To the Graduate Council:

I am submitting herewith a dissertation written by Robert E. Moore entitled "Effects of hearing loss on attentional effort during listening tasks." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

James W. Thelin, Ph.D.
Major Professor

We recommend this dissertation
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

EFFECTS OF HEARING LOSS ON ATTENTIONAL EFFORT DURING LISTENING TASKS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Robert E. Moore
May, 2000

DEDICATION

This dissertation is dedicated to two people. First is my wife, Jane. Without her help and encouragement, it is doubtful that this work would have been completed. After almost 30 years of marriage, she remains my best friend. Second, I would like to dedicate this dissertation to the memory of my father, Lawrence C. Moore, who passed away in 1995. While he was not well educated in the academic sense, I do believe I inherited my desire to learn from him. I still miss those talks, Dad.

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ABSTRACT

The purpose of this study was to determine the effects of listening task difficulty on attentional effort for normal hearing and hearing impaired individuals. The study utilized a dual-task paradigm involving an auditory task (primary task) of listening to speech in noise and a memory task (secondary task) of digit recall. The memory task was used to measure changes in attentional effort as the difficulty of the auditory task was changed.

The results of the study identified two main strategies for listening to speech in noise. The attentional effort strategy used by most subjects in this study was one of borrowing from the memory task as the auditory task became more difficult. The second attentional effort strategy used by a minority of subjects in this study was one of minimal borrowing from the memory task as the auditory task became more difficult. The group using the minimal borrowing strategy only demonstrated borrowing at the easiest auditory task condition. They did not show an increase in attentional effort as the task became more difficult.

Within the two main strategies, three sub-strategies were found to be used when the auditory task became very difficult or impossible. At this point, the majority of those using the borrowing strategy decreased attentional effort to the auditory task. This sub-strategy was labeled as punting. About one-third of those using the borrowing strategy continued to increase attentional effort to the auditory task, even when the auditory task became impossible. This sub-

strategy was labeled as trying. One minimal borrowing subject used the punting sub-strategy when the auditory task became impossible. One minimal borrowing subject did not increase attentional effort to the auditory task at any difficulty level. This sub-strategy was labeled as constant attention to memory.

Hearing impaired and normal hearing subjects were about equally likely to use the borrowing strategy. Hearing impaired subjects were slightly more likely to use the punting sub-strategy.

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CHAPTER I

Introduction

Effects of Noise on Speech Communication

Individuals are often compelled to communicate in noisy environments. Kennedy (1997) has described three types of noise that may be adverse to communication. These are competing speech, constant noise, and intermittent or fluctuating noise. Competing speech is found at restaurants, malls, parties, the work place, schools, and meetings. It is also present as the background noise of radio and television. Constant noise is found in the form of fan, air conditioners, car motors, vacuum cleaners, etc. Intermittent or fluctuating noise is found in the form of business machines, manufacturing equipment, traffic, and road noise.

The affects of noise on speech communication has been well documented in the literature. If noise and speech occur at the same time, the speech may become inaudible or "masked." Three parameters of the noise are important in its effectiveness to mask speech: (a) the long term spectrum, (b) the intensity fluctuation over time, and (c) the average intensity relative to the intensity of speech (Nabelek and Nabelek, 1994). Noise may make consonant identification difficult by masking the less intense segments of speech (Miller and Nicely, 1955). Vowels which have formant frequencies in close spectral proximity may be confused in the presence of noise (Pickett, 1957). Constant noise appears to affect speech perception of normal hearing individuals more than fluctuating noise (Carhart, et al., 1969; Festen and Plomp, 1990). Impulsive noise tends to be less disruptive than constant noise (Nabelek and Pickett, 1974). It is also apparent that noise can affect some individuals more than others. Nabelek et al., (1991) studied the tolerance of background noises for hearing aid users. They found that those hearing aid users who were full-time users tolerated higher levels of background noise better than those who were limited users or who had stopped using their hearing aids completely. Background noise is one of the major reasons for rejection of hearing aids (Surr et al., 1978; Kapteyn, 1977; Franks and Beckman, 1985).

Because of the detrimental effects of noise on speech perception, investigators have sought to quantify the effects of noise on an individual's performance in speech recognition tasks. Several researchers have compared speech recognition performance in noise to performance in quiet for normal hearing and hearing impaired subjects (Carhart and Tillman, 1970; Tillman et al, 1970; Jokinen, 1973; Cohen and Keith, 1976; Findlay, 1976; Dirks et al, 1982; Dubno et al, 1984; Plomp, 1986; Beattie, 1989; Wilson et al, 1990). The results of these studies generally indicated that hearing impaired individuals were more susceptible to the effects of noise than are normal hearing listeners. These results demonstrated that word recognition tests performed in noise are more effective in showing performance differences among individuals with varying degree of hearing loss, than those performed in quiet.

The Study of Attentional Effort

The studies on speech communication in noise offer a description of the difficulty listeners have in processing words in isolation in the presence of a competing noise. As such, they give little information concerning the strategies that individuals use in an effort to overcome the interfering effects of noise on communication. One method to further study the strategies used in communicating in noise is to investigate the use of attentional effort in these situations.

The methodology of attentional effort has its roots in the research of psychologists who were investigating information processing (Keele, 1973). Keele reported that these investigators found that limitations of space influence information processing. If two tasks cannot be performed simultaneously, then some aspect of the tasks is said to take space that causes interference between the two tasks. An example of two tasks that can be done simultaneously by most people is walking and talking. Neither activity interferes significantly with the other. Hence, the two processes involved in walking and talking must require no interfering space. In contrast, talking and solving a difficult math problem on a calculator appear to interfere strongly with each other, despite the fact that the two tasks use completely different sensory and motor systems. Some processes involved in conversing and some processes involved in solving math problems each take enough space so that they cannot occur simultaneously without interference.

The study of limitations of space also offers insight to the problem of the nature of attention. One use of the term attention implies that when a person is attending to one thing, he cannot simultaneously attend to something else without interference of one or both of the tasks (Keele, 1973). Solving a math problem is said to require attention because one cannot simultaneously do it and participate in conversation. In the context of space, solving a math problem would take space that interferes with participating in conversation. Walking is said to require very little attention because other tasks performed simultaneously, such as talking, interfere very little with walking. In the context of space, walking would not take space that interferes with walking.

Very early in the history of psychologic research, investigators suggested that attention might be understood in terms of task interference. Keele (1973) indicated that Binet found in 1890 that the task of mental addition interfered with the task of squeezing a rubber ball at a regular rate for a predetermined number of times. However, in cases where the number of repetitive movements and the movement accuracy did not need to be monitored, Binet found that there was no interference from such a task as reading. In 1898 Welch showed that the maintenance of a strong hand grip deteriorated during the performance of various mental tasks such as arithmetic (Keele, 1973).

These and other studies resulted in no general conclusions regarding attention, but they did result in a technique for studying attention. Kahneman (1973) proposed a capacity model of attention. He assumed that there was a general limit on man's capacity to perform mental tasks. Kahneman also suggested that capacity and arousal were closely related. Arousal and capacity both increase and decrease according to the changing demands of the activities being undertaken. In this context arousal and capacity are dependent on the difficulty of the task. If the task is difficult there will be greater arousal and capacity, than if the task is easy. His model also assumed that this limited capacity could be allocated with considerable freedom among concurrent activities (Moray and O'Brien, 1967). Kahneman (1973) used an analogy of an electric supply company. When an individual turns on an electrical device in their home, it causes an increase in electrical current. Without another source of current, the new load would cause a decrease in the current supplied to other users. However, the source generator has a governor, which increases the output as a result of the increased load. The increase will continue until the finite capacity of the generator is reached.

As noted by earlier researchers, different mental tasks impose different demands on a limited capacity. Easy tasks such as walking require little effort (little space), while difficult tasks such as solving math problems require much effort (more space). When the supply of attention does not meet demands, performance falters or fails. According to this model, performance can fail either because of a low capacity or because the allocation center channels some of the available capacity to other activities. In describing this model Kahneman (1973) proposed a procedure for evaluating attentional effort. He noted that the degree of attention being applied to a primary task could be assessed by measurement of a subject's ability to respond to a secondary stimulus. As attention or focus to the primary task increases, the capacity for processing and responding to the secondary stimulus decreases. This results in errors in secondary sensory system responses, or in delayed responses to the secondary task. In theory, as the difficulty of the primary task increases, performance on the secondary task declines.

Attentional Effort for Speech Understanding

Feuerstein (1992) used Kahneman's procedure to study the attentional effort required in monaural and binaural hearing. One of this researcher's interests was the difference in attentional effort in monaural hearing and binaural hearing. He noted that children with unilateral hearing loss often have greater problems in school and language acquisition. He speculated that a unilateral hearing loss, while not appearing to be audiometrically severe, could place demands on attentional effort from other tasks. In this study subjects were required to perform the Revised Speech in Noise (SPIN) test (Bilger et al., 1984). The speech and noise were delivered in sound field. The simulated unilateral conductive hearing loss was accomplished by use of an earplug in one ear. In the binaural condition the speech was presented to one ear and the noise to the other ear. In the monaural condition the speech was presented to the side of the ear with no simulated hearing loss and the noise to the ear with the simulated hearing loss(monaural-near condition). A second monaural condition had speech presented to the side with the simulated hearing loss and noise presented to side with no simulated hearing loss (monaural-far field). The secondary task was a reaction time test in which the subject was required to turn a lamp off as quickly as possible once it was lit. The amount of attentional effort was described as the difference in a baseline measurement of reaction time and the reaction time required while performing the speech recognition in noise tasks. The results showed that attentional effort was not significantly altered by a change from binaural to the monaural-near condition. However, when the speech was delivered to the side with the simulated hearing loss and noise to the ear with no simulated hearing loss (monaural-far condition) there was a significant increase in attentional effort. Feuerstein suggested that this was evidence that individuals with a unilateral hearing loss may have greater difficulty in certain listening situations than performance would indicate.

Subsequently, Rakerd, et al. (1996) studied the attentional effort required of hearing impaired subjects when they listened to speech, as compared to that of normal hearing subjects. The hearing impaired subjects consisted of groups of individuals with congenital and acquired hearing loss. The subjects were required to perform a primary and a secondary task. The primary task was a speech recognition task in which the subject was required to follow connected discourse and later recall information in that discourse. The secondary task was a memory task in which the subject was asked to retain, in order, previously displayed digits. Attentional effort was described as the difference from a baseline in the number of digits recalled following the speech recognition task. These investigators found that hearing impaired subjects required more attentional effort in a speech recognition task than normal hearing subjects. The congenital hearing-impaired group required more attentional effort than those with an acquired hearing loss. These researchers postulated that the congenital hearing impaired group required more attentional effort because of the combined effects of the peripheral hearing loss and central auditory deficits. However, the congenital hearing impaired group had three frequency (500, 1000, and 2000 Hz) pure tone averages ranging from 57 to 90 dB HL. The acquired hearing impaired group had three frequency pure tone averages ranging from 33 to 50 dB HL. It is possible that the difference in attentional effort seen between the two groups was due to the difference in degree of hearing loss rather than whether the hearing loss was acquired or congenital.

Present Study

While the studies of attentional effort show differences between normal hearing and hearing impaired listeners, it is unclear whether the differences in attentional effort are due to hearing loss, the difficulty of the task, or an interaction of the two factors. In order to study the interaction of attentional effort and task difficulty, it is necessary to vary the difficulty of the primary task and compare the results in attentional effort (the secondary task) at different levels of difficulty.

In the present study a dual-task procedure similar to that described by Rakerd, et al. (1996) was used. In such a paradigm, there is a primary task (on which the subject is instructed to focus) and a secondary task that creates the competition for space. The primary task is selected on the basis of area of interest, in this case. The primary task selected was a word recognition test in varying levels of background noise. The secondary task selected was a digit memory task, with the digits presented visually. Digit memorization has been shown to be a sensitive index to attentional effort (Anderson and Craik,1974; Downs and Crum, 1978; Rakerd, et al., 1996).

The purpose of this study was to determine the effects of listening task difficulty on attentional effort for normal hearing and hearing impaired individuals. There were two research questions: 1) does attentional effort increase with increases in the difficulty of the listening task, and 2) for listening conditions that vary in difficulty , does attentional effort differ for normal hearing individuals and hearing impaired individuals.

CHAPTER II

Review of Literature

The intelligibility of speech depends on three factors, the delivery, the reception, and the ambient listening conditions. Nabelek and Dagenais (1986) and Nabelek (1988) reported differences in vowel intelligibility for different talkers. Cox et al. (1987) found that some voices were more susceptible to degradation from noise and reverberation than others. The sex of the talker does not appear to influence the intelligibility of the talker's speech (Gengel and Kupperman, 1980). It has been demonstrated that individual talkers can improve the intelligibility of their speech through careful articulation known as "clear speech" (Pichney et al., 1985, 1986; Payton, et al., 1994).

Aging, Hearing Loss, and Speech Perception

That individuals with sensorineural hearing loss have difficulty understanding speech is well documented (Cooper and Cutts, 1971; Keith and Talis, 1972; Dirks et al, 1982; Suter, 1985; Plomp, 1986; Gordon-Salant, 1987; Crandell, 1991; Crandell et al, 1991). One of the earliest studies of presbycusis by Kelly (1939) demonstrated that older subjects performed more poorly on word recognition tests than younger subjects, especially for consonants. French and Steinberg (1947) studied the relative importance of pure tone frequencies to speech understanding. The percentage weights were 10% at 500 Hz, 20% at 1000 Hz, 26% at 2000 Hz, 21% at 3000 Hz, and 15% at 4000 Hz. Pestalozza and Shore (1955) evaluated audiometric data for patients over 60 years, comparing pure-tone thresholds at 500, 1000, and 2000 Hz with spondee thresholds and recognition of phonetically balanced (PB) words presented at 40 dB SL. They also compared the data from older subjects with that from younger subjects with sensorineural hearing loss. For the older subjects the relationship between word recognition and hearing loss was almost linear with 10 dB HL being associated with 70% recognition and 50 dB HL being associated with 20% recognition. For the younger subjects word recognition scores were 10 -18% better, except at 40 dB HL, where the two age groups were almost equal, and at 45-50 dB HL, where the older subjects performed better than the young subjects. Later, a study by Kryter (1988) found a greater importance of 3000 and 4000 Hz for word recognition.

Several studies have indicated that age may not be associated with the relationship between hearing sensitivity and word recognition ability. Kasden (1970) found that hearing loss was associated with poorer recognition, but age was not an important factor. Surr (1977) also found only a slight decline in the identification of PB words in older subjects who had small increases in speech reception thresholds. Using multiple regression techniques to access the contribution of age and hearing loss at various pure-tone frequencies to recognition of CID W-22 PB words, Marshall and Bacon (1981) discerned that the most important predictor of word recognition was pure-tone thresholds at high frequencies, with age accounting for a lesser amount of the variance. It appears from the literature that the effect of age on word recognition ability is most pronounced when the hearing loss is substantial.

There are two prominent theories regarding a reduction of speech understanding by those with a hearing loss in quiet conditions. The first assumes that a reduction in speech recognition is secondary to distortions accompanying a loss in pure tone sensitivity, such as reduced frequency selectivity and cochlear processing (Dirks et al, 1982; Plomp, 1986; Trees and Turner, 1986; Gordon-Salant, 1987; Irwin and McAuley, 1987; Summerfield, 1987; Turner et al, 1987; Tyler, 1988; Crandell, 1991; Crandell et al, 1991; van Rooj and Plomp, 1991). The second theory suggests that the reduction of speech recognition is due to the attenuation of the speech signal resulting from the reduction of pure tone sensitivity (Kamm et al, 1985; Humes et al, 1986, 1987, 1988; Humes and Roberts, 1990; Humes, 1991). Using sentences in noise, Needleman and Crandell (1995) found greater support for the first hypothesis.

Noise and Speech Recognition

Helfer and Wilber (1990) reported that age may be a factor when speech is heard in noise. However, research over the years is somewhat equivocal regarding the role of age in speech recognition in noise. Bergman (1980) studied the effects of age on speech understanding. He suggested that there was a decline in sentence interpretation in the presence of two competing talkers beginning at approximately age 40 years when the signal-to-noise ratio was -5 dB. Levitt et al. (1975) showed a decline in speech recognition in subjects in their mid-twenties when subway and traffic noise maskers were used. Jokinen (1973) found that the recognition of words in broadband noise decreased with age. Lower signal-to-noise ratios produced poorer speech recognition as would be expected. There was a small interaction between the age and signal-to-noise ratio. That is, the difference in recognition between the subjects in their 20's and those in their 70's was less than 15% when the signal-to-noise ratio was +22 but was almost 30% when the signal-to-noise ratio was +2. Using the Synthetic Sentence Identification test (Jerger, 1973), presented at five message-to-competition ratios, Orchik and Burgess (1977) found that older listeners consistently performed at poorer levels than did younger listeners. Smith and Prather (1971), using nonsense syllables in noise, studied the effect of various signal-to-noise ratios in young and old subjects. The older subjects did poorer at all signal-to-noise ratios; however, the signal-to-noise ratio appears to be an important factor in determining the age effect. Findlay and Denenburg (1977) presented monosyllabic words at 30 dB SL in quiet, -4 S/N babble, and low-pass noise to young subjects with normal hearing, young subjects with hearing loss, and old subjects with hearing loss. The three groups performed similarly in quiet. In the presence of the babble both groups with hearing loss performed worse than the young normal hearing group. Of the two hearing-impaired groups, the older subjects performed poorer. The older group had poorer hearing than the young hearing-impaired group, so it is unclear if this a hearing loss effect or an age effect.

Some individuals with normal hearing complain of difficulty understanding speech in noise. Thibodeau (1996) investigated auditory processing as a source of this difficulty. The results of this study show that there is no difference between those with no problem understanding speech in noise and those with difficulty understanding speech in noise for enhanced forward masking. There were significant differences in the two groups for two-tone suppression when the duration of the suppressor was varied. Those with difficulty understanding speech in noise showed greater suppression when the suppressor onset preceded the masker onset.

The characteristics of the noise can be a factor. Pekkarinen et al. (1990) studied the effect of noise level on word discrimination for both normal hearing and hearing impaired subjects. They found that as the noise level increased the word recognition ability decreased. Subjects with sensorineural hearing loss were more adversely affected than those with normal hearing and those with conductive hearing loss. Persons with a high-frequency hearing loss, cut-off point 1 kHz, suffered in noise similarly to those with sloping or flat hearing losses. In quiet and in moderate noise, the speech discrimination of subjects with a conductive hearing loss and subjects with normal hearing was similar, while at high noise levels, subjects with conductive hearing losses achieved better discrimination than normal hearing subjects.

Hygge et al. (1992) evaluated the performance on a conversation-following task by hearing impaired and normal hearing subjects in the presence of noise. The noise consisted of 1) speech-spectrum random noise, 2) a male voice, and 3) the male voice played in reverse. They found that hearing impaired subjects were equally affected by the three background noises. Normal hearing subjects were more affected by the background speech than by the noise. Bronkhorst and Plomp (1992) reported speech reception thresholds in various noise conditions for both normal hearing impaired subjects. They found that modulation of the masker acts as a release from the masking for normal hearing subjects, but it does not carry over to the hearing impaired group. They also found that location of the masker has an affect. When the maskers were moved from the frontal position to positions around the listener a gain of 1.5 to 8 dB occurred for the normal hearing group and of 1 to 6.5 dB for the hearing impaired group. The gain depended significantly on the number of maskers and their location, but less on the hearing loss.

Souza and Turner (1994) studied the contributions of various properties of background noise to the speech recognition difficulties experienced by young and elderly listeners with hearing loss and young normal hearing listeners. Four noise conditions were used: 1) high-pass noise, 2) high-pass noise with speech spectrum noise, 3) high-pass noise with speech spectrum noise temporally modulated by the envelope of multi-talker babble, and 4) high-pass noise with multi-talker babble. For all these conditions the hearing impaired groups consistently had poorer speech recognition scores than the normal hearing group. Although there was a trend toward poorer speech recognition scores as the masker condition more closely resembled speech babble, the effect of masker condition was not significant. Normal hearing listeners and those with hearing loss appeared to be affected similarly by the type of background noise.

when the long-term spectrum was held constant. Age did not appear to be a significant factor. Eisenberg et al. (1995) found that amplitude-modulated noise provided a release from masking greater for normal hearing subjects than those with hearing loss.

Attention

Traditionally, attention has been thought of as the act of selecting from several simultaneously possible objects or trains of thought, one on which to concentrate with the mind. It implies withdrawal from some things in order to deal effectively with other things. This presence of multiple concurrent stimuli also implies selective attention (Cowan, 1995).

In communication, selective attention plays a role when there are multiple speakers and one is asked to attend to one speaker. This may be referred to as the cocktail party phenomenon. Apparently, an individual is able to accomplish this using the physical location of the voices and the different frequency characteristics of different voices. Cherry (1953) simultaneously played two prose passages through separate earphones so that one message went to each ear of the subjects. The subjects were able to successfully repeat one message and ignore the other. Attempting to duplicate a more natural situation, Spieth, et al. (1954) simultaneously played two messages spoken by the same person but delivered through two separate speakers. When the speakers were located near each other, the subjects had significant difficulty in separating the messages. However, when the speakers were located some distance from each other, sucess in separating the messages was acheived. In a separate part of the same study these researchers also filtered the messages. One message was presented through a high-pass filter (cutoff at 1600 Hz) and the other through a low-pass filter (cutoff at 1600 Hz). With the two messages presented in this way, subjects had little difficulty in separating the two messages, even when the speakers were located near each other.

