recall  Directed Recall
Also as expected, young and older adults’ right ear performance was substantially better than left ear performance for all stimulus types and response conditions, resulting in an REA. For young adults, mean dichotic ear advantage was present but varied among stimulus type and response condition. Specifically, a negligible ear advantage for sentences (-0.3% FR, 0.63% DR) became more pronounced for digits (2.96% FR, 1.85% DR), then words (7.80% FR, 6.20% DR), and finally CVs (14.90% FR, 19.30% DR) having the strongest ear advantage. For older adults, ear advantage also varied among stimulus types: digits had the smallest free recall REA (7.94% FR, 3.17% DR), followed by words (8.29% FR, 4.29% DR), then by CVs (9.05% FR, 15.24% DR) and finally sentences had the largest free recall REA, but the smallest directed recall REA (13.81% FR, 1.90% DR).

When comparing mean performance between the two groups (Figures 1-4), young adults on average performed better than older adults for all stimulus types and response conditions, which was expected. Specifically, for free recall, the mean performance for young adults for the right and left ears respectively were 99.67% and 100% for sentences, 95.18% and 92.22% for digits, 91.2% and 83.4% for words, and 66% and 51% for CVs. Meanwhile, mean thresholds for older adults were much lower than means for young adults across stimulus types. For right and left ears respectively percent correct performance was 96.67% and 82.86% for sentences, 84.39% and 76.46% for digits, 69.71% and 61.43% for words, and 53.81% and 44.76% for CVs.

Statistical Analysis

In order to address the error in variance associated with percentage data, all data were transformed to rationalized arcsine units (raus) before statistical analysis occurred.
(Studebaker, 1985). A repeated measures analysis of variance (ANOVA) was performed to further examine the data using age group as the between-subjects variable and stimulus type, response condition, and ear as the within-subjects variables. A standard alpha level of 0.05 was to determine significance. The ANOVA showed a significant main effect for age group ($F_{1,45}=14.60, p<.05$). Specifically, older adults performed significantly poorer than young adults overall. There were also significant main effects for stimulus type ($F_{3,45}=389.23, p<.05$), response condition ($F_{1,15}=41.14, p<.05$) and ear ($F_{1,15}=21.56, p<.05$). Specifically, for ear the results indicated that right ear performance was better than left ear performance overall across both response conditions and all stimulus types.

Post hoc analysis for the main effect of stimulus type was performed using a t-test of means. Results revealed dichotic speech recognition was significantly different for both young and older adults across all stimulus types. Specifically, for young adults dichotic recognition performance was significantly better for sentences than for CVs ($t_{39}=-27.21, p<.008$), for digits ($t_{39}=-6.03, p<.008$) and for words ($t_{39}=-14.79, p<.008$). Young adult performance on digits was significantly better than for words ($t_{39}=-8.03, p<.008$) and for CVs ($t_{39}=-17.79, p<.008$). Young adult performance was also significantly better for words than for CVs ($t_{39}=-16.76, p<.008$). Similarly, for older adults, dichotic recognition performance was significantly better for sentences than for CVs ($t_{27}=-15.72, p<.008$), for digits ($t_{27}=-4.30, p<.008$) and for words ($t_{27}=-13.94, p<.008$). Older adult performance on digits was significantly better than for words ($t_{27}=-8.09, p<.008$) and for CVs ($t_{27}=-11.11$). Older adult performance was also significantly better for words than for CVs ($t_{27}=-6.87, p<.008$).
Post hoc analysis using a t-test of means was also performed for the main effect of response condition. Results showed a significant difference in response condition for the young adult group for word and digit stimuli and for the older adult group for word, digit, and sentence stimuli. There was no significant difference in response condition for sentence stimuli for the young adults or for the CV stimuli for either group. Specifically, young adult dichotic recognition performance was significantly better for the directed recall response condition than the free recall response condition for both words ($t_{19}=-4.68, p<.0125$) and digits ($t_{19}=-5.72, p<.0125$). For older adults, dichotic recognition performance was significantly better for the directed response condition than the free recall response condition for words ($t_{13}=-4.78, p<.0125$), digits ($t_{13}=-8.18, p<.0125$) and sentences ($t_{13}=-3.15, p<.0125$).

The ANOVA also revealed significant interactions for stimulus x response condition ($F_{3}=18.33, p<.05$) and stimulus x ear x age group ($F_{3}=3.79, p<.05$). The interaction of stimulus and response condition indicated that the differences in performance for dichotic tasks varied for response condition as a function of stimulus type. The interaction between stimulus type, ear, and age group was due to results that showed differences between right and left ear in performance was greater for older adults than younger adults and varied across stimulus type.