Early attempts to develop a model of selective attention led to a filter theory proposed by Broadbent (1957, 1958). According to this theory the filter would block messages having certain physical characteristics (such as frequency and location), while allowing others to pass (with different frequency and location). The filtering would occur early in process. This theory implies that a listener would not remember anything about an ignored message since it was filtered out prior to achieving meaning. The only exception would be when the attended message did not require all the available processing time, and channel switching was possible. In the Cherry (1953) study in which messages were directed to different ears, significant changes were made to the unattended message without the changes being noted by the subjects. For instance, they did not notice when the unattended message changed from English to German or when the message was played backwards. However, they did notice when the voice changed from a male talker to a female talker or tone. This is supportive of the filter theory since the filter is based on the frequency characteristic of the ignored message. When the frequency is changed, the filter must be readjusted.

Other studies were not supportive of the filter theory. Moray (1959) found that individuals can notice their name being spoken while listening to another message. This is true even if their name is spoken from a different location or in a different frequency of the attended message. In a study using French-English bilingual subjects, Treisman (1964) played an English message in one ear and a different French message in the other ear. The subjects were to repeat the English message. After a period of time the French message was switched to a French translation of the English message. When the French message was lagged slightly behind the English message, most subjects recognized that both messages had the same meaning. From these findings, Treisman suggested that the unattended message is not filtered, but is attenuated. She suggested that if a message is important to an individual (the person's name) or becomes likely in the context of the message being attended, then it can be detected even though it is weakened. Even though the French words were attenuated, they were detected when they fit into the context of the English message. This change in the original filter theory is called the Broadbent-Treisman filter theory of selective attention.

Later, Deutsch and Deutsch (1963) took a different approach suggesting that all information is completely analyzed automatically, with attention being used only to determined which of this analyzed information will enter into the individual's response. This has been termed a "later filter" theory of attention in contrast to the "early filter" of Broadbent (1958). Broadbent (1971) added a "later filter" in combination with his "early filter." He described this "later filter" as "pigeonholing." In describing this addition, he suggested that it was possible to select stimuli on the basis of semantic properties and not just on the basis of physical characteristics. Support for the addition of the "later filter" was found by Greenwald (1972) who found evidence for both a perceptual set (filtering) and response set (pigeonholing), and Johnston and Heinz (1978) found evidence that selection on the basis of physical cues is less effortful than selection on the basis of semantic cues, though both can be carried out. In the Greenwald (1972) study subjects read digits while hearing as a distraction various types of spoken items that included repetitive or changing digits, or tapping sounds as a control. Exemplifying filtering, there was less interference when the distracting items were repetitive than when the distracting items kept changing. Exemplifying pigeonholing, responses were slower when the current visual item was the same digit as the previously presented series of distracting digits. In the Johnston and Heinz (1978) study a tape recording was presented binaurally to the subjects. The tape recording included two concurrent speeches that differed in the speaker's voice only, in topic only, or in both voice and topic. Subjects repeated the message in one channel while performing a subsidiary task, pressing a key as quickly as possible whenever a visual signal was presented. The visual reaction time served as a measure of attentional allocation. The finding was that the reaction times were shorter when a physical cue was present than when it was absent. Semantic differences between the two channels resulted in less benefit in reducing reaction times.

The major difference between these two schools of thought concerning attention was that the "early filter" theory does not assert that attention operates only at an early level. However, the "late filter" theory does deny that some filtering takes place at an early level. There is evidence against the "late filter' theory. Behaviorally, Treisman and Geffen (1967) presented dichotic tapes in which sentences within both channels contained target words. Subjects were to repeat one channel and, at the same time, make a tapping response whenever there was a target word on either channel. Target recognition was significantly better on the attended channel than on the unattended channel. Moray and O'Brien (1967) obtained similar results and also obtained intermediate results for targets in a split-attention condition. There is also electrophysiological evidence against the "late filter" theory. Woldorff, et al. (1991) found that the mismatch negativity wave, a component of the event-related neural potential that occurs to discriminable changes in the auditory stimulus, depends on whether the subject is attending toward the channel in which the change occurs. In addition, Woldorff et al. (1993) reported attentional effects on neuromagnetic fields beginning about 20 milliseconds (ms) after the auditory stimulus. Using both neuromagnetic and magnetic resonance imaging techniques these researchers localized the neural generators of the attention-sensitive brain responses in the auditory cortex on the supratemporal plane. They concluded that these findings were supportive of psychological theories of attention that include an early, pre-perceptual selection of stimuli. Giard, et al. (1994) found evidence that attention to one of two tone frequencies affects the magnitude of otoacoustic emissions produced in the cochlea. They postulated that effects of selective attention can be observed at the cochlear receptor.

While almost all theories of attention can be crudely placed in one of the two filter theories discussed above, intermediate theories have also been proposed. Noting that none of the early theories of attention explained all situations, Kahneman (1973) proposed the capacity theory of attention. This theory suggests that an individual's cognitive operations are far more flexible than either of the filter theories can account for. The capacity theory states that an individual has a fixed amount of capacity available for distribution according to whatever strategy the individual uses. The distribution of capacity for processing a particular set of stimuli is said to lead to the experience of attention. If a large proportion of the available capacity is allocated to one source of stimuli then the subject is said to be attending to that source. This does not mean that other stimuli cannot be processed. If the total amount of available capacity is not consumed by the primary task, then secondary tasks may be performed simultaneously with the primary task (Underwood and Moray, 1971; Kahneman, 1973). Thus, we can recall a memorized series of digits after a period of time even if other cognitive tasks were performed during that period of time. Our performance in recalling the digits will depend on the amount of capacity used in performing the other cognitive task.

In addition to the concept of capacity as it relates to attention, Kahneman (1973) also introduced the concept of attentional effort. In the capacity theory of attention it is assumed that effort is controlled by feedback from the execution of ongoing activities. If the demands of the activities increase, there is an increase in the level of effort. It is also suggested that the individual does not voluntary control this effort and, in fact, cannot reach the effort level for performing a difficult task while performing an easy task. To test this hypothesis Kahneman, et al. (1968) used a physiological measurement of arousal (pupil diameter) as a reflection of effort. They asked subjects to perform both easy and difficult tasks under high-incentive (more monetary award or penalty) and low-incentive (less monetary award or penalty) conditions. Their results showed that incentive had little effect in the easy task condition, and no effect in the hard task condition. The major determinant of arousal (effort) was the difficulty of the task. Broadbent (1958) had earlier found similar results. Broadbent distorted speech in various ways and to varying degrees. He found little change in speech intelligibility under the different conditions. He did find a significant difference in the subjects' perceived listening effort.

Kahneman (1973) proposed a method for measuring attentional effort . It is based on the capacity theory of attention. He suggested that if an individual has limited capacity to attend to stimuli, the attentional effort required of a primary task could be measured by the performance of the individual on a secondary task. As the difficulty of the primary task increases, thereby increasing the amount of attentional effort required to perform the task, the ability to perform the secondary task decreases. This results in errors or delayed responses in the secondary task. It is felt to be important that the two tasks utilize different sensory modalities to assure that the secondary task reflects but does not affect the primary task.

The first audiology study using this methodology was by Downs and Crum (1978). They used a speech listening task as their primary task and a visual task as their secondary task in a study of auditory learning under adverse listening conditions. The adverse listening conditions were created by attenuating the signal and adding noise in one condition. All subjects had normal hearing. Their subjects were required to turn off a randomly lit lamp as quickly as possible while performing an auditory learning task. The difference in the reaction time to the lamp during the auditory learning task and a baseline reaction time obtained without the auditory learning task was considered an index of the attentional effort required of the auditory learning task. They found that the variables of signal intensity level and signal-to-competition level did not significantly alter learning performance. Also, a change in signal intensity did not significantly affect attentional effort. However, the addition of noise to the signal did significantly increase attentional effort. Feuerstein (1992) used the same methodology to evaluate attentional effort in monaural and binaural listening conditions. The monaural condition was a simulated conductive hearing loss in one ear, produced by occluding one ear with an earplug. There were two monaural listening conditions. In one condition the occluded ear was oriented toward the speech signal, while in the other condition the un-occluded ear was oriented toward the speech signal. Attentional effort was not significantly affected by changing from a binaural to a monaural condition. However, attentional effort increased significantly when the occluded ear was oriented toward the speech signal, as compared with the un-occluded ear toward the signal. Rakerd, et al. (1996) compared attentional effort in three groups of subjects, normal hearing, congenital hearing loss, and acquired hearing loss. Their methods differed from those of earlier studies in that they used a speech listening task as a primary task and a visual memory task as the secondary task. The visual memory task required the subject to memorize nine random digits displayed on a computer screen. The index of attentional effort for the speech listening task was the number of digits that were not remembered. Both hearing impaired groups required greater attentional effort than the normal hearing group. The congenital hearing impaired group required greater attentional effort than the acquired hearing impaired group.

To summarize, the findings of the Feuerstein (1992) and the Rakerd, et al. (1996) studies suggest that changes in attentional effort can be measured as listening conditions change (physically and acoustically). They do not provide information concerning how changes in the listening situation result in changes in attentional effort in a single individual. They also do not provide information concerning the difference in normal hearing and hearing impaired individuals as it pertains to changes in attentional effort as a result of changes in listening conditions. Finally, these studies also do not offer information comparing attentional effort when performance is equal, but conditions are different. The current study will attempt to evaluate these areas.

CHAPTER III

Methods

Subjects

Prior to participation in this study, each subject read and signed a Statement of Informed Consent form approved by the University of Tennessee-Knoxville. Appendix A contains the Statement of Informed Consent.

Thirty-two individuals between the ages of 50 and 59 years served as subjects. All subjects were native speakers of American English. The thirty-two subjects were divided equally between 16 females and 16 males. The average age of both the female and male groups was 55 years. The range of age for the female group was 50 to 59 years. The range of age for the male group was 51 to 58 years.

The male and female groups were divided equally into 8 normal hearing and 8 hearing impaired subjects. All of the hearing impaired subjects had acquired hearing losses. The subject's better ear was chosen as the test ear. Each normal hearing subject had a speech reception threshold (SRT) no poorer than 20 dB HL (ANSI, 1989) in the test ear. If the SRTs in the two ears were identical, the subject chose the test ear. Each hearing impaired subject had an SRT no better than 25 dB HL (ANSI, 1989) in the test ear. If both ears met the criteria the subject's better ear was chosen as the test ear. If the SRTs were identical, the subject chose the test ear.

Equipment and Stimuli

Pure-tone air-conduction thresholds and SRTs were obtained with an audiometer (Virtual Model 320) calibrated in accordance with ANSI (1989) specifications for a Type 2 audiometer. All test signals were presented monaurally through an earphone (TDH 50-P) mounted in a supra-aural cushion (P/N 510C017-1) and a standard headband. All audiometric qualification, auditory tasks, memory tasks, and dual-tasks were performed with the subject seated in a sound-treated room (Industrial Acoustics Company, 1203) meeting ANSI specifications for permissible ambient noise (ANSI, 1991). The speech and noise stimuli were produced using two cassette tape players (Eika, Model 5090A). The speech and noise stimuli were routed to a 6-channel audio mixer (TEAC, Model 2) to produce the various signal-to-noise ratios used in the study. The stimuli were presented to the subject using the audiometer and headphones. The noise was recorded 12-person, multi-talker babble. The SRT test material was the recorded male talker version of the CID W-1 word lists. The test material for the auditory task was the recorded male talker version of the NU-6 50 item word lists. Biologic checks of the audiometer were performed each day before testing.

Test Procedures

All testing was accomplished during one session lasting approximately two hours. To minimize fatigue, rest periods were given as needed. Each subject was given at least one rest period. Following audiometric qualification tests, each subject performed memory tasks, auditory tasks, and dual-tasks.

Audiometric Qualification

Pure-tone air-conduction thresholds and SRTs were obtained using a standard clinical procedure (ASHA, 1978). Pure-tone thresholds were obtained at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.

The Memory Task

In the memory task, subjects were asked to memorize as many digits as possible out of a string of displayed digits. The memory task was performed to obtain a digit recall baseline and as practice for the subject. Seventeen one-half inch high digits were displayed on a 8 1/2" X 11" sheet of paper. An example of a digit list used in the study is shown in Appendix B. The subject was asked to study the digits and, after they were removed, to remember them and their order. Digit strings were displayed for 15 seconds. Once the digits were removed from the subject's sight, a memory retention interval of 65 seconds was initiated. The time period of 65 seconds was selected because that was the time required to deliver 15 words in the listening task portion of the dual-task section of the study. During the memory retention interval the subject listened to the multi-talker babble used in the listening task in the ear which had been selected as the test ear.

At the end of the retention interval, the subject was prompted to recall the digits in the correct order. Scoring was based on consecutive digits repeated correctly. While omissions were rare, a subject was permitted to omit one digit in the sequence if it was followed by two correct digits. For example, if the correct sequence was 2, 3, 4, 5, 6, 7, 8, and 9, and the subject responded with 2, 3, 4, 5, 6, 8, and 9, the subject was given credit for 7 correct digits recalled. However, if the subject responded with 2, 3, 4, 5, 6, 7, and 9, the subject was given credit for 6 correct digits recalled. The sequence was terminated when the subject stopped responding, when a digit was recalled incorrectly, or if there were two omissions. Amount of digit recall was the number of digits repeated in sequence correctly. This procedure was repeated two more times. The baseline for digit recall was the median score of these three trials.

The Auditory Task

The auditory task was performed to obtain baseline speech understanding scores at each signal-to-noise ratio used in the study and in quiet. It was also used as practice for the subject. Each subject was tested using recorded NU-6 words in quiet and at signal-to-noise ratios of -12 dB, -6 dB, 0 dB, +6 dB, +12 dB. One subject was also tested at -15 dB signal-to-noise ratio. The speech was presented at a level that the subject judged to be comfortable. For the purpose of this study this level was designated as the most comfortable level (MCL). At each signal-to-noise ratio 45 words were presented to the subject. The subject was instructed to repeat each word as it was presented. The subject was encouraged to guess.

The 45 words were divided into three 15 word blocks for scoring purposes. If any part of a word was repeated incorrectly, it was scored as incorrect. The number of correct responses was tabulated for each block. The median number of correct responses of the three blocks was used as the baseline words correct score for quiet and each signal-to-noise ratio.

Dual-task

In order to study attentional effort, the primary and secondary tasks were performed as part of a test sequence. The auditory task and the memory task were combined to form the dual-task. It was emphasized to each subject that they should try to do well on the auditory task. For this portion of the study, the subject was first presented the digits for memory retention, for 15 seconds. During the 65 second retention period 15 words in noise were presented and the subjects were required to repeat the words. At the end of the auditory task the subject was asked to recite the digits in order. Scoring of the auditory task and the memory task portions of the dual-task was identical to that described previously for each task. These procedures were repeated three times at each signal-to-noise ratio. The order of the signal-to-noise ratios was randomized for each subject.

Statistical Analysis

The data from this study was analyzed using the multivariate analysis of variance (MANOVA). This method was used due to the existence of multiple dependent variables.

Test Protocol

The total test time for each subject was approximately two hours. The sequence of test procedures and approximate test times is shown below:

1. Informed consent and audiometric qualification (20 minutes)
2. Memory task (15 minutes)
3. Auditory task (30 minutes)
4. Rest period (15 minutes)
5. Dual-task (40 minutes)

During the rest period and after the dual-task, subjects would often comment on the difficulty of the tasks and would discuss their listening strategies. Informal notes were made of these comments.

CHAPTER IV

Results

Results are presented for audiometric qualification data and then for experimental procedures. Raw data for each subject are shown in Appendix C.

Audiometric Qualification Results

A summary of all the audiometric qualification measurements for all subjects is shown in Table 1. In addition, low frequency and high frequency pure tone averages were computed. The low frequency average (LFA) was defined as the average threshold for 250, 500, 1000, and 2000 Hz. The high frequency average (HFA) was defined as the average threshold for 3000, 4000, 6000, and 8000 Hz.

The analysis of the audiometric qualification measurements is summarized in Table 2. SRTs were significantly poorer for the hearing impaired subjects than for the normal hearing subjects, as required by subject selection criteria. LFAs which are correlated with SRTs were also poorer for the hearing impaired subjects. SRTs and LFAs were not different for males and females within the hearing impaired and normal hearing groups.

High frequency hearing loss (which was not a factor for subject selection in the present study) is known to affect word recognition ability. In the present study, the male subjects in the hearing impaired and normal hearing groups had

Table 1: Means of audiometric qualification measures

	Normal Hearing Group		Hearing Loss Group	
Threshold (dB HL)	Males Mean (SD)	Females Mean (SD)	Males Mean (SD)	Females Mean (SD)
250 Hz	11.3 (2.2)	15.0 (5.6)	17.5 (6.1)	20.0 (8.7)
500 Hz	7.5 (5.0)	7.7 (7.1)	12.5 (5.6)	19.4 (6.8)
1000 Hz	8.1 (4.3)	8.1 (5.0)	23.8 (6.0)	26.3 (6.5)
2000 Hz	7.5 (5.0)	6.9 (4.3)	36.9 (6.6)	33.1 (7.5)
3000 Hz	16.3 (11.7)	10.6 (5.3)	45.6 (15.5)	36.9 (7.0)
4000 Hz	23.8 (16.5)	12.5 (6.6)	56.3 (20.3)	40.0 (7.9)
6000 Hz	32.5 (20.0)	19.4 (5.3)	51.3 (21.2)	39.4 (9.2)
8000 Hz	38.8 (25.7)	20.6 (10.1)	43.1 (24.5)	35.6 (12.6)
SRT	11.3 (3.3)	10.0 (2.5)	27.5 (3.5)	28.8 (4.1)
LF Avg.	8.6 (5.2)	9.4 (6.0)	22.7 (11.0)	24.7 (9.3)
HF Avg.	27.8 (21.0)	15.8 (8.3)	49.1 (21.2)	38.0 (9.6)

Table 2: Results of MANOVA for audiometric qualification measures

Source	Dependent Variable	df	F	p
SRT	Hearing Status (HS)	1,28	182.93	.00*
	Gender (G)	1,28	0.00	1.00
	HS X G	1,31	0.93	.34
LFA	Hearing Status (HS)	1,28	91.96	.00*
	Gender (G)	1,28	0.93	.34
	HS X G	1,31	0.13	.73
HFA	Hearing Status (HS)	1,28	18.67	.00*
	Gender (G)	1,28	5.35	.03*
	HS X G	1,31	0.02	.90

* significant

SRT - speech rececption threshold
LFA - low frequency average
HFA - high frequency average

significantly poorer high frequency hearing than the female subjects. On average, HFA was 11.6 dB poorer for the males.

Baseline Memory Task Results

The average number of digits recalled without performing the auditory task for all subjects was 7.8 digits with a range of 6 to 12 digits. For females the average number of digits recalled was 7.7 digits, and for males the average number of digits recalled was 7.8 digits. For normal hearing subjects the average number of digits recalled was 8.1 digits, and for hearing impaired subjects the average number of digits recalled was 7.4 digits. There was no significant difference in the baseline digits recalled for gender ($F(1,28) = 0.00$, $p = 1.00$) or for hearing status ($F(1,28) = 0.04$, $p = .97$)

Auditory Task Results

Data were obtained for three auditory tasks: word recognition in quiet (WRQ), word recognition in noise baseline with no memory task (WRBL), and word recognition in noise with memory task (WRMT). The results for these three tasks are shown for the four experimental groups in Table 3.

Word Recognition in Quiet (WRQ)

The WRQ task was not difficult for most subjects. For the three WRQ trials the median score was 15/15 or 14/15 words correct for 29 of 32 subjects. The mean WRQ scores for each experimental groups are shown in the right hand column of Table C. The mean WRQ for all subjects was 14.5. WRQ did

Table 3: WRMT and WRBL: Mean results as a function of subject group and signal-to-noise ratio

Group	-12	-6	0	+6	+12	Avg*	Quiet
FN WRMT	0.5	6.6	10.3	12.9	13.9	10.9	
(WRBL)	(0.3)	(6.4)	(9.6)	(12.6)	(14.3)	(10.7)	14.6
MN WRMT	0.0	4.4	7.6	11.3	13.5	9.1	
(WRBL)	(0.0)	(3.9)	(7.8)	(11.3)	(13.8)	(9.2)	14.5
FH WRMT	0.0	3.6	8.5	12.4	13.9	9.6	
(WRBL)	(0.0)	(4.0)	(7.4)	(12.1)	(13.5)	(9.3)	14.4
MH WRMT	0.0	2.1	5.8	9.8	11.6	7.3	
(WRBL)	(0.0)	(2.3)	(5.9)	(9.8)	(12.0)	(7.5)	14.4
Avg WRMT	0.1	4.2	8.0	11.6	13.2		
(WRBL)	(0.1)	(4.1)	(7.7)	(11.4)	(13.4)		14.5

* average of -6, 0, +6, and +12 only

FN - normal hearing females
MN - normal hearing males
FH - hearing impaired females
MH - hearing impaired males

not depend on hearing status ($F(1,28) = 1.39$, $p = .25$) or gender ($F(1,28) = 2.05$, $p = .16$).