Another repeated measure Analysis of Variance (ANOVA) was performed to determine differences in ear advantage with age group as the between-subjects variable and stimulus and response condition as the within-subject variables. The ANOVA revealed a main effect for age group ($F_{1}=21.53, p<.05$) indicating that older adults had a
significantly larger ear advantage than young adults varying by stimulus type. However, the ANOVA did not reveal significant main effects for stimulus or response condition.

Significant interactions were also found for response condition x group ($F_1=5.42, p<.05$) indicating the magnitude of ear advantage for response condition differs according to group. Specifically, older adults exhibited a larger ear advantage than young adults, varying as a function of response condition. Significant interactions were also found for stimulus x group ($F_1=3.02, p<.05$) indicating the magnitude of ear advantage differs as a function of stimulus between groups. Specifically, older adults exhibited a larger ear advantage than younger adults, varying by stimulus.

**Individual Analysis**

The presence of age-related hearing loss and processing deficits is reflected by the considerable variability of older adult performance on the dichotic speech tasks. To illustrate this variability, data from two different subjects has been shown in Figure 5 and Figure 6. The first is for older adult subject 6, a male aged 76 years old who showed atypical performance levels. As expected, for sentences, digits, and words his REA was more robust for the free recall response condition than for directed recall. Unexpectedly, for CVs his REA was greater for directed than free recall, although this was consistent with the mean data for the older adult group. Interestingly, the magnitude of the ear advantage of OA 6 was much greater overall than the means of the older adult group. Specifically, his REA for the free recall response condition was 53% for sentences, 35% for digits, 46% for words, and 20% for CVs. His REA scores were substantially greater than mean REAs for free recall for the older adult group of 13.81% for sentences, 7.94% for digits, 8.39% for words and 9.05% for CVs as can be seen in Table 2.
Another variable older adult performance is shown in Figure 6 and shows ear advantage levels for older adult subject 3, a 72 year old male. This older adult demonstrates an REA for sentences (18%) in the free recall response condition that disappears (no ear advantage) for the directed recall condition. For digits, he has a left ear advantage for the free recall response condition (-9%) that becomes a right ear advantage for directed recall (7%). For words, he has a small right ear advantage for free recall (4%) that becomes much greater for directed recall (26%). Finally, for CVs, he has a left ear advantage for both response conditions of -17% for free recall increasing to -30% for directed recall.
**Figure 5:** Individual data for older adults subject 6 (a 76 year old male) showing differences in REA (in percent) for sentences, digits, words, and CVs across both free and directed recall response conditions.
Figure 6: Individual data for older adult subject 3 (a 72 year old male) showing differences in REA (in percent) for sentences, digits, words, and CVs across both free and directed recall response conditions.
Chapter 4

Discussion

The primary purpose of the present study was to determine variability of (a) performance and (b) ear advantage on dichotic speech recognition tasks for both young and older adults. Specifically, four types of stimuli were used including: (1) sentences, (2) digits, (3) words, and (4) CVs across three different response conditions including: (1) free recall, (2) directed recall right and (3) directed recall left.

Overall performance results revealed substantial variability among the four different stimulus types for both young and older adult groups. A clear hierarchy of stimulus difficulty emerged for mean dichotic performance for both subject groups. Specifically, sentences presented the easiest task for both young and older adults. Mean performance approached ceiling levels for both right and left ears on the free and directed recall conditions. Digits and then words were the next most difficult stimulus types, and CVs were the hardest. Both young and older adults performed significantly worse on the syllable task than the other three stimuli.

Performance on the dichotic sentence task for young adult listeners was as expected with mean performance approaching ceiling levels. Specifically, every listener performed at 97% or better for both right and left ears across response conditions. This is consistent with Noffsinger et al.’s (1994) proposed cut-off performance level of 90% or better. For young adults with no age-related cognitive deficits, the closed-set nature of the sentence stimuli presented a very easy task. Specifically, young adults performed at 99% or better for both free and directed recall. Older adults also performed better than expected, with mean performance slightly poorer than young adults for free recall.
(96.67% and 82.86% correct for the right and left ears respectively) but again mean performance approached ceiling levels for directed recall (100% and 98.1% for the right and left ears respectively). Older adult performance level was expected to be poorer due to the higher cognitive demand and lexical content present in the DSI (Jerger & Martin, 2006). Older adult free recall performance on sentences was better than a study by Noffsinger et al. (1996) in which free recall performance was 91.4% and 79.6% for the right and left ears respectively. The small sample size of the present study and variability associated with older adult listeners may contribute to the better mean performance observed in the present study.

It was hypothesized that group performance on three-pair dichotic digits would fall in between performance on sentences and CVs, which the results of the present study supported. Performance for young and older adults was consistent with or better than performance reported by previous studies (Strouse & Wilson, 1999). Overall performance for older adults was poorer than young adults on the digits task which was also expected.

Group performance on dichotic word stimuli was also hypothesized to be between the extremes of sentences and syllables, yet remain sensitive to auditory processing differences between young and older adults and between right and left ears. In addition, older adults’ mean performance for words was expected to be poorer than young adults due to age-related auditory deficits. The results from the present study supported both hypotheses. However, mean group performance for young and older adults was better than expected when compared with previous studies. Specifically, for free recall the young adult group had mean performances of 91.2% and 83.4% correct for the right and
Effects of Stimulus Type and Response Condition

left ears respectively, compared to 96.9% and 84.4% correct reported in a study by Roup et al. (2006). In the present study older adults (ages 67-80 years) had a mean performance of 69.71% and 61.43% correct for right and left ears respectively. The present study’s older adult performance scores are much higher than both older adult groups tested in Roup et al. Specifically, Roup et al. reported mean performance for the 60-69 year old group of 65.2% and 49.9% correct and the oldest group averaged 48.3% and 36.1% correct. Again, higher mean level of performance could be due to the present study’s smaller sample size and variability associated with older adult listeners.

Mean dichotic performance on CVs was expected to be much poorer and more variable than the other three stimuli. The present study supported this hypothesis as performance on CVs for both young and older adults was significantly poorer than the other stimulus types. However, while performance on sentences, digits, and words was consistent with or substantially better than performance reported in previous studies, performance on CVs in the present study was worse than previous studies. Specifically, young adult mean performance for free recall was 66% and 51% for the right and left ears respectively, much lower than the 74% and 76% mean correct performance reported by Noffsinger et al. (1994). Older adult performance was 53.81% and 44.76% correct for the right and left ears respectively, more consistent with mean performance of 58.4% correct for the right ear and 41.6% correct for the left ear reported by Noffsinger et al. (1996).

Figures 7-10 show a series of scatterplots of young and older adult recognition performance for all four stimulus types. These scatterplots illustrate the variability of individual recognition performance across stimulus type. As illustrated by Figure 7,
**Figures 7-10**: Scatterplots of mean dichotic recognition performance for young and older adult groups for free and directed recall across four stimulus types: sentences, digits, words, and CVs.

**Figure 7: Sentences**

**Figure 8: Digits**
Figure 9: Words

Figure 10: CVs
performance on sentences was the least variable with the data points clustered closely together, followed by digits, then words, then CVs. As is apparent in the scatterplots, digit and word stimuli were fairly consistent with a few outliers, especially for older adults in the free recall response condition.

Individual performance on CV syllables was the most variable for both young and older adults as illustrated by Figure 10. Unexpectedly, young adults were less variable (the data points are shown more clustered together) for the free recall response condition than the easier directed recall condition. Specifically, free recall performance on CVs for young adults ranged between 63% and 80% for the right ears and 43% and 63% for the left ears. For older adults on CVs performance ranged from 40% to 63% for the right ears and 23% to 70% for the left ears. This variability is consistent with previous studies that report broad ranges of dichotic recognition performance on CVs. Specifically, for young adults Hallgren et al. (2001) reported left ear ranges from 22.2% to 88.9% for the left ear and 50% to 88.9% for the right ear. For older adults, left ear performance ranges from 11.1% to 77.8% for free recall and 27.8% to 83.3% for directed recall. Due to the high level of difficulty and variability present in the dichotic CV task, as well as the surprisingly poor performance reported in the present study for the young adult listeners, the usefulness of dichotic syllables in a clinical test battery is questionable.

Young and older adult performance improved for the directed recall response condition relative to the free recall response condition for sentences, digits, and words. This was expected due to the higher cognitive load present in free recall tasks as they require the listener to attend to, remember, and repeat back two distinct stimuli. The cognitive demand is lessened for directed recall tasks which has the listener to attend to,
remember, and repeat back only one stimulus, either what was heard in the right or left ear (Jerger & Martin, 2006). Improvement for sentences, digits, and words from the free recall to directed recall response conditions is consistent with previous studies (see Jerger & Martin, 2006; Strouse & Wilson, 1999; and Roup et al., 2006 respectively).