Word Recognition in Noise: WRBL and WRMT

There were four variables in analyzing the word recognition in noise scores: word recognition task (WRMT v. WRBL), signal-to-noise ratio, hearing status, and gender. The mean data for these four conditions are shown in Table 3, and the MANOVA for these data is shown in Table 4.

Word Recognition Tasks (WRMT v. WRBL)

The results of the statistical analysis (Table 4) indicated that the results for WRMT and WRBL were not significantly different. This was different than what had been expected. It had been anticipated that word recognition would be better without the competing memory task. Because the WRBL scores were always obtained before the WRMT scores, there is the possibility that learning improved the WRMT scores relative to the WRBL scores.

Signal-to-noise Ratio

The average word recognition score with the memory task at +12 dB signal-to-noise ratio was 13.2 (Table 3). This was a slight decrease in word recognition from the WRQ score of 14.5. From +12 dB signal-to-noise ratio there was a systematic decline in word recognition scores as the signal-to-noise ratio decreased. At +6 dB signal-to-noise ratio the average word recognition score was 11.8, at 0 dB signal-to-noise ratio it was 8.0, and at -6 dB signal-to-noise ratio it was 4.2. At -12 dB signal-to-noise ratio 31 of 32 subjects had a word recognition score of 0. The decrease in word recognition with decreases in

Table 4: MANOVA for word recognition in noise (WRMT and WRBL)

Source	df	F	p
Task (T)	1,28	1.88	.18
Signal-to-noise ratio (S)	3,84	300.61	.00*
Hearing Status (H)	1,28	6.64	.02*
Gender (G)	1,28	8.11	.01*
T X S	3,84	1.73	.17
T X H	1,28	0.39	.54
T X G	1,28	0.56	.46
S X H	3,84	1.48	.23
S X G	3,84	0.99	.40

* significant

signal-to-noise ratio was highly significant.

Hearing Status

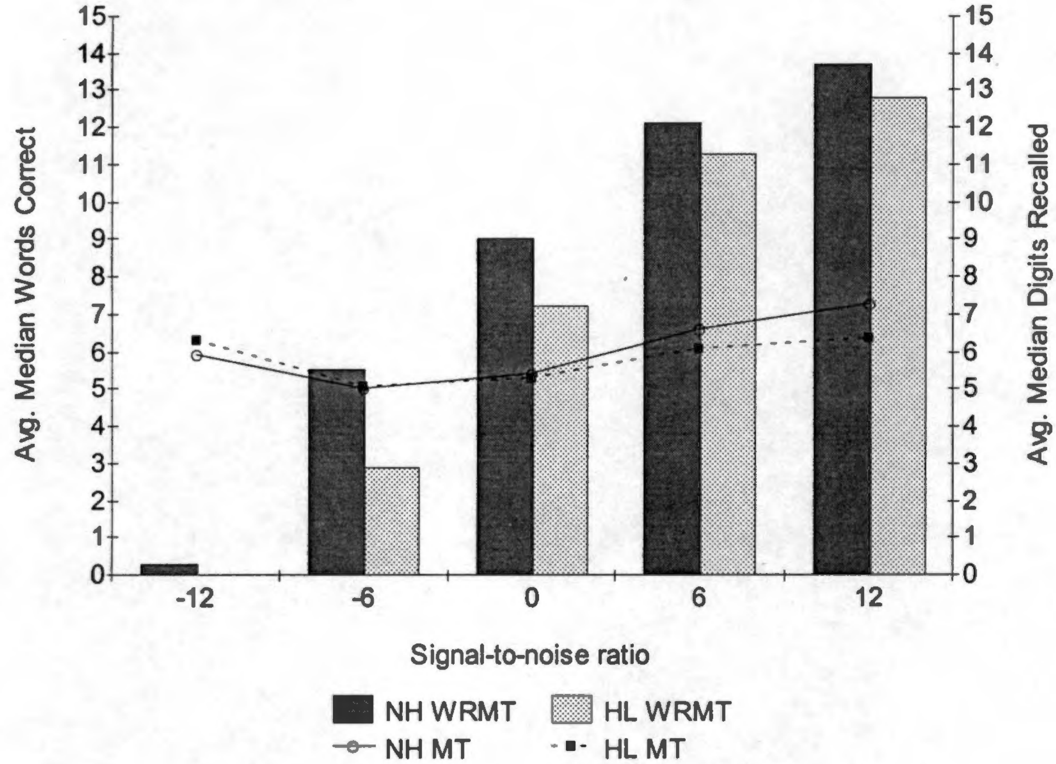
The statistical results as shown in Table 4 indicate that the word recognition scores were significantly poorer for hearing impaired subjects than normal hearing subjects. At each signal-to-noise ratio the hearing impaired subjects missed 1.6 more words on average than the normal hearing subjects.

Gender

The statistical results as shown in Table 4 indicate that word recognition scores were significantly poorer for male subjects than for female subjects. At each signal-to-noise ratio the males missed on average 2.1 words more than the females. However, based on the audiometric qualification data, this difference may be attributable to a difference in high frequency hearing rather than gender. Subject classification was based on SRTs which is a widely accepted measure of hearing loss. The SRT depends on low frequency and middle frequency hearing sensitivity. In the present study the mean HFA for normal hearing females was 12.0 dB better than for male normal hearing subjects. For hearing impaired subjects, the female mean HFA was 11.1 dB better than for the male hearing impaired subjects.

Memory Task Results

Figure 1 shows the mean MT and WRMT results plotted for normal hearing and hearing impaired subjects. The mean MT scores are depicted by the line graphs and the mean WRMT scores are represented by the bar graphs.



NH WRMT - Auditory Task with Memory Task (normal hearing subjects)
HL WRMT - Auditory Task with Memory Task (hearing impaired subjects)
NH MT - Memory Task (normal hearing subjects)
HL MT - Memory Task (hearing impaired subjects)

Figure 1: Mean WRMT and MT scores for 16 normal hearing and 16 hearing impaired subjects.

The MANOVA of the MT scores for the signal-to-noise ratios of 0, +6, and +12 dB is summarized in Table 5. The signal-to-noise ratios of -6 and -12 dB were not included in the analysis to eliminate the confounding effects of changes in strategy. The MT scores for the genders were not significantly different, and MT scores for hearing status were also not significantly different. The MT scores at each signal-to-noise ratio were significantly different.

Memory Task Listening Strategies

Borrowing Strategy

In the present study, subjects were instructed to place primary emphasis on correctly repeating words in the auditory task. Thirty of 32 subjects demonstrated a reduction in digit recall as the difficulty of the auditory task increased. This reduction in digit recall was interpreted as an indication that these thirty subjects had borrowed from the memory space being used for digit recall in an attempt to maximize performance of the auditory task. This was considered evidence of attentional effort that was expended. The 30 subjects whose recall of digits declined systematically as auditory task difficulty increased were classified as using a listening strategy called "borrowing." The remaining two subjects provided evidence of having a primary focus on the memory task because they showed only minimal evidence of borrowing as the auditory task increased in difficulty. They were classified as "minimal borrowers."

Table 5: MANOVA for digits recalled (MT) at 0, +6, and +12 signal-to-noise ratio

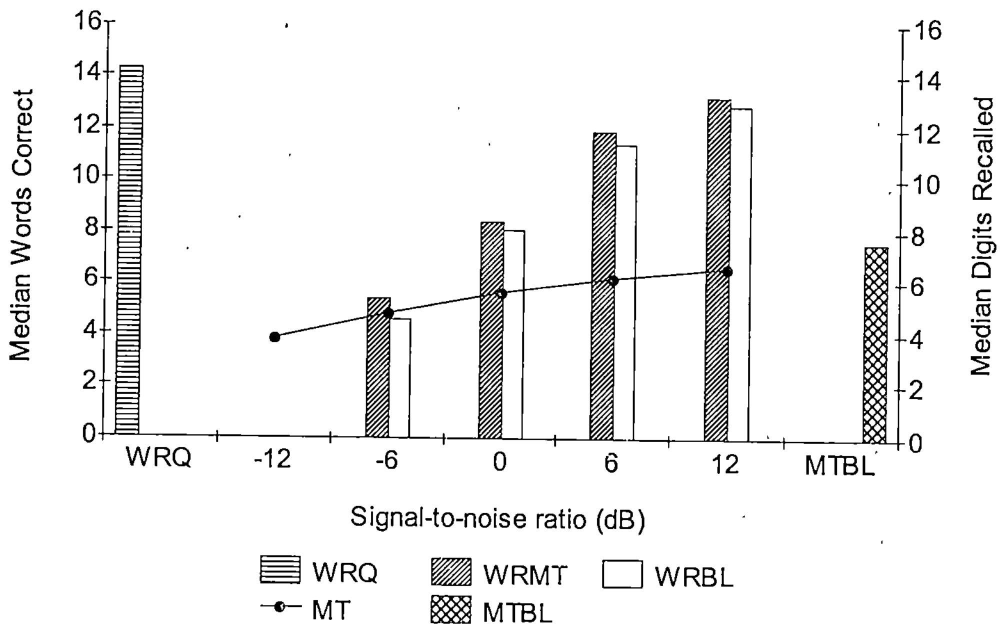
Source	df	F	p
Signal-to-noise ratio (S)	2,56	26.61	.00*
Hearing Status (H)	1,28	1.21	.28
Gender (G)	1,28	2.93	.10
G X H	1,28	1.12	.30
S X H	2,56	0.91	.41
S X G	2,56	0.32	.73

* significant

Trying and Punting Strategies

There was evidence of additional differentiation in listening strategies based on the patterns of change in digit recall as auditory task difficulty increased. Subjects were placed in three response pattern groups: triers, punters, and constant memory focus.

Subjects were classified as triers if they increased their borrowing (measured as a reduction in digit recall) as the difficulty of the listening task increased, even when the listening task was impossible (0% word recognition). There were 11 borrowers who were triers. The 11 triers represented 34% of the total subject population. Five of the triers were males and six were females. Six of the 11 triers (55%) had normal hearing. Mean data for this group are shown in Figure 2. The bar on the left side of the figure is the average median words correct in quiet for the triers. The average median words correct at each signal-to-noise ratio for both baseline and memory task trials are shown by the bar graphs in the center of the figure. The bar graphs indicated that WRMT and WRBL scores declined as the signal-to-noise ratio decreased. Also, for the triers WRBL scores were slightly worse at each signal-to-noise ratio than the WRMT scores. The average median digits recalled is shown by the bar on the right of the figure. The average median digits recalled at each signal-to-noise ratio is represented by the line graph in the center of the figure, superimposed with the bar graphs showing the average median words correct at each signal-to-noise ratio. This line graph shows a decrease in digits recalled with the introduction of noise at a signal-to-noise ratio of +12 dB. On average, digit recall decreased



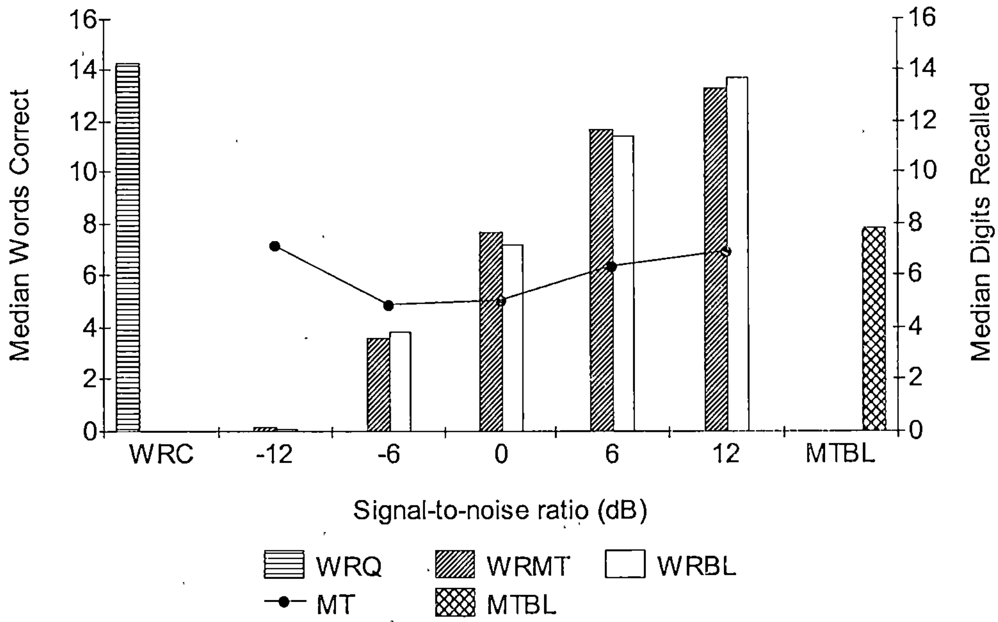
WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

Figure 2: Mean auditory task and memory task results for 11 triers.

from 6.6 digits at a signal-to-noise ratio of +12 dB to 3.8 digits at a signal-to-noise ratio of -12 dB. As the signal-to-noise ratio decreases there is a consistent decrease in the number of digits recalled. This is indicative that more attentional effort was used for the auditory task as the signal-to-noise ratio decreased.

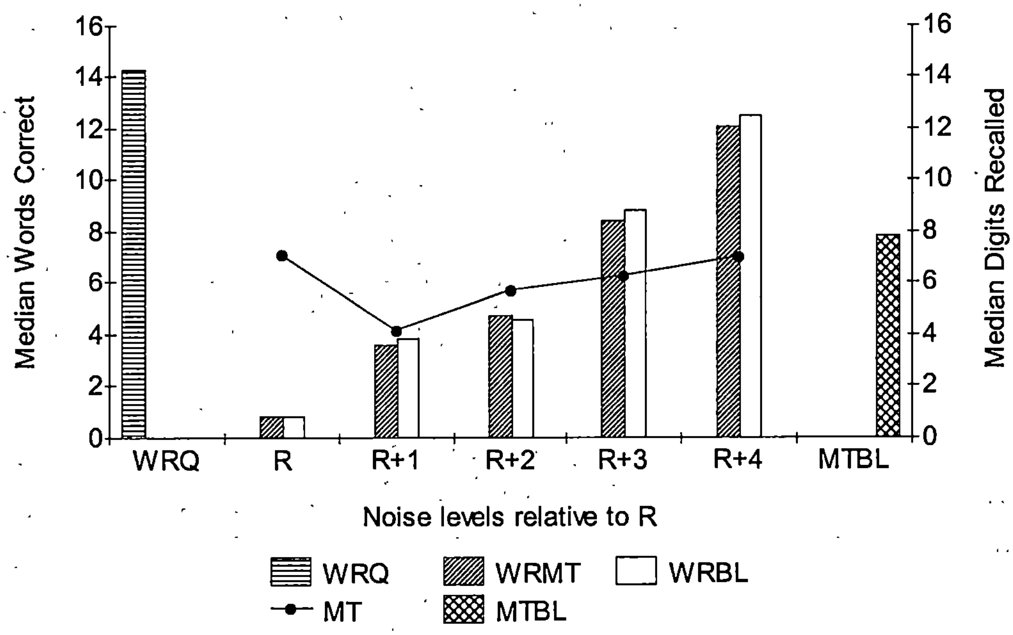
Subjects were classified as punters if they were triers who stopped borrowing (measured as an increase in digit recall) when the listening task became very difficult or impossible. There were 20 punters, representing 63% of the total subject population. Nineteen of the 20 punters were borrowers (95%). The 19 borrowing punters represented 59% of the total subject population. Ten of the 19 borrowing punters were males and 9 were females. Eight of the 19 borrowing punters had normal hearing. Mean data for the 19 punters who were borrowers are shown in Figure 3. Figure 3 is identical in form to Figure 2. The bar graphs at each signal-to-nose ratio again show decreasing average median WRMT and WRBL scores as the signal-to-noise ratio decreased. They also show little difference between average median WRMT and WRBL scores at each signal-to-noise ratio. For 16 borrowing punters, the change in strategy occurred when the WRMT score was 0%, for one subject when the score was 7%, for one subject when the WRMT score was 40%, and for one subject when the WRMT score was 53%. This is represented in Figure 3 as an upturn of the MT function at -12 dB signal-to-nose ratio.

The results of the 19 borrowing punters have been replotted in Figure 4. The abscissa of the figure has been changed to reference digit recall data and WRMT data relative to the change in listening strategy. In Figure 4, "R"



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

Figure 3: Mean auditory task and memory task results for 19 borrowing punters.



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)
R - Signal-to-noise Ratio at Which Reversal Occurred
R+1 - Signal-to-noise Ratio One Level Better Than R
R+2 - Signal-to-noise Ratio Two Levels Better Than R
R+3 - Signal-to-noise Ratio Three Levels Better Than R
R+4 - Signal-to-noise Ratio Four Levels Better Than R

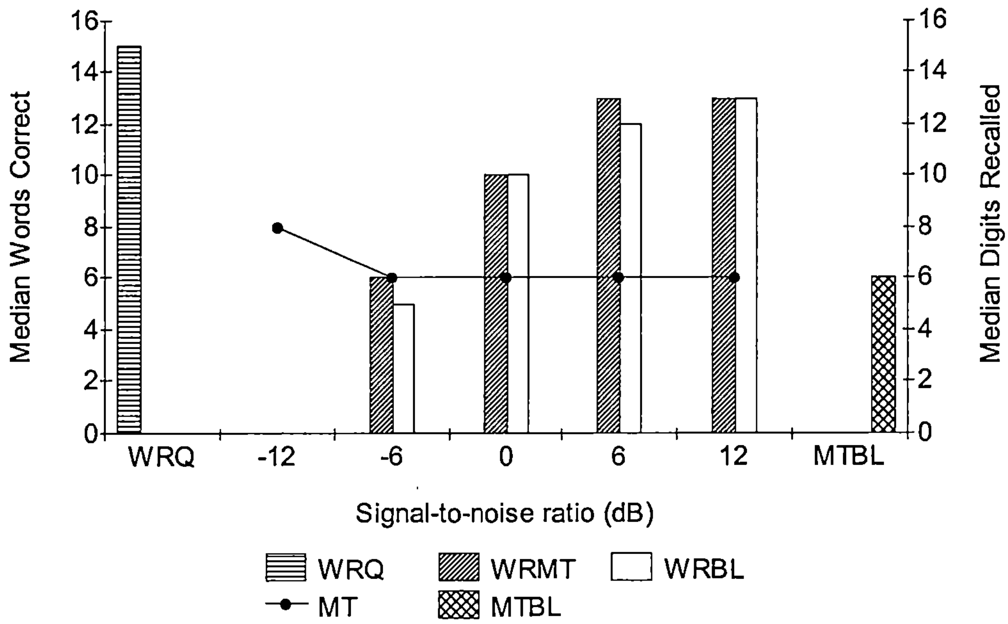
Figure 4: Mean auditory task and memory task results for 19 borrowing punters with data plotted relative to the signal-to-noise ratio at which reversal occurred.

represents the signal-to-noise ratio at which strategy changed from trying to punting. "R+1" represents one signal-to-noise ratio level better than "R", and so on. The presentation of the data in this form normalizes for strategy rather than for signal-to-noise ratio.

There was one subject from the minimal borrower group who was classified as a punter. This subject was a hearing impaired male. This subject's data is shown in Figure 5 and was not included in Figure 3. As can be seen in Figure 5, there was minimal borrowing with the introduction of background noise at +12 dB signal-to-noise ratio. However, unlike the MT results shown in Figures 2 and 3 there was no borrowing as the signal-to-noise ratio decreased. The upturn in MT at -12 dB signal-to-noise ratio is similar to that shown in Figure 3 and indicated a change in listening strategy to punting.

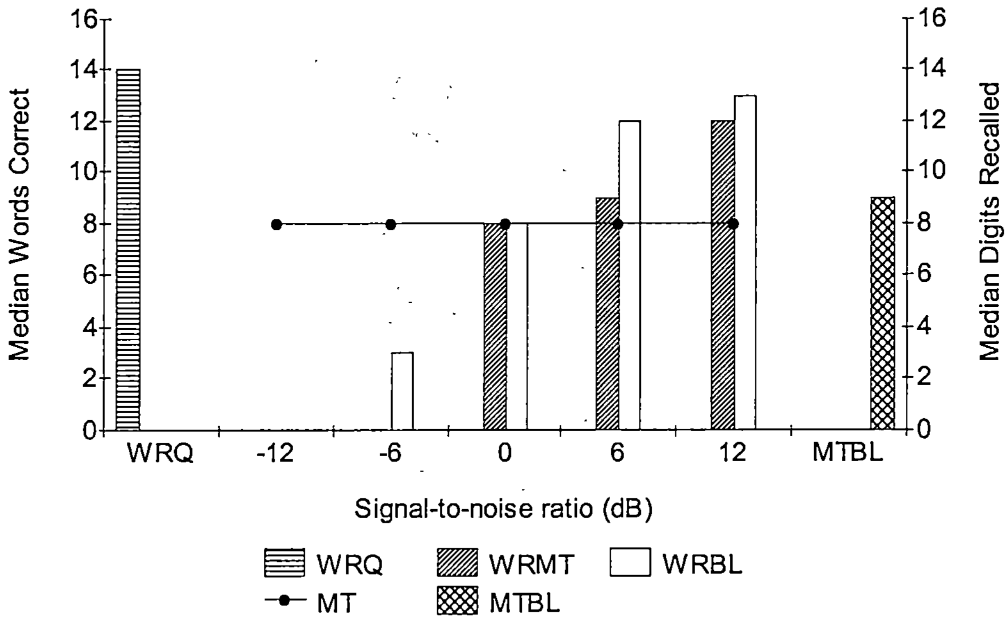
Constant Attention to Memory

One subject from the minimal borrower group had the same high level of digit recall regardless of the difficulty of the auditory task. Since the digit recall did not change with increasing difficulty in the auditory task, these results were interpreted as a constant attention to memory strategy. This subject was a female with normal hearing. The data for this subject are shown in Figure 6. MT scores were slightly poorer than baseline but were high and invariant for all signal-to-noise ratios during WRMT. Almost no space was taken from memory during even the most difficult auditory tasks. An interesting feature of Figure 6 is that the subject's WRMT tended to be worse than the WRBL, particularly at -6 and +6 dB signal-to-noise ratio. This subject was the only subject to show this



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

Figure 5: Auditory task and memory task results for one minimal borrowing punter.



WRQ - Words Correct in Quiet
WRBL - Words Correct in Noise Baseline (no memory task)
WRMT - Words Correct in Noise with Memory Task
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

Figure 6: Auditory task and memory task results for one subject with constant attention to memory.

pattern. These reductions in WRMT were probably a result of the subject placing attention to the memory task rather than the auditory task in the dual-task procedure.

CHAPTER V

Discussion

Discussion of Results

In the formative stages of this study it was expected that individuals would exert more effort to understand speech as the task became more difficult. It was believed that individuals with normal hearing and those with hearing loss would use the same basic strategy as the task become more difficult. However, it was thought to be likely that individuals that were hearing impaired would use more effort to understand speech at all levels of difficulty. The results of this study indicated a more complex difference in strategies used to deal with listening to speech in noise.

In the present study, individuals used two basic strategies to cope with the difficulty of understanding in noise. Most individuals simply applied more effort to the task as the task became more difficult. This strategy was labeled as borrowing. A minority of individuals applied no more attentional effort to a difficult listening task in noise than they did to an easy listening task in noise. This strategy was labeled as minimal borrowing.

When the listening task became very difficult or impossible, there was a diversion of strategies in both cases. At this point most borrowers no longer used attentional effort in listening to the speech in noise. This sub-strategy was labeled as punting. A smaller group of borrowers continued to apply more attentional effort to the task, even when it became impossible. This strategy was labeled as trying.

The two minimal borrowers also used two different strategies when the task became impossible. In one case, attentional effort did not change with changes in task difficulty. This sub-strategy was labeled as constant attention to memory. In a second case, attentional effort did not change as the task became more difficult until the task became impossible. At this point attentional effort decreased. This sub-strategy was also labeled as punting.

Clearly, the majority of the subjects in this study were borrowers - either triers or punters (31/32). If we project these strategies into day-to-day situations, trying would almost assuredly lead to frustration in dealing with noise in verbal communication. In fact, since they do no better understanding speech in noise than the punters, the trying strategy may actually be counterproductive. Triers may be those individuals who clinically present themselves as having a great deal of difficulty communicating when there is background noise. Often this can be attributed to the degree and type of hearing loss, however at other times it appears that the complaint outweighs the severity of the hearing problem. This non-proportional problem with difficult listening situations may be caused by a lack of flexibility in adapting to the situation. These individuals may lack the ability or choose not to use other sensory modalities, such as vision, in dealing with difficult listening situations.

Punters, on the other hand, may be those individuals who perform better in verbal communication in noise than we would expect from their audiometric results. The subjects in this study who demonstrated a willingness to switch attentional effort from one task to another once the primary task became difficult to perform, may be showing flexibility in listening strategies. They may be those individuals who easily use other sensory modalities to assist hearing in difficult listening situations. If true, it would appear that punters would be more receptive to non-verbal aural rehabilitation procedures such as lipreading. Punters, in fact, may be those individuals who appear to be excellent lipreaders without formal training. Of course, this begs the question of whether triers can be trained to be punters or would choose to be punters if given the choice. There is the possibility that the instructions given in this study to do as well as possible on the auditory task may have led some subjects to be triers. If this is true, one has to wonder why almost two-thirds of subjects ignored these instructions.

The change in strategy employed by the punters not only reduced the attentional effort being used on the auditory task, it appears to have eliminated it. The mean number of digits recalled by the punters at the signal-to-noise ratio at which the strategy changed was 6.9 (standard deviation = 0.0). The mean number of digits recalled by the punters at baseline was 7.8 (standard deviation = 1.2). These means were not significantly different as determined by a t-test ($t = 0.001$, $p > 0.01$). It appears that once the strategy change occurs very little, if any, attentional effort is given to the primary task.

The third strategy of constant attention to memory is used by few individuals. The one subject in this study who used this strategy was one of two subjects with normal hearing and a WRMT score of 0% at -6 dB signal-to-noise ratio. The second normal hearing subject (as defined by the SRT) had a significant high frequency hearing loss. This could explain the second subject's WRMT score of 0% at -6 dB signal-to-noise ratio. As for the subject with constant attention to memory, this subject's WRMT score at this signal-to-noise ratio may be explained by the subject's history. It may also give reason to the listening strategy used by the subject. This subject indicated in an informal discussion following testing that she had a learning disorder as a child and had possibly had undiagnosed dyslexia. The strategy demonstrated by this subject in this study may be one learned over time to overcome the childhood learning disorder. By using relatively little attentional effort with even impossible tasks, the subject may be effectively leaving the attentional effort free to be used in a more global way. By doing so, as many input modalities as possible could be used to receive information.

Summary

The two research questions of this study were: 1) does attentional effort increase with increases in the difficulty of the auditory task, and 2) for listening conditions that vary in difficulty, does attentional effort differ for normal and hearing impaired individuals. As to the first question of the study, it appears that for most individuals attentional effort increases with increases in the difficulty of the auditory task up to the point when the task becomes impossible. At that point some individuals stop trying on the auditory task and focus their effort elsewhere. As to the second question of the study, it appears that the majority of both normal hearing and hearing impaired individuals use borrowing strategies to gain additional space for auditory processing. When the task becomes very difficult or impossible about 60% of the borrowers become punters and stop trying. A slightly larger percentage of hearing impaired listeners adopt the punting strategy compared with normal hearing listeners.

Relationship of Results to Previous Research

The present study may have been the first to report on multiple levels of difficulty (changes in signal-to-noise ratios) of an auditory task to evaluate changes in attentional effort. While broad comparisons to other studies are possible, direct comparisons are difficult.

Several researchers (Carhart and Tillman, 1970; Tillman et al, 1970; Jokinen, 1973; Cohen and Keith, 1976; Findlay, 1976; Dirks et al, 1982; Dubno et al, 1984; Plomp, 1986; Beattie, 1989; Wilson et al, 1990) have generally found that hearing impaired individuals were more susceptible to the effects of noise than are normal hearing listeners. This finding is based on speech understanding scores in noise for both groups. In the present study, the hearing impaired subjects also seem to be more susceptible to the effects of noise, missing on average 1.6 words more words at each signal-to-noise ratio than the normal hearing group. One of the unique features of the present study was that attentional effort was also measured with performance on the auditory task. The hearing impaired individuals in this study did not appear to have used significantly more attentional effort than normal hearing individuals. This is somewhat surprising, since intuitively one would expect that hearing impaired listeners would use more attentional effort in listening to speech. The lack of a significant difference in attentional effort between the two groups in the present study may be due to the relatively mild hearing loss of most individuals in the hearing impaired group.

Three studies in the audiologic literature used an attentional effort measurement technique similar to the one used in the present study. Downs and Crum (1978) studied the attentional effort used in auditory learning under adverse listening conditions in normal hearing listeners. They found the only adverse listening condition to cause a significant change in attentional effort was the addition of noise to the signal at a signal-to-noise ratio of +6 dB. This is in agreement with the findings with normal hearing individuals at +6 dB signal-to-noise ratio in the present study.

Feuerstein (1992) studied the difference in attentional effort in normal hearing and simulated unilateral hearing loss while listening to speech in noise. He found a significant difference in attentional effort only when speech was presented to the ear with the simulated hearing loss and noise was presented to normal hearing ear. Unfortunately, Feuerstein did not alter the signal-to-noise ratio from -5 dB signal-to-noise, making a direct comparison of the data impossible.

A third audiologic study (Rakerd et al,1996) investigated the effort required of hearing impaired individuals and normal hearing individuals when they listened to speech. Using a dual-task paradigm, they found that hearing impaired subjects used more attentional effort to gather information from recorded passages. Further, they found that subjects with congenital hearing loss used more attentional effort than those with acquired hearing loss. While these researchers attribute the differences between the congenital and acquired hearing loss groups to a possible central auditory deficit, it is also possible that the difference was due to the fairly large difference in degree of hearing loss between the two groups. The hearing impaired group in the present study did not have the wide range of hearing loss that was present in this study, so a direct comparison of the results was difficult. Also, noise was not a factor in the Rakerd et al, (1996) study.

Future Research

Future research should focus on developing a better understanding of attentional effort as it relates to verbal communication. Developing a better understanding of attentional effort and its relationship to hearing may provide insight to issues ranging from aural rehabilitation to alternative descriptions of auditory processing disorders. Future research should address whether one attentional effort strategy is better for use by hearing impaired individuals. If there is a better strategy, it would be helpful to know if attentional effort strategies can be altered and the possible benefits of doing so. Finally, it would be important to investigate both normal hearing and hearing impaired individuals for the existence of a listening strategy disorder.

REFERENCES

American National Standards Institute. (1989). Specification for Audiometers, ANSI S3.6-1989. American National Standards Institute, New York.

American National Standards Institute. (1991). Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms, ANSI S3.1-1991. American National Standards Institute, New York.

American Speech-Language-Hearing Association. (1978). Guidelines for Manual Pure-tone Audiometry. ASHA, 20, 297-301.

Anderson, C.M.B. and Craik, F.I.M. (1974). The effect of a concurrent task on recall from primary memory. Journal of Verbal Learning and Verbal Behavior, 13, 107-113.

Beattie, R. (1989). Word recognition functions for the CID W-22 Test in multi-talker noise for normally hearing and hearing-impaired subjects. Journal of Speech and Hearing Disorders, 54, 20-32.

Bergman, M. (1980). Aging and the Perception of Speech. Baltimore: University Press.

Bilger, R.C., Nuetzel, J.M., Rabinowitz, W.M., and Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. Journal of Speech and Hearing Research, 27, 32-48.

Broadbent, D.E. (1957) A mechanical model for human attention and immediate memory. Psychological Review, 64, 205-215.

Broadbent, D.E. (1958). Perception and Communication. London: Pergamon.

Broadbent, D.E. (1971). Decision and Stress. London: Academic Press.

Bronkhorst, A.W. and Plomp, R. (1992). Effect of multiple speechlike maskers on binaural speech recognition in normal and impaired hearing. Journal of the Acoustical Society of America, 92, 3132-3139.

Carhart, R.C., Tillman, T.W., and Greetis, E.S. (1969). Perceptual masking in multiple sound backgrounds. Journal of the Acoustical Society of America, 45, 694-703.

Carhart, R.C. and Tillman, T.W. (1970). Interaction of competing speech signals with hearing losses. Archives of Otolaryngology, 91, 273-279.

Cherry, E.C. (1953). Some experiments in the recognition of speech, with one and with two ears. Journal of the Acoustical Society of America, 25, 975-979.

Cohen, R.L. and Keith, R.W. (1976). Use of low-pass noise in word recognition. Journal of Speech and Hearing Research, 19, 48-54.

Cooper, J. and Cutts, B. (1971). Speech discrimination in noise. Journal of Speech and Hearing Research, 14, 332-337.

Cowan, N. (1995) Attention and Memory: An Integrated Framework. New York, New York. Oxford University Press.

Cox, R.M., Alexander, G.C., and Gilmore, C. (1987). Intelligibility of average talkers in typical listening environments. Journal of the Acoustical Society of America, 81, 1598-1608.

Crandell, C.C. (1991). Individual differences in speech recognition ability: implications for hearing aid selection. Ear and Hearing, 12(Suppl), 100S-108S.

Crandell, C.C., Henoch, M.A., and Dunkerson, K.A. (1991). A review of speech perception and aging: some implications for aural rehabilitation. Journal of the Academy of Rehabilitative Audiology, 24, 121-132.

Dirks, D.D., Morgan, D.E., and Dubno, J.R. (1982). A procedure for quantifying the effects of noise on speech recognition. Journal of Speech and Hearing Disorders, 47, 114-123.

Downs, D.W., & Crum, M.A. (1978). Processing demands during auditory listening under degraded listening conditions. Journal of Speech and Hearing Research, 21, 702-714.

Deutsch, J.A. & Deutsch, D. (1963). Attention: Some theoretical considerations. Psychological Review, 70(1), 80-90.

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

Eisenberg, L.S., Dirks, D.D., and Bell, T.S. (1995). Speech Recognition in amplitude-modulated noise of listeners with normal and listeners with impaired hearing. Journal of Speech and Hearing Research, 38, 222-233.

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

Feuerstein, J.F. (1992). Monaural versus binaural hearing: Ease of listening, word recognition, and attentional effort. Ear and Hearing , 13, 80-86.

Findlay, R.C. (1976). Auditory dysfunction accompanying noise-induced hearing loss. Journal of Speech and Hearing Disorders, 41, 374-380.

Findlay, R.C. and Denenburg, L.J. (1977). Effects of subtle mid-frequency auditory dysfunction upon speech discrimination in noise. Audiology, 16, 252-259.

Franks, J.R. and Beckman, N. (1985). Rejection of hearing aids: attitudes of a geriatric sample. Ear and Hearing, 6, 161-167.

French, N.R. and Steinberg, J.C. (1947). Factors governing the intelligibility of speech sounds. Journal of the Acoustical Society of America, 19, 90-119.

Gengel, R.W. and Kupperman, G.I. (1980). Word discrimination in noise: Effect of different speakers. Ear and Hearing, 1, 229-331.

Giard, M.-H., Collet, L., Bouchet, P., and Pernier, J. (1994). Auditory selective attention in the human cochlea. Brain Research, 633, 353-356.

Gordon-Salant, S. (1987). Consonant recognition and confusion patterns among elderly hearing-impaired subjects. Ear and Hearing, 8, 270-276.

Greenwald, A.G. (1972). Evidence of both perceptual filtering and response suppression for rejected messages in selective attention. Journal of Experimental Psychology. 94, 58-67.

Helfer, K.S. and Wilber, L.A. (1990). Hearing loss, aging, and speech perception in reverberation and noise. Journal of Speech and Hearing Research, 33, 149-155.

Humes, L.E. (1991). Understanding the speech-understanding problems of the hearing-impaired. Journal of the American Academy of Audiology, 2, 59-69.

Humes, L.E., Dirks, D.D., Bell, T.S., Ahlstrom C., and Kincaid, G.E. (1986). Application of the articulation index and the speech transmission index to the recognition of speech by hearing-impaired and normal-hearing listeners. Journal Speech and Hearing Research, 29, 447-462.

Humes, L.E., Dirks, D.D., Bell, T.S., and Kincaid, G.E. (1987). Recognition of nonsense syllables by hearing-impaired listeners and by noise-masked normal hearers. Journal of the Acoustical Society of America, 81, 765-773.

Humes, L.E., Espinoza-Varas B., and Watson, C.S. (1988). Modeling sensorineural hearing loss. I. Model and retrospective evaluation. Journal of the Acoustical Society of America, 83, 188-202.

Humes, L.E. and Roberts, L. (1990). Speech-recognition difficulties of the hearing-impaired elderly: the contributions of audibility. Journal of Speech and Hearing Research, 33, 726-735.

Hygge, S., Ronnberg, J., Larsby, B., and Arlinger, S. (1992). Normal-hearing and hearing-impaired subjects' ability to just follow conversation in competing speech, reversed speech, and noise backgrounds. Journal Speech and Hearing Research, 35, 208-215.

Irwin, R.J. and McAuley, S.F. (1987). Relations among temporal acuity, hearing loss, and the perception of speech distorted by noise and reverberation. Journal of the Acoustical Society of America, 81, 1557-1565.

Jerger, J. (1973). Audiological findings in aging. Advances in Oto-Rhino-Laryngology, 20, 115-124.

Johnson, W.A. and Heinz, S.P. (1978). Flexibility and capacity demands of attention. Journal of Experimental Psychology: General. 107(4), 420-435.

Jokinen, K. (1973). Presbycusis VI. Masking of speech. Acta Oto-Laryngologica, 76, 426-430.

Kahneman, D., Peavler, W.S., and Onuska, L. (1968). Effects of verbalization and incentive on the pupil response to mental activity. Canadian Journal of Experimental Psychology, 22, 186-196.

Kahneman, D. (1973). Attention and Effort. Englewood Cliffs, NJ: Prentice-Hall.

Kamm, C.A., Dirks, D.D., and Bell, T.S. (1985). Speech recognition and the Articulation Index for normal and hearing-impaired listeners. Journal of the Acoustical Society of America, 77, 281-288.

Kapteyn, T.S. (1977). Satisfaction with fitted hearing aids. I. An analysis of technical information and II. An investigation into the influence of psycho-social factors. Scandinavian Audiology, 6, 147-177.

Kasden, S.D. (1970). Speech discrimination in two age groups matched for hearing loss. Journal of Auditory Research, 10, 210-212.

Keele, S.W. (1973). Attention and Human Performance. Pacific Palisades, CA: Goodyear Publishing Company, Inc.

Keith, R. and Talis, H. (1972). The effects of white noise on PB scores of normal-hearing and hearing-impaired listeners. Audiology, 11, 177-186.

Kelley, N.H. (1939). A study in presbycusis. Auditory loss with increasing age and its effect on the perception of music and speech. Archives of Otolaryngology, 29, 506-513.

Kennedy, E. (1997). Circuitry options: signal processing under adverse listening conditions. In Tobin, H., Ed. Practical Hearing Aid Selection and Fitting. Baltimore: Rehabilitation Research and Development Service, Department of Veteran Affairs, 35-47.

Kryter, K.D. (1988). Definitions: Presbycusis, sociocusis, and nosiocusis. The Aging Ear (conference), St. Louis.

Levitt, H., Mayer, C., and Bergman, M. (1975). Criteria for ambient noise zone quality standards. In M. Bergman (Ed.), Aging and the Perception of Speech, Baltimore: University Park Press.

Luce, P.A., Feustel, T.C., & Pisoni, D.B. (1983). Capacity demands in short-term memory for synthetic and natural word lists. Human Factors, 25, 17-32.

Marshall, L. and Bacon, S.P. (1981). Prediction of speech discrimination scores from audiometric data. Ear and Hearing, 2, 148-155.

Miller, G.A. and Nicely, P.A. (1955). An analysis of perceptual confusions among some English consonants. Journal of the Acoustical Society of America, 27, 338-352.

Moray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. Quarterly Journal of Experimental Psychology, 11, 56-60.

Moray, N. and O'Brien, T. (1967). Signal-detection theory applied to selective listening. Journal of the Acoustical Society of America, 42, 765-772.

Nabelek, A.K. (1988). Identification of vowels in quiet, noise, and reverberation: Relationships with age and hearing loss. Journal of the Acoustical Society of America, 84, 476-484.

Nabelek, A.K. and Pickett, J.M. (1974). Monaural and binaural speech perception through hearing aids under noise and reverberation with normal and hearing-impaired listeners. Journal of Speech and Hearing Research, 17, 724-739.

Nabelek, A.K. and Dagenais, P.A. (1986). Vowels in noise and in reverberation by hearing-impaired listeners. Journal of the Acoustical Society of America, 80, 741-748.

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

Nabelek, A.K. and Nabelek, I.V. (1994). Room acoustics and speech perception. In Katz, J., Ed. Handbook of Clinical Audiology Fourth Edition. Baltimore: Williams & Wilkins, 624-637.

Needleman, A.R. and Crandell, C.C. (1995). Speech recognition in noise by hearing-impaired and noise-masked normal-hearing listeners. Journal of the American Academy of Audiology, 6, 414-424.

Norman, D.A. (1968). Toward a theory of memory and attention. Psychological Review, 75, 522-536.

Norman, D.A., & Bobrow, D.G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Orchik, D.J. and Burgess, J. (1977). Synthetic sentence identification as a function of age of the listener. Journal of the American Audiological Society, 3, 42-44.

Payton, K.L., Uchanski, R.M., and Braida, L.D. (1994). Intelligibility of conversational and clear speech in noise and reverberation for listeners with normal and impaired hearing. Journal of the Acoustical Society of America, 95, 1581-1592.