However, unexpectedly, for CVs both groups (young and older adults) performed better for free recall than for directed recall. This decrease in performance from free recall to directed recall occurred for both right and left ear levels of performance for young adults, but only occurred in the left ear for older adults (older adults did exhibit a small mean right ear performance increase of 2.86% from the free to directed recall). This is inconsistent with the findings of Hallgren et al. (2001) who reported performance on dichotic CVs improved from free to directed recall for both young and older listeners for both right and left ears. This unexpected poorer performance on free recall may be explained by the small number of participants in this study and the variable nature of CV syllables; however, once again the usefulness of CVs is questionable.

The nature of the auditory pathways during dichotic listening results in subjects more accurately identifying stimuli presented to the right ear (termed an REA). The magnitude of the REA is generally smaller for normal hearing listeners (young adults) or for dichotic listening tasks with a lower linguistic workload. Therefore, the magnitude of the REA should increase as both a function of age and difficulty of the stimulus presented (Kimura, 1961; Jerger et al., 1994)

In the present study, for all stimulus types and response conditions right ear performance was better than left ear performance as expected. The magnitude of the REA varied significantly with stimulus type and response condition between young and
older adults. Young adults performed as expected with REA’s becoming more robust as a function of stimulus difficulty. Specifically, the smallest mean REAs were exhibited for sentences, followed by digits and words, then CVs. This was not the case for older adults in the present study. Even though performance level decreased as a function of difficulty, it did not result in a more robust REA. Older adults’ recognition performance was best for sentences (the easiest task), but older adults also had the strongest REA of 13.81% for free recall on sentences. Older adults exhibited the same REA of 8.29% for free recall for words, 7.29% for digits and a 9.05% REA for CVs. Compared to previous studies, older adults would have been expected to show a much larger REA for the more difficult CVs than the other stimuli (Hallgren et al., 2001).

Overall differences for ear advantage between young and older adult groups were not as robust as expected. Previous studies reported large LEDs for older adult listeners which would be expected due to cognitive and auditory processing deficits, especially as stimulus difficulty increases (Strouse & Wilson, 1999; Jerger et al., 1994; Bryden, 1988). In the present study, older adults did exhibit a much larger ear advantage of 13.81% for free recall on sentences than young adults who had a negligible mean REA. For digits, older adults had a slightly larger ear advantage of 7.29% compared to 2.96% for young adults. However, for words young and older adults had similar REAs of 7.8% and 8.29% respectively on free recall and for CVs older adults exhibited a smaller REA than young adults for free recall (9.05% compared to 14.9%). The unexpected REA results illustrate a drawback of the current study in which there was a small sample size for both young and older adults.
Clinical Implications

In conclusion, the present study allowed for comparison of stimulus type and response condition between the same set of young and older adult listeners. By including four stimulus types commonly found in clinical test batteries for APD it becomes apparent that results of clinical tests must be compared and evaluated carefully depending on the stimulus and response condition used. In addition, conclusions can be drawn as to which stimuli may be preferred when determining normal and abnormal levels of performance. The present study suggests that sentences may not be a valuable stimulus type due to the near perfect performance by young adults, making it difficult to determine cut-off performance levels. In addition, while the higher lexical content and cognitive demand of sentences were expected to result in poorer older adult performance, in the present study all but one older adult scored above 80% for free recall and directed recall performance approached ceiling levels for both ears. Again, it becomes difficult to determine what a common versus uncommon score is.

Results from the present study taken with those of previous studies suggest that CVs may also not be a useful stimulus for determining the presence of APD. The present study revealed the variability of syllables with results such as unexpectedly poor mean young adult performance compared to previous studies and unexpectedly poorer free recall than directed recall performance. The general unpleasantness and difficulty of the task and great variability among individual performance for both young and older adults, along with findings of previous studies (Noffsinger et al., 1994; Noffsinger et al., 1996) leads to the conclusion that CV syllables may not be a clinically useful dichotic stimulus.
In addition, the results of the present study taken with previous studies provides support for including both a free recall and directed recall response condition in clinical test batteries. For sentences, digits, and words performance improved from free recall to directed recall which was consistent with previous studies. Including both response conditions as a standard can help determine whether poorer performance by a listener is primarily cognitive (poor free recall performance improving for directed recall) or auditory (poor free and directed recall performance) in origin (Jerger & Martin, 2006).

One drawback of the present study is the small sample size for both young and older adult subjects (10 young adults and 7 older adults). The small sample may have led to increased variability in performance results and skewed mean performance levels. This study could be improved through increasing the number of participants in both groups. In addition, older adult listeners present a substantial increase in variability of performance as a function of age-related factors. This study could be improved by comparing performance across specific age range groups.
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