Pekkarinen, E., Salmivalli, A., and Suonpaa, J. (1990). Effect of noise on word discrimination by subjects with impaired hearing, compared with those with normal hearing. Scandinavian Audiology, 19, 31-36.

Pestalozza, G. and Shore, J. (1955). Clinical evaluation of presbycusis on the basis of different tests of auditory function. Laryngoscope, 65, 1136-1163.

Pichney, M.A., Durlach, N.I., and Braida. L.D. (1985). Speaking clearly for the hard of hearing I: Intelligibility differences between clear and conversational speech. Journal of Speech and Hearing Research, 28, 96-103.

Picket, J.M. (1957). Perception of vowels heard in noises of various spectra. Journal of the Acoustical Society of America, 29, 613-620.

Plomp, R. (1986). A signal-to-noise ratio model for the speech-reception threshold of the hearing impaired. Journal of Speech and Hearing Research, 29, 146-154.

Rakerd, B., Seitz, P.F., & Whearty, M. (1996). Assessing the cognitive demands of speech listening for people with hearing losses. Ear and Hearing, 17, 97-106.

Smith, R.A. and Prather, W.F. (1971). Phoneme discrimination in older persons under varying signal-to-noise conditions. Journal of Speech and Hearing Research, 14, 630-638.

Souza, P.E. and Turner, C.W. (1994). Masking of speech in young and elderly listeners with hearing loss. Journal of Speech and Hearing Research, 37, 655-661.

Spieth, W., Curtis, J.F., and Webster, J.C. (1954). Responding to one of two simultaneous messages. Journal of the Acoustical Society of America, 26, 391-396.

Summerfield, Q. (1987). Speech perception in normal and impaired hearing. British Medical Journal, 43, 909-925.

Surr, R.K. (1977). Effect of age on clinical hearing aid evaluation results. Journal of the American Audiological Society, 3, 1-5.

Surr, R.K., Schuchman, G.I., and Montgomery, A.A. (1978). Factors influencing use of hearing aids. Archives of Otolaryngology, 104, 723-736.

Suter, A. (1985). Speech recognition in noise by individuals with mild hearing impairments. Journal of the Acoustical Society of America, 78, 887-900.

Thibodeau, L.M. (1996). Evaluation of auditory enhancement and auditory suppression in listeners with normal hearing and reduced speech recognition in noise. Journal Speech and Hearing Research, 39, 947-956.

Tillman, T. and Carhart, R. (1966). An expanded test for speech discrimination utilizing CNC monosyllablic words. Northwestern University Auditory Test No. 6. USAF School of Aerospace Medicine Technical Report. Brooks Air Force Base, Texas.

Tillman, T.W., Carhart, R., and Olsen, W.O. (1970). Hearing aid efficiency in a competing speech situation. Journal of Speech and Hearing Research, 13, 789-811.

Trees, D. and Turner, C. (1986). Spread of masking in normal subjects and subjects with high-frequency hearing loss. Audiology, 25, 70-83.

Treisman, A.M. (1964). Monitoring and storage of irrelevant messages in selective attention. Journal of Verbal Learning and Verbal Behavior, 3, 449-459.

Treisman, A.M. and Geffen, G. (1967). Selective attention: perception or response? Quarterly Journal of Experimental Psychology, 19, 1-17.

Turner, C.W., Holte, L.A., and Relkin, E. (1987). Auditory filtering and the discrimination of spectral shapes by normal and hearing-impaired subjects. Journal of Rehabilitation Research and Development, 24, 229-238.

Tyler, R.S. (1988). Signal processing techniques to reduce the effects of impaired frequency resolution. Hearing Journal, 41, 34-47.

Underwood, G. and Moray, N. (1971). Shadowing and monitoring for selective attention. Quarterly Journal of Experimental Psychology, 23, 284-295.

van Rooj, J.C.G.M. and Plomp, R. (1991). Auditive and cognitive factors in speech perception by elderly listeners. II: multivariate analyses. Journal of the Acoustical Society of America, 88, 2611-2624.

Wickens, C.D. (1987). Information processing, decision making, and cognition. In G. Salvendy (Ed.), Handbook of Human Factors. New York: Wiley Interscience.

Wilson, R.H., Zizz, C.A., Shanks, J.E., and Causey, G. (1990). Normative data in quiet, broadband noise, and competing message for Northwestern University Auditory Test No. 6 by a female speaker. Journal of Speech and Hearing Disorders, 55, 771-778.

Woldorff, M.G., Hackley, S.A., and Hillyard, S.A. (1991). The effects of channel-selective attention on the mismatch negativity wave elicited by deviant tones. Psychophysiology, 28, 30-42.

Woldorff, M.G., Gallen, C.C., Hampson, S.A., Hillyard, S.A., Pantev, C., Sobel, D., and Bloom, F.E. (1993). Modulation of early sensory processing in human auditory cortex. Proceedings of the National Academy of Science, 90, 8722-8726.

APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

INFORMED CONSENT FOR A RESEARCH PROJECT ENTITLED
"Effects of Hearing Loss on Attentional Effort During Listening Tasks"

PROJECT DESCRIPTION

You are being asked to participate in an experimental study aimed at evaluating the effects of the difficulty of listening tasks on attentional effort in normal hearing and hearing impaired subjects. The results or this study will be included in a dissertation by Robert E. Moore. Should you agree to participate, the test session will not exceed three hours.

Before the study, you will be given a hearing test (routine audiometry) to determine if your hearing is normal (15 dB HL or better speech reception threshold) or abnormal (20 dB HL or greater speech reception threshold). This testing will be performed in a sound treated room. You will be provided with the results of the hearing test.

Following the hearing test, you will be asked to memorize a list of numbers for 15-seconds. After an 65-second retention period, during which you will listen to noise at a comfortable level, you will be asked to recall the numbers in order. This will be repeated two more times. This portion of the study will be the memory task.

After the memory task, you will be asked to repeat words presented in quiet and presented with noise competition (several people talking at once). The words will be presented at a comfortable level, as judged by you. The level of the noise competition will be varied as it relates to the presentation level of the words. This portion of the study will be the listening task.

Following the listening task, you will again be asked to memorize a list of numbers for 15-seconds. During the 65-second retention period you will be asked to repeat words presented in noise as you did during the listening task. Again, at the end of the 65-second retention period you will be asked to recall the numbers in order. These procedures will be repeated fourteen times. This portion of the study will be the dual-task.

The above procedures are routine clinical procedures which offer no known health risks. Regardless, every effort will be made to minimize any potential risk or discomfort. Rest periods will be given as you desire. The only benefit you will receive from your participation in this study will be a free hearing test. However, you will contribute to our understanding of the relationship of hearing loss, listening difficulty, and attentional effort.

CONFIDENTIALITY

Any information obtained about you for this study will be kept strictly confidential. Confidentiality of your data as well as any identifying material will be protected by limiting access to only the Principle Investigator and his Advisor. Your identity will not be revealed in any description or publication of this research. This consent form will be stored for three years following completion of the study at a secured location at the University of Tennessee.

RIGHT TO REFUSE OR TO END PARTICIPATION

Your are free to refuse to participate in this study or to withdraw at any time without having it affect your care in any of the University of Tennessee Clinics or the Baptist Ear Center. You will suffer no loss of benefits to which you are otherwise entitled.

VOLUNTARY CONSENT

I have read the above information, and the Principal Investigator has explained the procedures and answered all my questions concerning this project. It has been explained to me that my identity will not be revealed in any description or publication of this research. Therefore, I consent to such publication for scientific purposes.

Any questions I have concerning my rights as a research subject will be answered by Robert E. Moore, the Principle Investigator at the Baptist Ear Center (632-5995), or by Dr. J.W. Thelin, the Advisor, at 457 South Stadium Hall (974-1796).

My signature below means that I have had all my questions answered and freely agree to participate in the experimental study.

Signature of the subject: ______________________ Date: ______________

INVESTIGATOR'S CERTIFICATION

I certify that I have explained to the above individual the nature and purpose, the potential benefits, and the possible risks associated with participating in this experimental study. I have answered any questions that have been raised, and have witnessed the above signature.

Signature of Investigator: ______________________ Date: ______________

APPENDIX B

SAMPLE DIGIT LIST

59026813729481692

APPENDIX C

SUBJECT DATA SHEETS AND CHARTS

DATA SHEET SUBJECT 1

Gender: Female **Age:** 57 **Test Ear:** Right **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	15	15	10	15	25	25	40	10	50
LE	15	10	10	15	25	30	30	25	10	

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	8	9	13	14
Trial 2:	15	-	0	3	11	11	15
Trial 3:	14	-	0	6	10	11	13
Median:	15	-	0	6	10	11	14

Words Correct With Memory Task at Each Signal/Noise Ratio

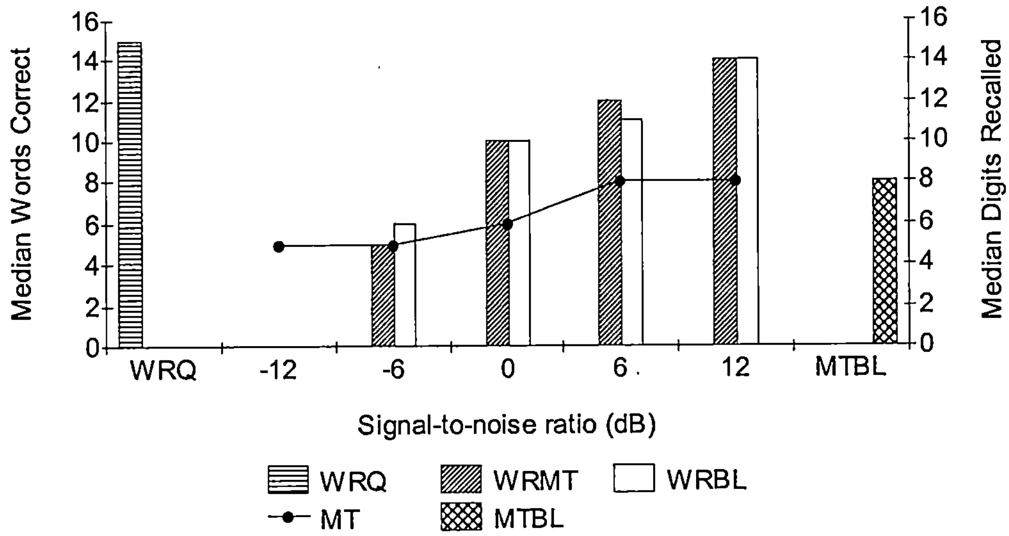
	-15	-12	-6	0	+6	+12
Trial 1:	-	0	8	10	12	13
Trial 2:	-	0	3	8	12	14
Trial 3:	-	0	5	10	12	14
Median:	-	0	5	10	12	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	7	-	5	10	4	8	5
Trial 2:	9	-	2	5	8	8	8
Trial 3:	8	-	7	5	6	8	8
Median:	8	-	5	5	6	8	8

Subject 1

Female, Normal Hearing



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 2

Gender: Female **Age:** 58 **Test Ear:** Left **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	35	20	15	15	10	30	35	55	20	
LE	25	20	15	25	30	40	50	60	25	60

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	5	7	14	15
Trial 2:	15	-	0	4	7	14	14
Trial 3:	15	-	0	10	7	12	15
Median:	15	-	0	5	7	14	15

Words Correct With Memory Task at Each Signal/Noise Ratio

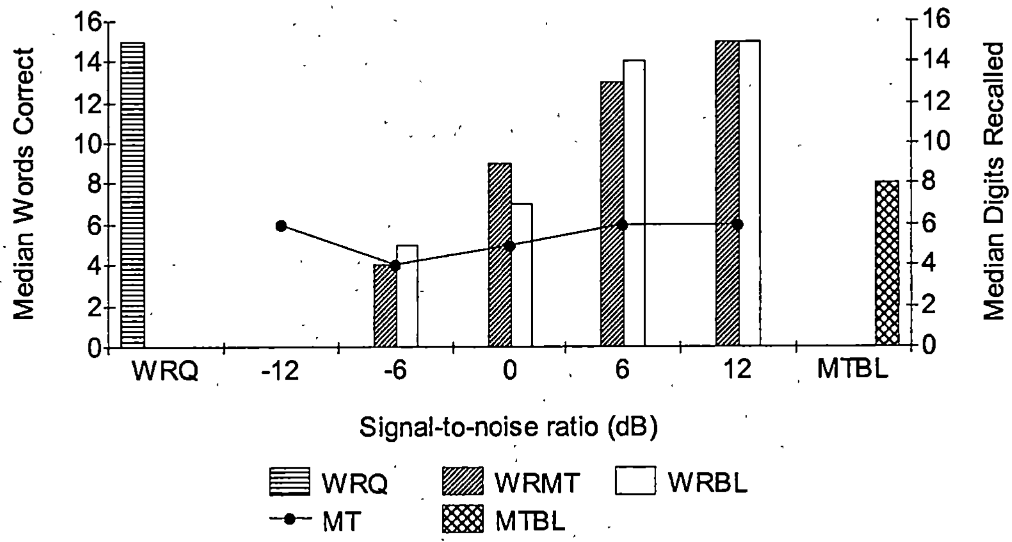
	-15	-12	-6	0	+6	+12
Trial 1:	-	0	4	7	12	14
Trial 2:	-	0	7	9	13	15
Trial 3:	-	0	4	9	15	15
Median:	-	0	4	9	13	15

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	-	4	5	5	6	3
Trial 2:	8	-	6	2	4	4	8
Trial 3:	6	-	6	4	9	9	6
Median:	8	-	6	4	5	6	6

Subject 2

Female, Hearing Loss



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 3

Gender: Male **Age:** 58 **Test Ear:** Right **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	15	15	10	35	55	75	90	15	55
LE	15	20	20	35	50	50	80	75	15	

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	5	11	10	12
Trial 2	14	-	0	9	6	11	13
Trial 3:	15	-	0	5	6	13	13
Median:	14	-	0	5	6	11	13

Words Correct With Memory Task at Each Signal/Noise Ratio

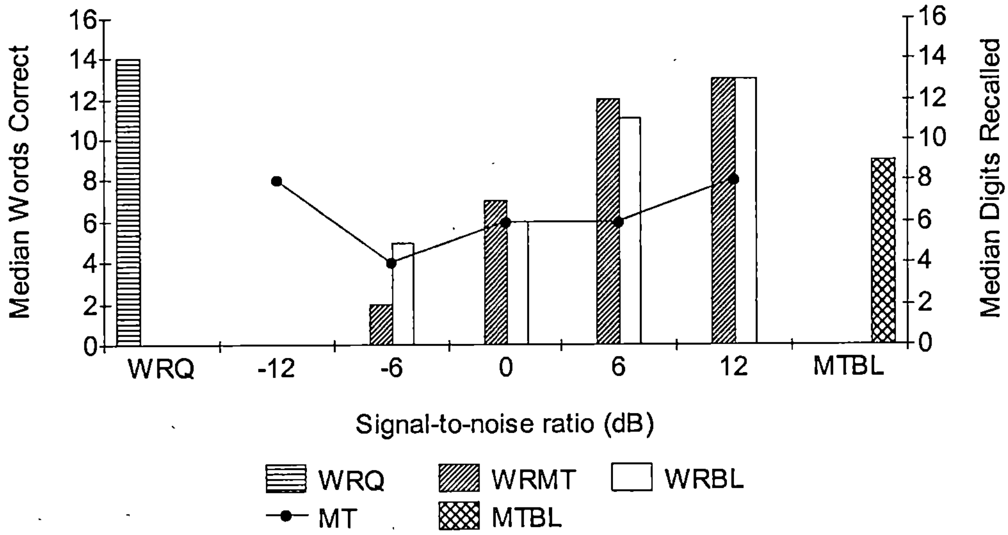
	-15	-12	-6	0	+6	+12
Trial 1:	-	0	2	4	15	14
Trial 2:	-	0	2	7	12	13
Trial 3:	-	0	2	7	9	13
Median:	-	0	2	7	12	13

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	10	-	8	9	9	5	10
Trial 2:	5	-	7	4	6	8	6
Trial 3:	9	-	8	3	6	6	8
Median:	9	-	8	4	6	6	8

Subject 3

Male, Normal Hearing



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 4

Gender: Female **Age:** 58 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	15	5	10	10	15	5	20	40	15	
LE	15	5	5	10	15	10	15	25	10	50

Baseline Words Correct at Each Signal/Noise Ratio

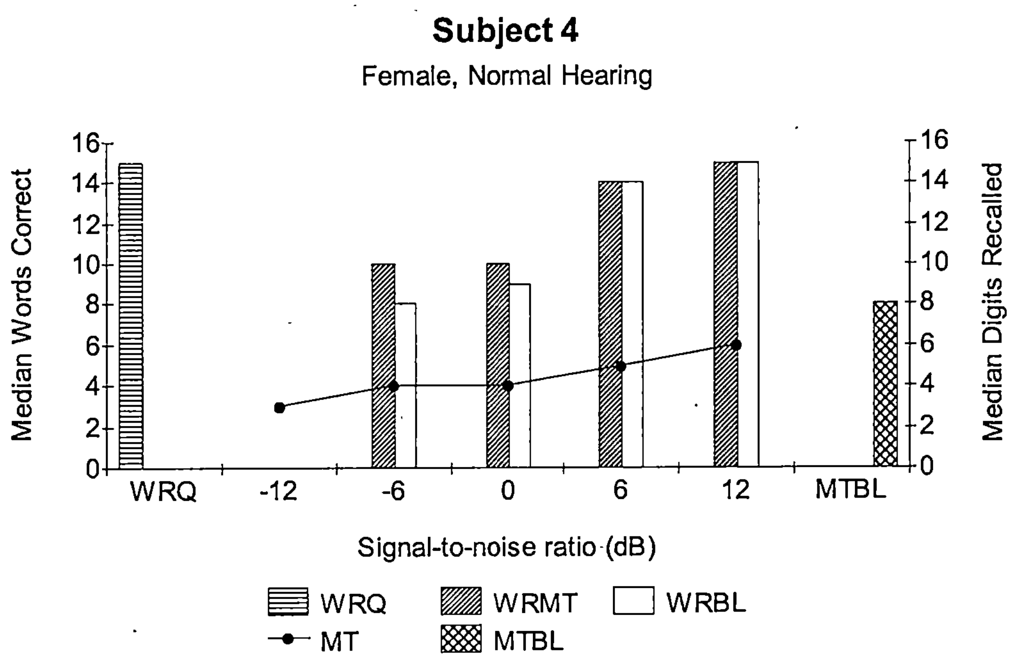
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	3	8	9	14	15
Trial 2:	13	-	0	9	10	14	14
Trial 3:	15	-	0	6	9	15	15
Median:	15	-	0	8	9	14	15

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	11	10	14	15
Trial 2:	-	3	10	10	13	14
Trial 3:	-	0	6	10	15	15
Median:	-	0	10	10	14	15

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	9	-	6	4	8	5	4
Trial 2:	6	-	0	4	3	5	6
Trial 3:	8	-	3	6	4	9	7
Median:	8	-	3	4	4	5	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 5

Gender: Male **Age:** 53 **Test Ear:** Left **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	5	0	5	35	35	40	45	15	
LE	5	10	15	35	30	35	40	45	25	60

Baseline Words Correct at Each Signal/Noise Ratio

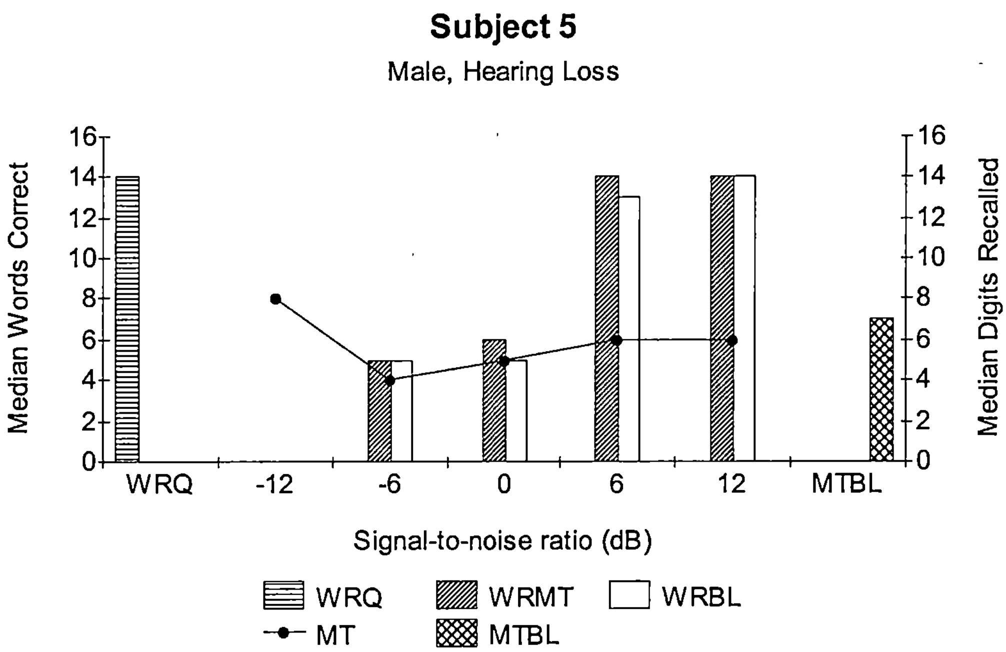
	Quiet	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	14	-	0	5	4	14	15
Trial 2:	14	-	0	5	9	13	14
Trial 3:	15	-	0	6	5	13	14
Median:	14	-	0	5	5	13	14

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	-	0	6	8	15	14
Trial 2:	-	0	4	6	13	15
Trial 3:	-	0	5	6	14	14
Median:	-	0	5	6	14	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	9	-	9	8	2	9	6
Trial 2:	7	-	8	2	8	6	5
Trial 3:	5	-	5	4	5	6	9
Median:	7	-	8	4	5	6	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 6

Gender: Male **Age:** 55 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	25	10	10	10	5	20	15	10	5	
LE	15	10	5	0	10	25	15	15	5	45

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	11	7	10	13
Trial 2:	15	-	0	6	10	12	13
Trial 3:	15	-	0	7	8	11	15
Median:	15	-	0	7	8	11	13

Words Correct With Memory Task at Each Signal/Noise Ratio

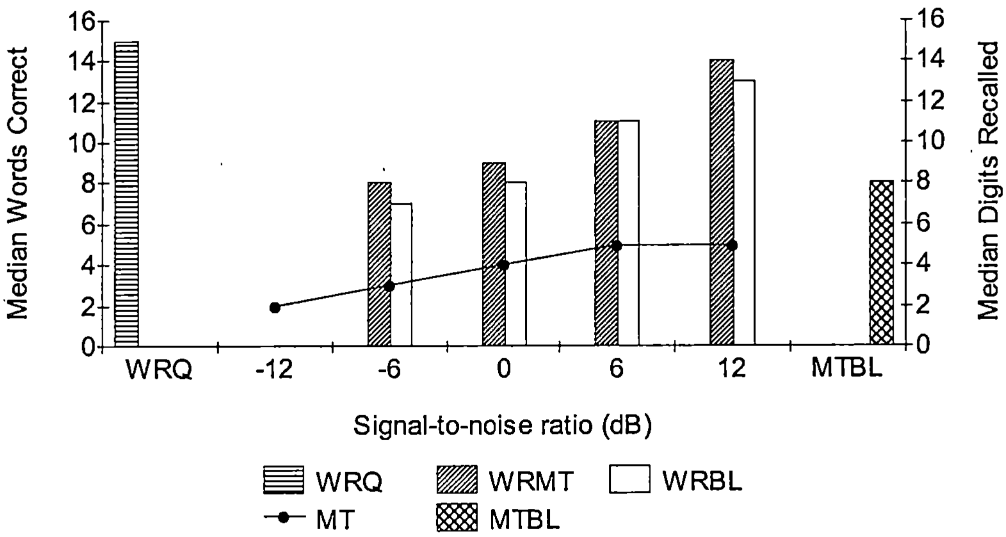
	-15	-12	-6	0	+6	+12
Trial 1:	-	0	8	7	11	14
Trial 2:	-	0	8	10	12	14
Trial 3:	-	0	7	9	11	14
Median:	-	0	8	9	11	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	6	-	5	3	2	7	5
Trial 2:	8	-	2	2	6	4	9
Trial 3:	9	-	2	5	4	5	5
Median:	8	-	2	3	4	5	5

Subject 6

Male, Normal Hearing



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 7

Gender: Female **Age:** 55 **Test Ear:** Right **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	15	15	5	5	5	20	25	25	15	55
LE	5	10	5	0	15	25	20	10	15	

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	2	7	11	11	14
Trial 2:	15	-	0	10	7	14	15
Trial 3:	15	-	0	8	8	12	12
Median:	15	-	0	8	8	12	14

Words Correct With Memory Task at Each Signal/Noise Ratio

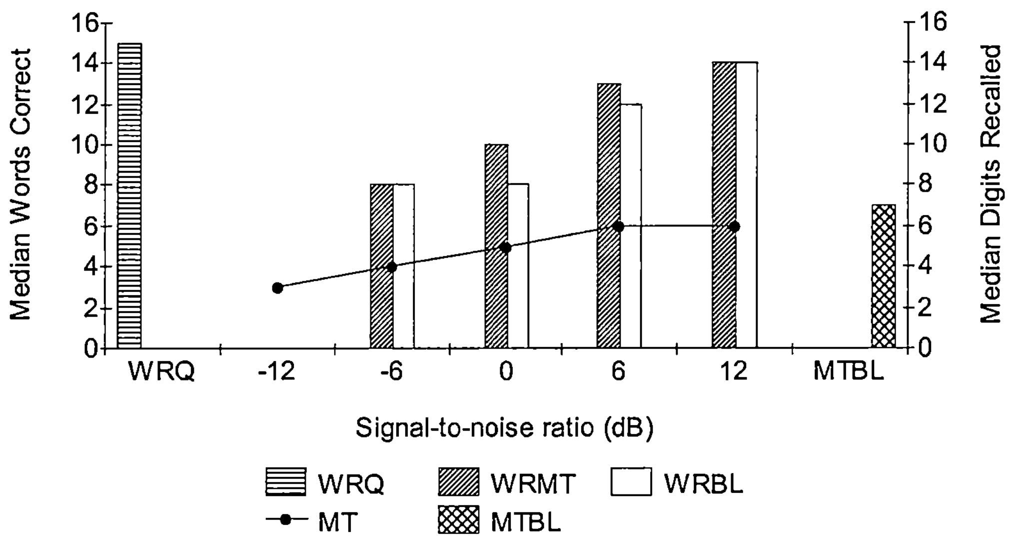
	-15	-12	-6	0	+6	+12
Trial 1:	-	0	5	7	13	14
Trial 2:	-	0	9	10	13	15
Trial 3:	-	0	8	12	12	13
Median:	-	0	8	10	13	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	-	7	4	8	5	3
Trial 2:	7	-	1	7	5	6	6
Trial 3:	7	-	3	2	3	7	7
Median:	7	-	3	4	5	6	6

Subject 7

Female, Normal Hearing



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 8

Gender: Female **Age:** 56 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	10	15	10	5	10	30	25	15	
LE	15	5	5	5	10	10	25	15	10	50

Baseline Words Correct at Each Signal/Noise Ratio

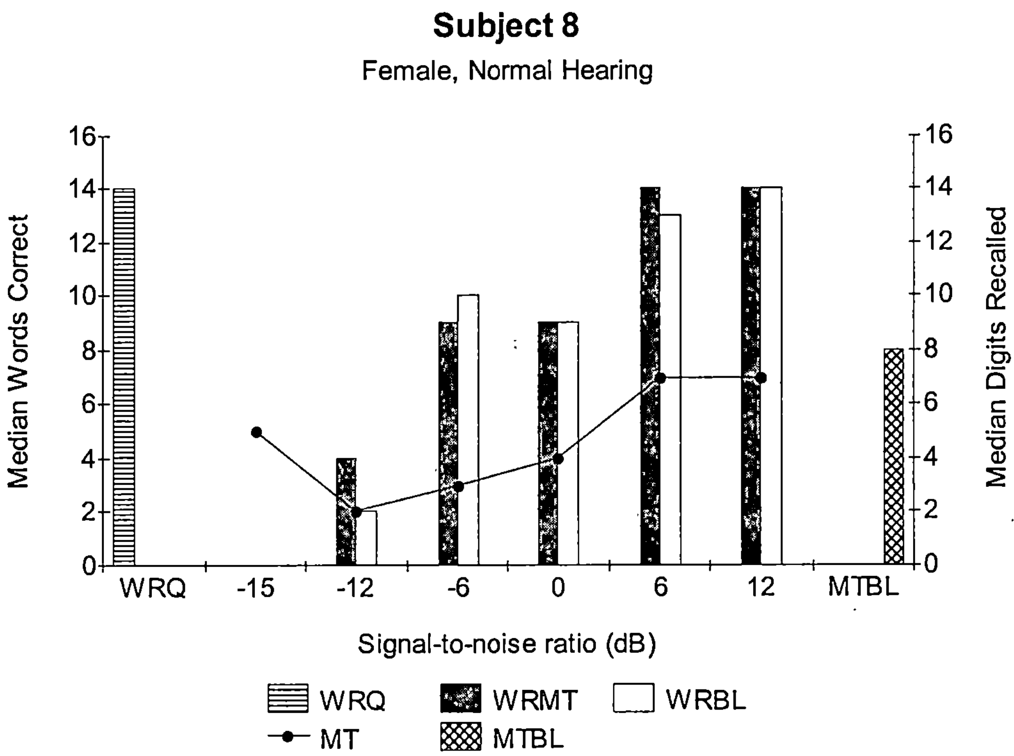
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	0	9	10	9	11	14
Trial 2:	14	0	2	11	9	13	14
Trial 3:	15	0	1	7	11	15	15
Median:	14	0	2	10	9	13	14

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	0	1	7	9	12	15
Trial 2:	0	4	10	9	14	14
Trial 3:	0	5	9	10	14	14
Median:	0	4	9	9	14	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	5	2	6	4	7	7
Trial 2:	6	4	2	2	8	6	7
Trial 3:	9	6	6	3	4	9	6
Median:	8	5	2	3	4	7	7



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 9

Gender: Female **Age:** 59**Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	15	30	45	50	55	40	30	35	65
LE	15	15	25	30	35	35	40	45	25	

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	3	5	10	14
Trial 2:	15	-	0	2	10	11	12
Trial 3:	15	-	0	2	2	11	15
Median:	15	-	0	2	5	11	14

Words Correct With Memory Task at Each Signal/Noise Ratio

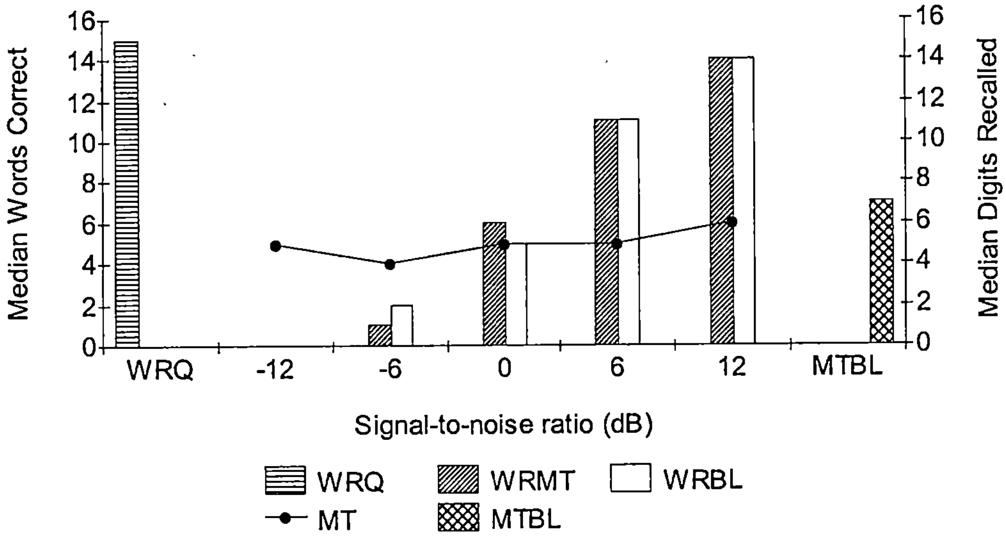
	-15	-12	-6	0	+6	+12
Trial 1:	-	0	1	5	11	14
Trial 2:	-	0	4	7	11	15
Trial 3:	-	0	1	6	12	13
Median:	-	0	1	6	11	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	7	-	5	4	3	9	6
Trial 2:	9	-	8	3	9	5	6
Trial 3:	6	-	2	7	5	5	6
Median:	7	-	5	4	5	5	6

Subject 9

Female, Hearing Loss



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 10

Gender: Female **Age:** 55 **Test Ear:** Left **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	15	15	15	10	25	25	35	35	15	
LE	15	20	25	35	35	35	30	25	30	70

Baseline Words Correct at Each Signal/Noise Ratio

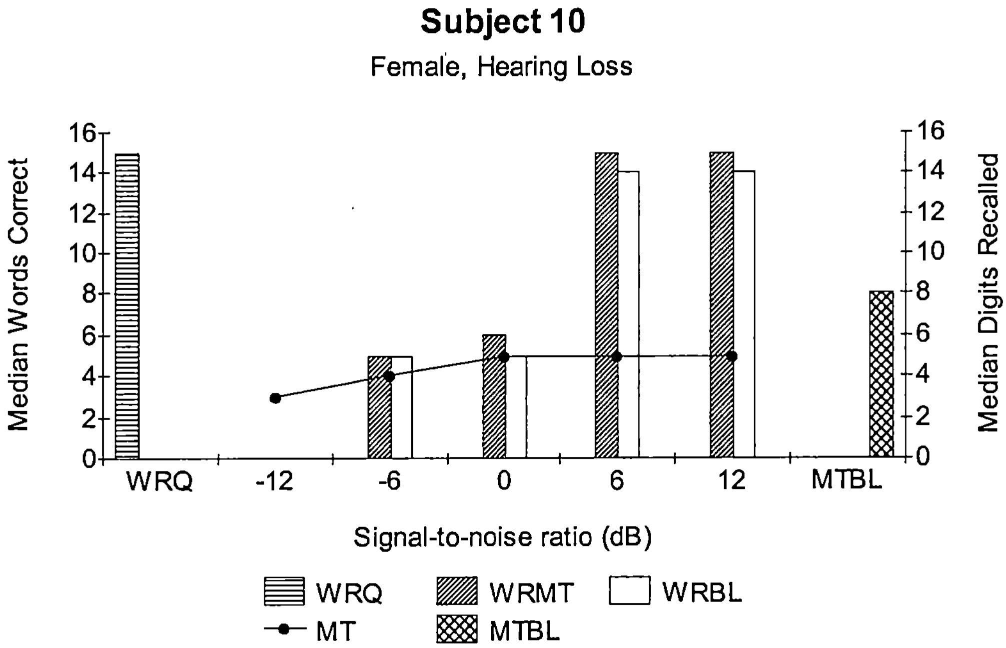
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	8	5	14	15
Trial 2:	15	-	0	0	7	14	14
Trial 3:	15	-	0	5	5	14	13
Median:	15	-	0	5	5	14	14

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	5	6	12	13
Trial 2:	-	0	3	6	15	15
Trial 3:	-	0	5	7	15	15
Median:	-	0	5	6	15	15

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	-	7	4	4	6	5
Trial 2:	8	-	3	4	5	5	8
Trial 3:	6	-	1	7	6	3	5
Median:	8	-	3	4	5	5	5



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 11

Gender: Female **Age:** 51 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	30	20	15	15	20	10	20	20	15	
LE	25	10	10	15	20	15	20	25	10	50

Baseline Words Correct at Each Signal/Noise Ratio

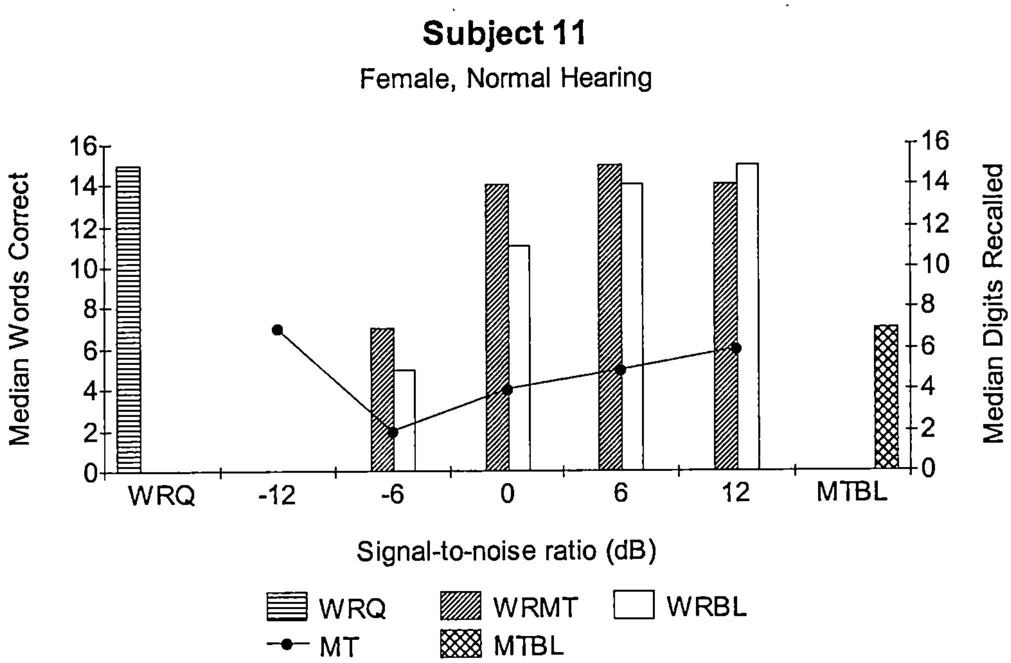
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	1	4	11	14	15
Trial 2:	15	-	0	10	11	15	15
Trial 3:	15	-	0	5	13	13	14
Median:	15	-	0	5	11	14	15

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	8	13	15	14
Trial 2:	-	1	6	14	13	14
Trial 3:	-	0	7	14	15	15
Median:	-	0	7	14	15	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	7	-	8	2	3	8	6
Trial 2:	7	-	7	1	6	4	5
Trial 3:	6	-	7	6	4	5	6
Median:	7	-	7	2	4	5	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 12

Gender: Female **Age:** 55 **Test Ear:** Left **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	15	15	25	20	25	25	20	15	15	
LE	15	15	20	30	35	30	25	25	25	65

Baseline Words Correct at Each Signal/Noise Ratio

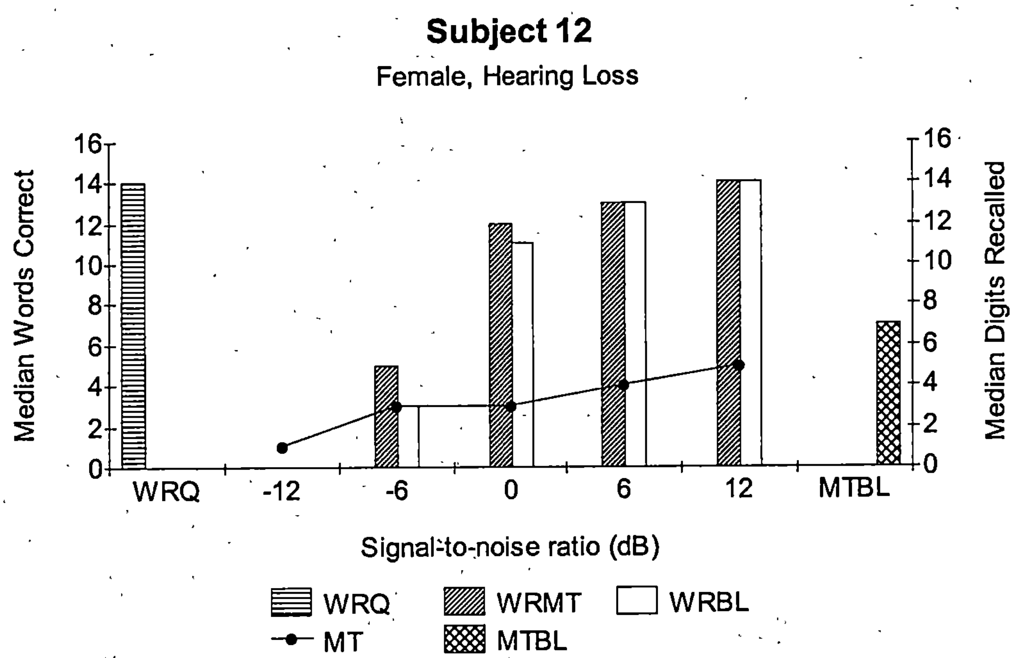
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	8	9	13	15
Trial 2:	14	-	0	2	11	13	14
Trial 3:	14	-	0	3	11	13	12
Median:	14	-	0	3	11	13	14

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	5	12	13	14
Trial 2:	-	0	2	10	13	15
Trial 3:	-	0	5	12	12	14
Median:	-	0	5	12	13	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	-	1	5	3	8	5
Trial 2:	7	-	0	3	5	4	3
Trial 3:	5	-	1	2	3	4	7
Median:	7	-	1	3	3	4	5



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 13

Gender: Female **Age:** 55**Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	15	30	25	30	35	40	45	25	60
LE	10	15	10	25	25	30	35	40	15	

Baseline Words Correct at Each Signal/Noise Ratio

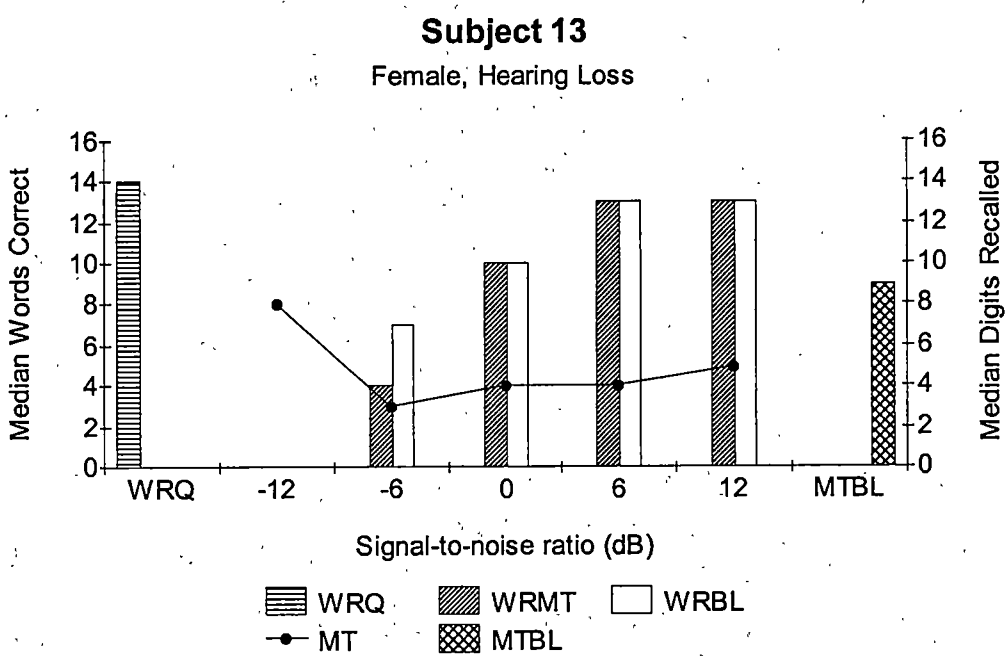
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	7	13	12	13
Trial 2:	14	-	0	7	10	14	13
Trial 3:	14	-	0	5	9	13	14
Median:	14	-	0	7	10	13	13

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	4	12	10	13
Trial 2:	-	0	4	8	13	15
Trial 3:	-	0	7	10	13	13
Median:	-	0	4	10	13	13

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	13	-	9	2	4	8	3
Trial 2:	9	-	5	3	9	4	9
Trial 3:	5	-	8	6	2	3	5
Median:	9	-	8	3	4	4	5



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 14

Gender: Female **Age:** 56 **Test Ear:** Right **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	5	5	15	5	10	5	10	10	10	50
LE	5	5	5	10	20	25	30	35	5	

Baseline Words Correct at Each Signal/Noise Ratio

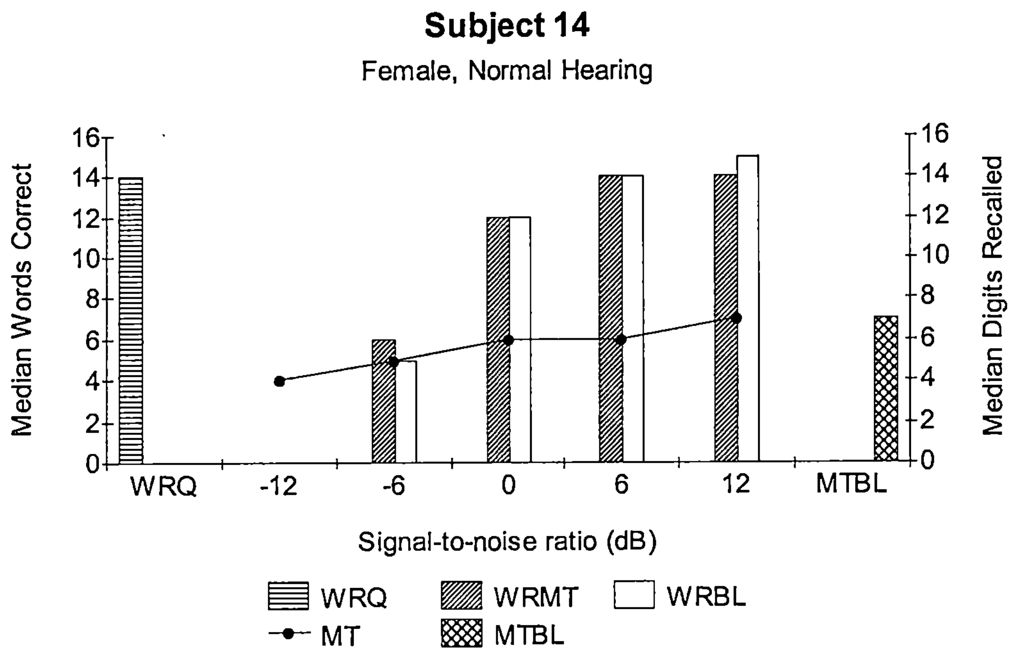
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	5	15	15	15
Trial 2:	14	-	0	8	9	14	15
Trial 3:	15	-	1	5	12	12	12
Median:	14	-	0	5	12	14	15

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	6	11	14	15
Trial 2:	-	0	8	13	15	14
Trial 3:	-	0	5	12	13	13
Median:	-	0	6	12	14	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	5	-	3	5	8	5	7
Trial 2:	8	-	6	5	3	9	8
Trial 3:	7	-	4	8	6	6	5
Median:	7	-	4	5	6	6	7



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 15

Gender: Male **Age:** 50 **Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	0	20	40	45	50	20	15	25	65
LE	70	65	65	50	50	65	75	75	60	

Baseline Words Correct at Each Signal/Noise Ratio

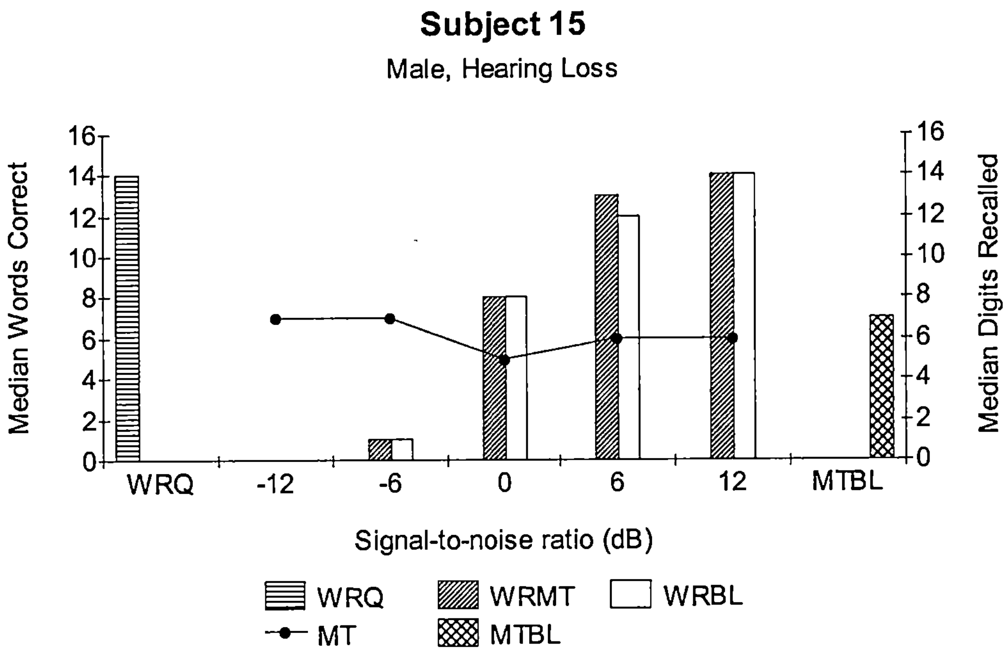
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	13	-	0	1	5	12	14
Trial 2:	15	-	0	0	9	13	14
Trial 3:	14	-	0	1	8	10	14
Median:	14	-	0	1	8	12	14

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	0	6	11	14
Trial 2:	-	0	1	8	13	13
Trial 3:	-	0	1	9	13	15
Median:	-	0	1	8	13	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	9	-	7	8	7	9	6
Trial 2:	6	-	9	7	3	6	6
Trial 3:	7	-	7	7	5	6	8
Median:	7	-	7	7	5	6	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 16

Gender: Female **Age:** 50**Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	15	15	30	45	40	45	50	35	25	65
LE	15	15	10	45	45	50	45	30	15	

Baseline Words Correct at Each Signal/Noise Ratio

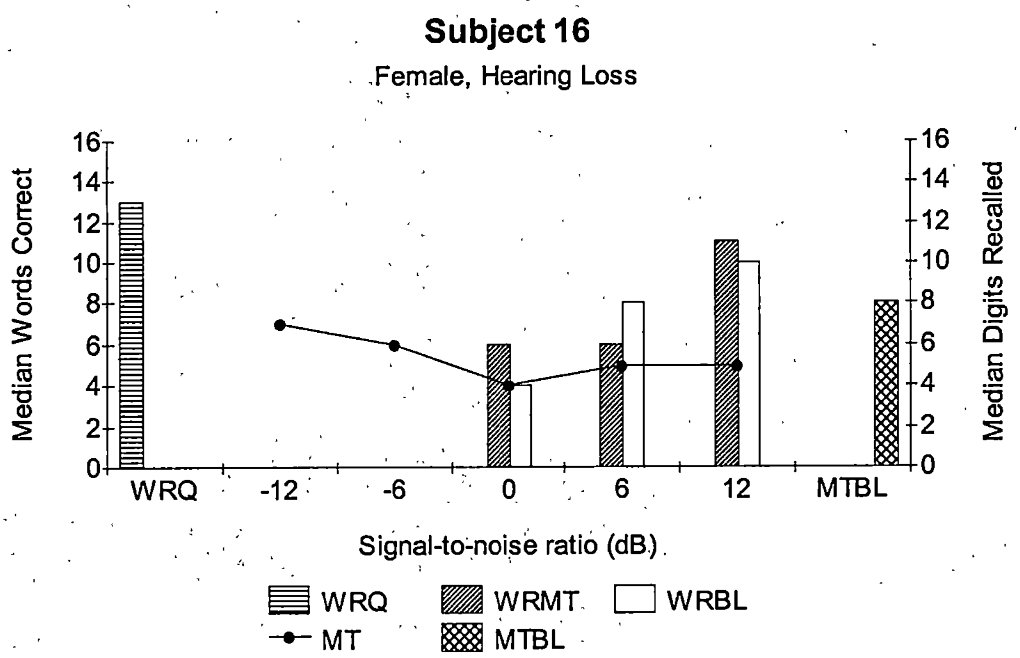
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	13	-	0	0	2	8	10
Trial 2:	15	-	0	0	4	10	8
Trial 3:	13	-	0	0	7	7	15
Median:	13	-	0	0	4	8	10

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	0	6	11	10
Trial 2:	-	0	0	4	6	11
Trial 3:	-	0	0	7	6	11
Median:	-	0	0	6	6	11

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	6	-	7	8	6	9	3
Trial 2:	8	-	8	5	4	4	8
Trial 3:	12	-	7	6	3	5	5
Median:	8	-	7	6	4	5	5



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 17

Gender: Female **Age:** 54 **Test Ear:** Right **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	0	0	0	5	10	20	20	5	45
LE	5	0	0	5	15	15	15	15	5	

Baseline Words Correct at Each Signal/Noise Ratio

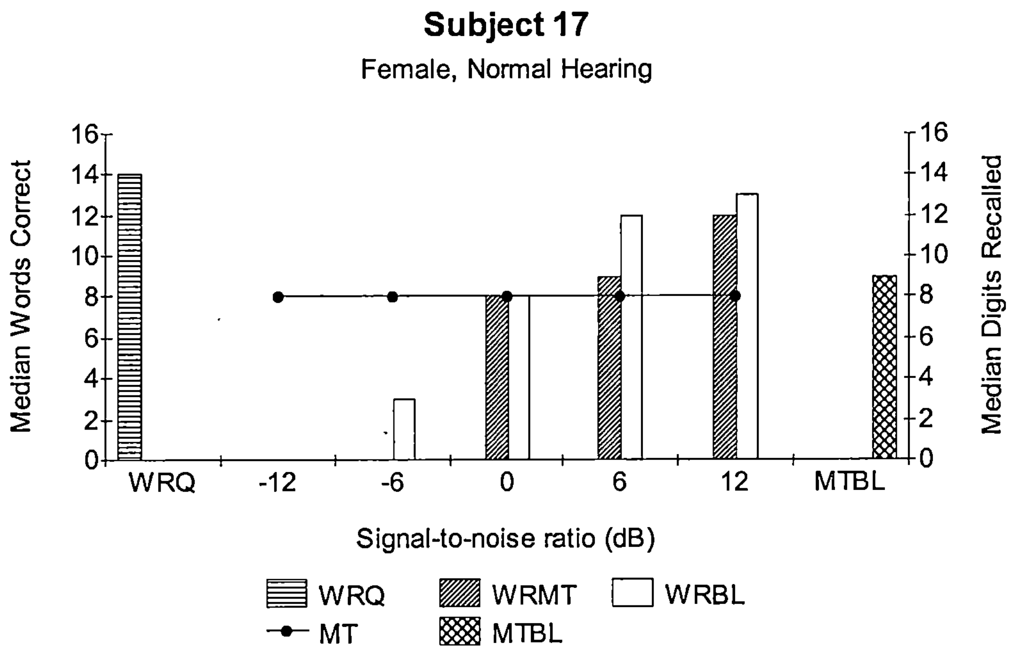
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	3	8	8	13
Trial 2:	13	-	1	9	7	14	13
Trial 3:	14	-	0	3	10	12	12
Median:	14	-	0	3	8	12	13

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	0	8	11	13
Trial 2:	-	0	0	10	13	12
Trial 3:	-	0	3	8	9	12
Median:	-	0	0	8	11	12

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	7	-	8	8	8	8	8
Trial 2:	9	-	5	6	10	8	8
Trial 3:	9	-	8	10	7	10	3
Median:	9	-	8	8	8	8	8



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 18

Gender: Male **Age:** 58 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	10	15	25	35	30	40	55	20	
LE	10	10	10	15	30	40	50	65	10	50

Baseline Words Correct at Each Signal/Noise Ratio

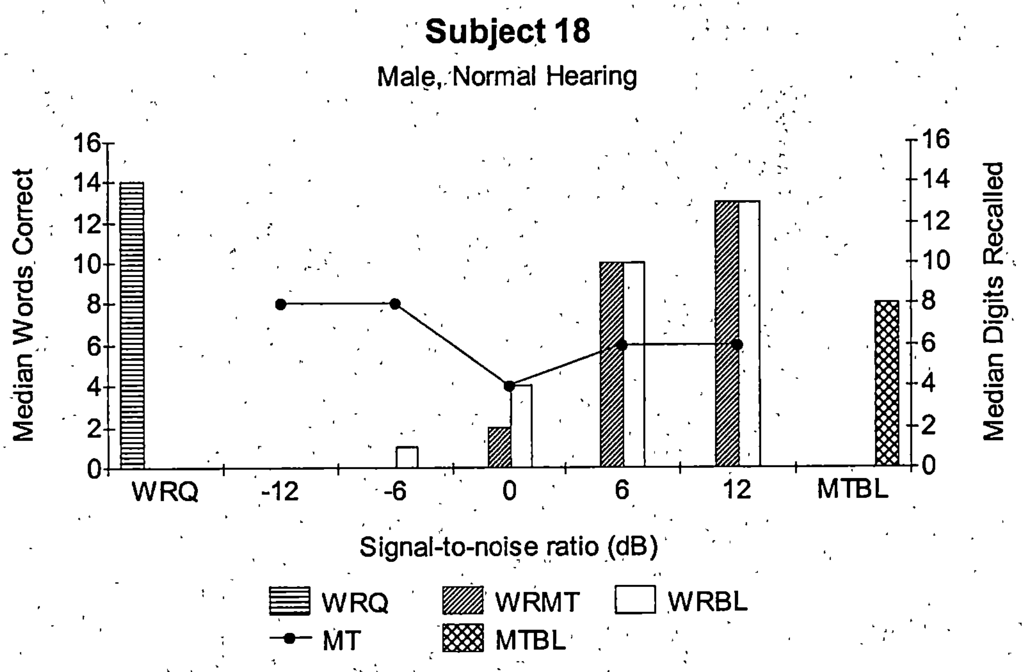
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	1	4	10	13
Trial 2:	14	-	0	3	5	12	12
Trial 3:	14	-	0	1	4	8	13
Median:	14	-	0	1	4	10	13

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	0	2	10	13
Trial 2:	-	0	2	1	12	12
Trial 3:	-	0	0	5	8	13
Median:	-	0	0	2	10	13

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	-	6	4	8	6	5
Trial 2:	10	-	8	8	4	4	8
Trial 3:	8	-	9	8	4	8	6
Median:	8	-	8	8	4	6	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 19

Gender: Male **Age:** 58 **Test Ear:** Left **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	15	15	15	10	10	30	30	15	20	
LE	20	20	25	25	15	30	35	20	25	65

Baseline Words Correct at Each Signal/Noise Ratio

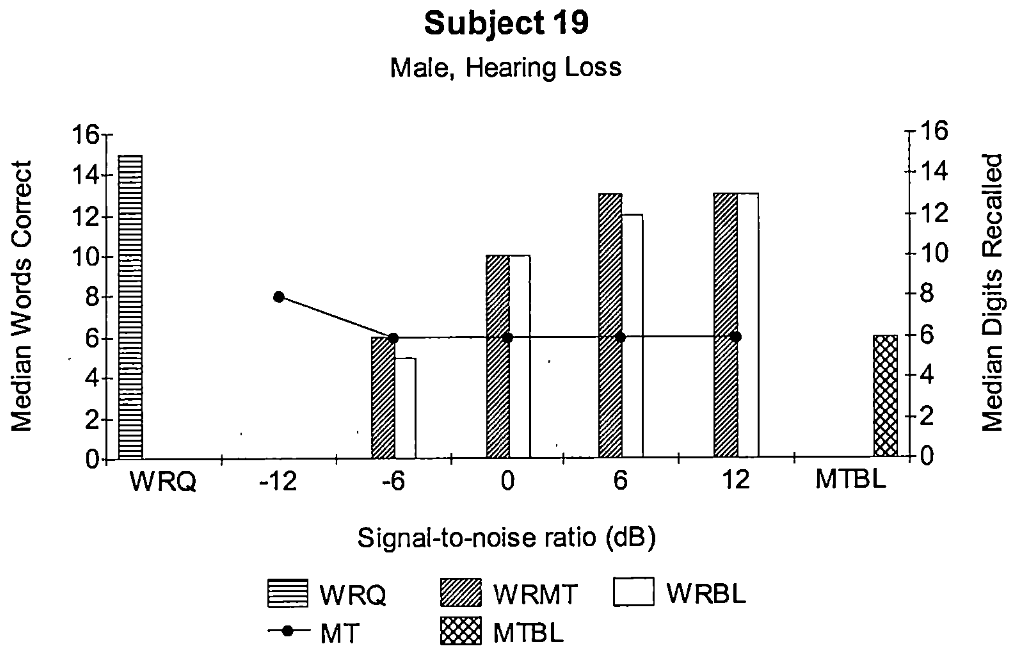
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	2	10	9	13
Trial 2:	13	-	0	8	8	14	12
Trial 3:	15	-	0	5	11	12	15
Median:	15	-	0	5	10	12	13

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	7	10	13	13
Trial 2:	-	1	6	7	13	15
Trial 3:	-	0	5	11	12	13
Median:	-	0	6	10	13	13

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	2	-	8	9	9	7	6
Trial 2:	6	-	8	6	5	6	4
Trial 3:	8	-	8	6	6	5	6
Median:	6	-	8	6	6	6	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 20

Gender: Female **Age:** 51 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	15	10	5	0	5	20	20	5	10	
LE	15	5	10	5	5	5	15	5	10	50

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	7	7	15	14
Trial 2:	15	-	0	6	12	11	14
Trial 3:	13	-	0	4	10	10	14
Median:	15	-	0	6	10	11	14

Words Correct With Memory Task at Each Signal/Noise Ratio

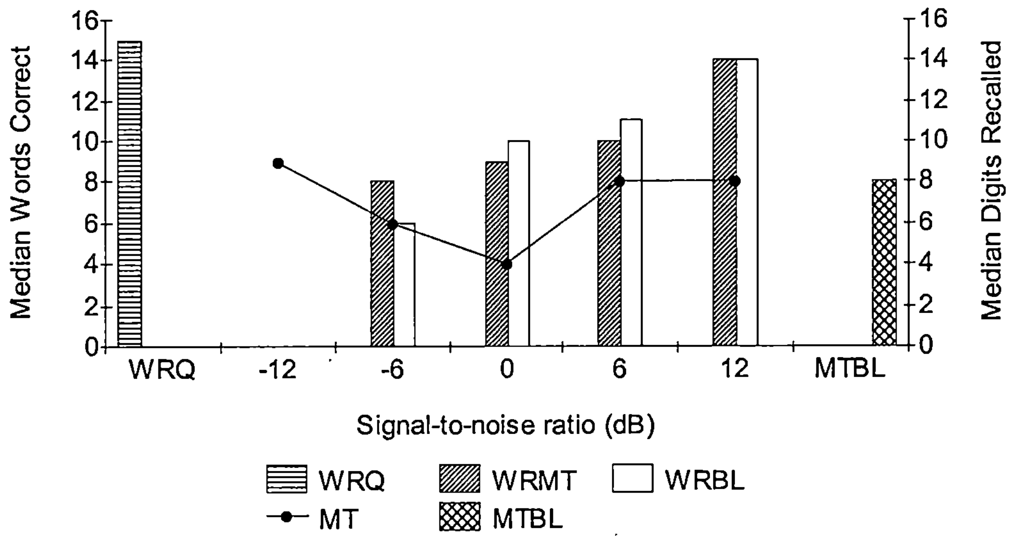
	-15	-12	-6	0	+6	+12
Trial 1:	-	0	8	10	14	14
Trial 2:	-	0	9	9	8	13
Trial 3:	-	0	5	9	10	14
Median:	-	0	8	9	10	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	10	-	10	6	3	8	8
Trial 2:	6	-	9	8	4	8	9
Trial 3:	10	-	9	6	5	7	8
Median:	8	-	9	6	4	8	8

Subject 20

Female, Normal Hearing



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 21

Gender: Female **Age:** 51**Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	40	35	35	30	30	30	45	45	35	70
LE	30	30	25	25	30	30	35	35	30	

Baseline Words Correct at Each Signal/Noise Ratio

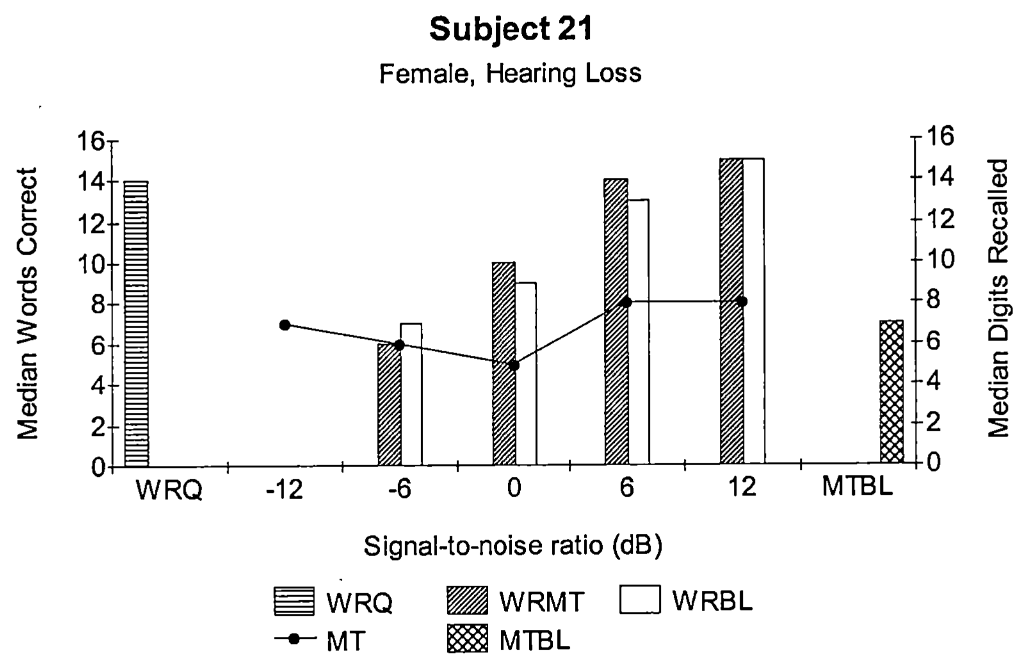
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	9	9	13	15
Trial 2:	14	-	0	4	11	13	15
Trial 3:	14	-	0	7	7	14	14
Median:	14	-	0	7	9	13	15

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	5	10	14	15
Trial 2:	-	0	6	10	14	15
Trial 3:	-	0	8	8	12	14
Median:	-	0	6	10	14	15

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	-	5	7	7	8	7
Trial 2:	4	-	7	6	3	8	8
Trial 3:	7	-	8	4	5	6	8
Median:	7	-	7	6	5	8	8



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 22

Gender: Male **Age:** 57 **Test Ear:** Left **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	10	15	15	60	60	65	60	15	
LE	25	15	30	50	65	75	70	60	30	70

Baseline Words Correct at Each Signal/Noise Ratio

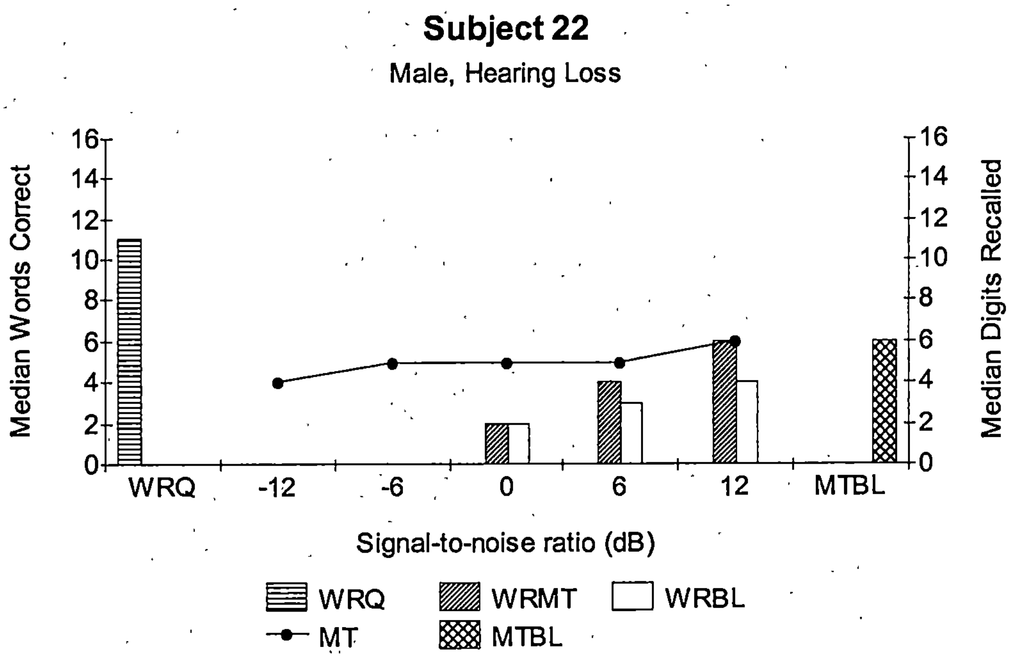
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	11	-	0	0	2	1	4
Trial 2:	7	-	0	0	2	3	4
Trial 3:	14	-	0	0	1	3	4
Median:	11	-	0	0	2	3	4

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	0	1	4	6
Trial 2:	-	0	0	2	2	7
Trial 3:	-	0	0	2	4	5
Median:	-	0	0	2	4	6

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	6	-	4	4	6	4	6
Trial 2:	9	-	4	5	5	5	1
Trial 3:	6	-	7	6	5	5	6
Median:	6	-	4	5	5	5	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 23

Gender: Male **Age:** 51 **Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	10	20	40	55	95	85	80	30	70
LE	10	10	10	35	35	75	85	85	25	

Baseline Words Correct at Each Signal/Noise Ratio

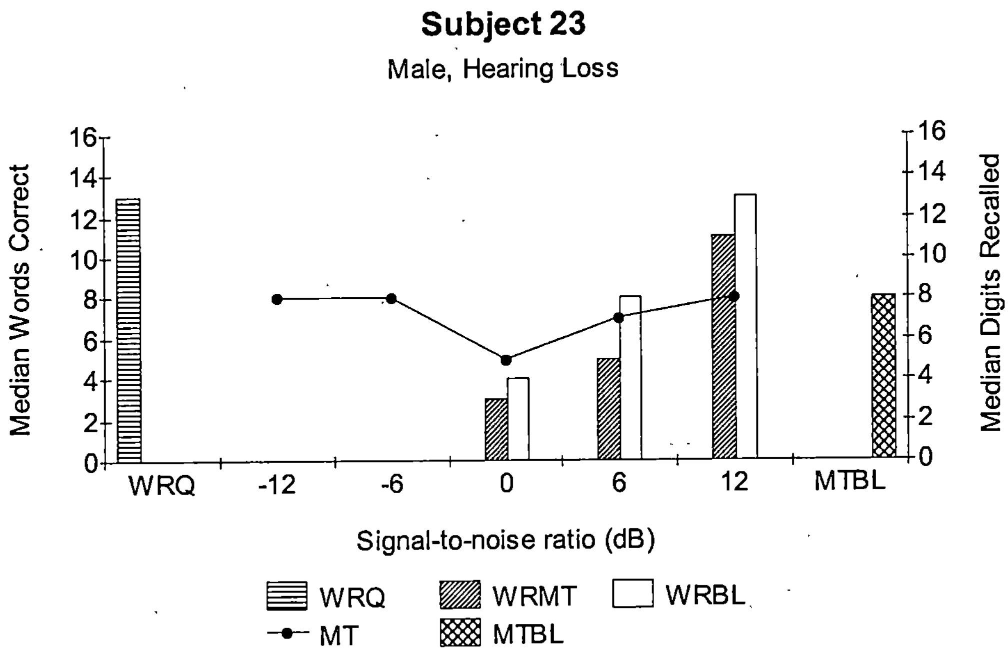
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	13	-	0	0	3	8	15
Trial 2:	15	-	0	0	4	5	13
Trial 3:	12	-	0	0	4	10	10
Median:	13	-	0	0	4	8	13

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	0	1	1	9
Trial 2:	-	0	0	5	5	11
Trial 3:	-	0	0	3	5	12
Median:	-	0	0	3	5	11

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	10	-	6	5	4	7	8
Trial 2:	6	-	8	8	8	8	8
Trial 3:	8	-	10	9	5	6	8
Median:	8	-	8	8	5	7	8



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 24

Gender: Male **Age:** 55 **Test Ear:** Left **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	30	20	20	25	25	40	25	20	20	
LE	20	15	25	35	40	45	55	55	25	65

Baseline Words Correct at Each Signal/Noise Ratio

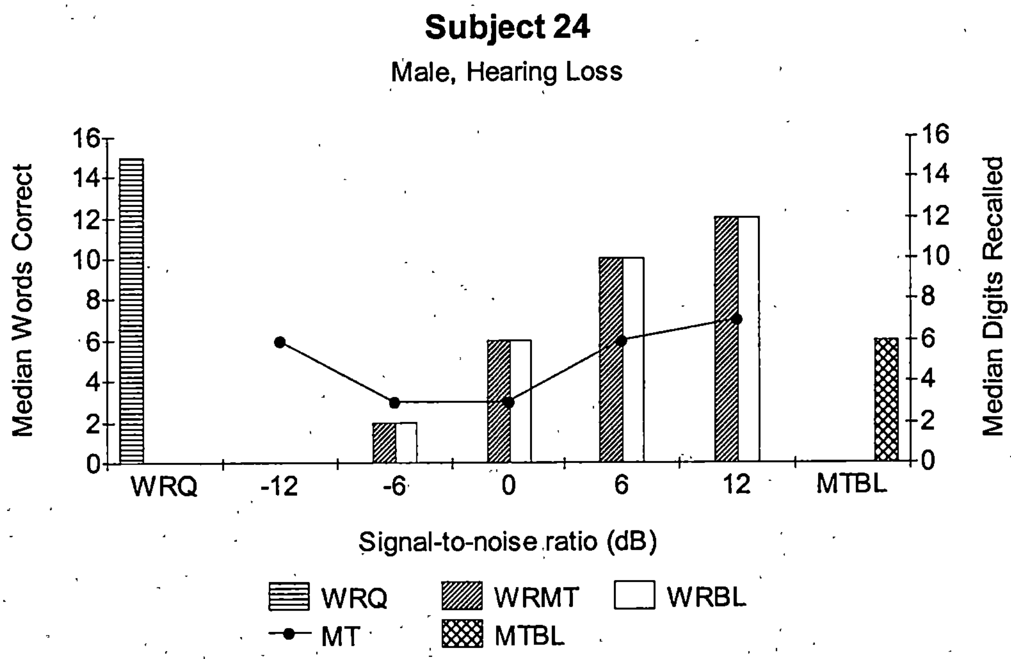
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	3	5	10	14
Trial 2:	15	-	0	2	8	9	12
Trial 3:	13	-	0	2	6	10	11
Median:	15	-	0	2	6	10	12

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	1	4	11	11
Trial 2:	-	0	4	8	7	12
Trial 3:	-	0	2	6	10	13
Median:	-	0	2	6	10	12

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	5	-	6	3	6	6	1
Trial 2:	8	-	4	3	2	7	8
Trial 3:	6	-	6	5	3	4	7
Median:	6	-	6	3	3	6	7



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 25

Gender: Male **Age:** 55 **Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	15	35	35	45	45	30	30	35	75
LE	15	10	30	45	55	60	45	35	30	

Baseline Words Correct at Each Signal/Noise Ratio

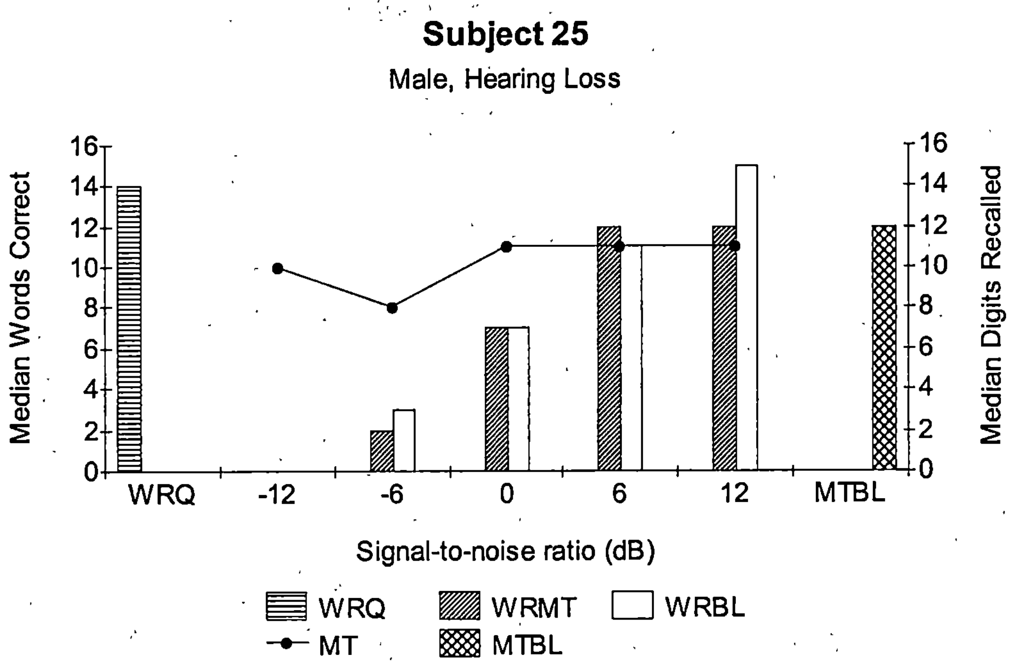
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	14	-	0	3	6	11	15
Trial 2:	14	-	0	1	7	10	13
Trial 3:	15	-	0	4	9	14	15
Median:	14	-	0	3	7	11	15

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	2	6	13	12
Trial 2:	-	0	2	11	12	12
Trial 3:	-	1	1	7	11	12
Median:	-	0	2	7	12	12

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	10	-	10	8	10	6	10
Trial 2:	12	-	10	10	12	12	11
Trial 3:	12	-	13	6	11	11	11
Median:	12	-	10	8	11	11	11



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 26

Gender: Male **Age:** 55 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	10	15	15	50	65	55	65	15	
LE	15	10	5	10	25	30	40	50	15	55

Baseline Words Correct at Each Signal/Noise Ratio

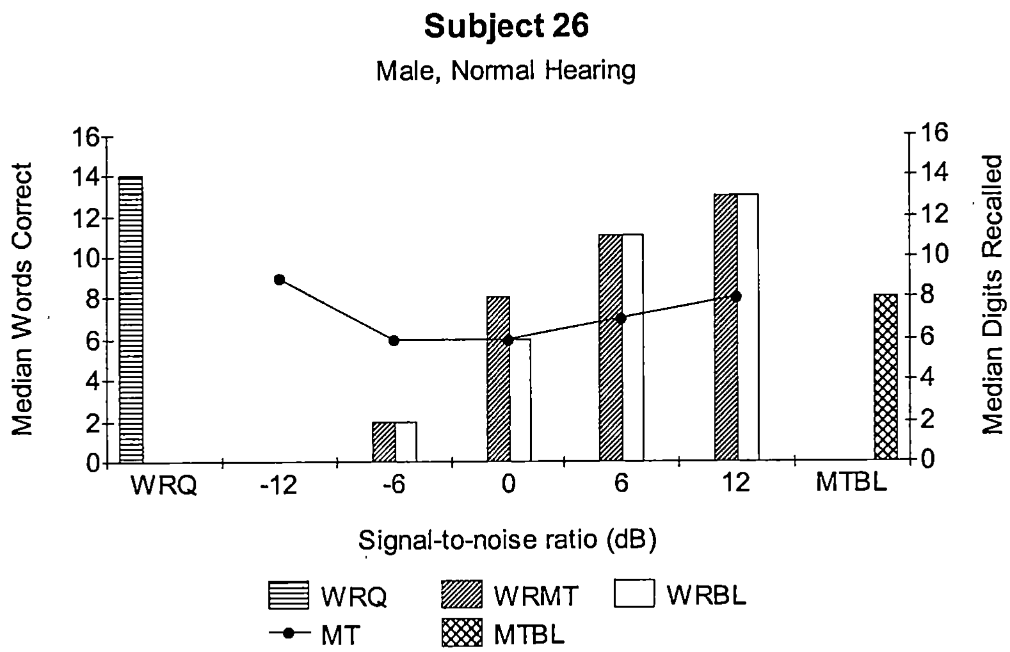
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	2	5	7	13
Trial 2:	13	-	0	3	6	11	13
Trial 3:	14	-	0	2	10	14	12
Median:	14	-	0	2	6	11	13

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	2	11	12	13
Trial 2:	-	0	2	8	11	13
Trial 3:	-	0	2	8	10	15
Median:	-	0	2	8	11	13

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	12	-	9	6	5	9	4
Trial 2:	11	-	9	9	4	4	9
Trial 3:	10	-	9	3	6	7	8
Median:	8	-	9	6	6	7	8



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 27

Gender: Male **Age:** 51 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	5	10	5	0	40	25	25	10	
LE	10	0	5	5	10	15	15	20	10	50

Baseline Words Correct at Each Signal/Noise Ratio

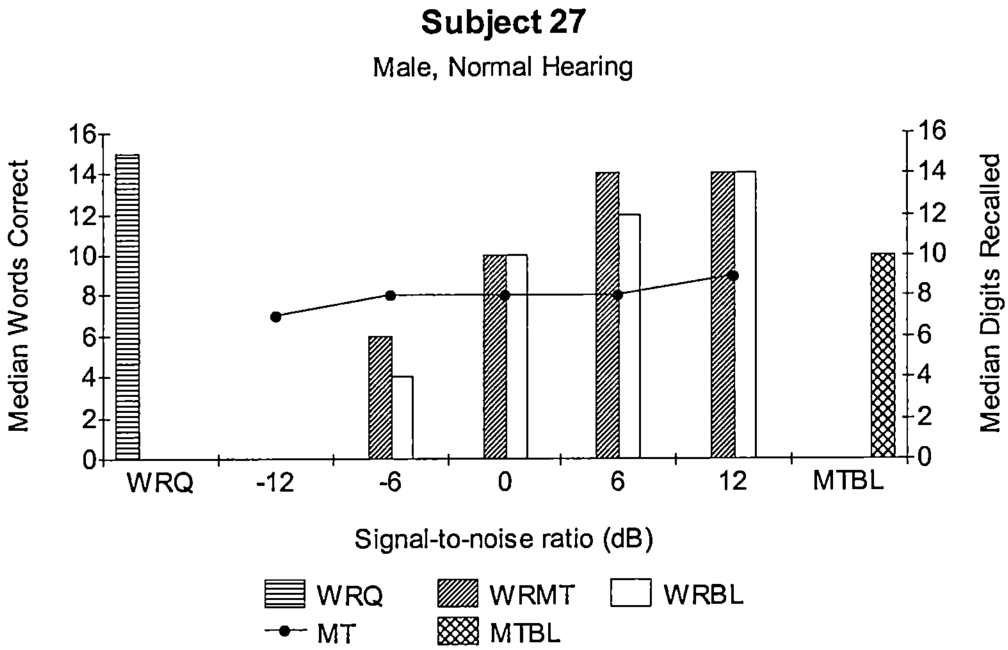
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	4	12	12	14
Trial 2:	15	-	0	7	10	12	14
Trial 3:	13	-	0	2	8	15	15
Median:	15	-	0	4	10	12	14

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	1	7	12	13	14
Trial 2:	-	0	6	10	14	14
Trial 3:	-	0	2	9	14	14
Median:	-	0	6	10	14	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	13	-	7	10	10	7	10
Trial 2:	7	-	7	6	7	8	7
Trial 3:	10	-	6	8	8	8	9
Median:	10	-	7	8	8	8	9



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 28

Gender: Male **Age:** 53 **Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	15	20	35	65	70	70	70	25	65
LE	15	15	20	30	60	60	50	50	25	

Baseline Words Correct at Each Signal/Noise Ratio

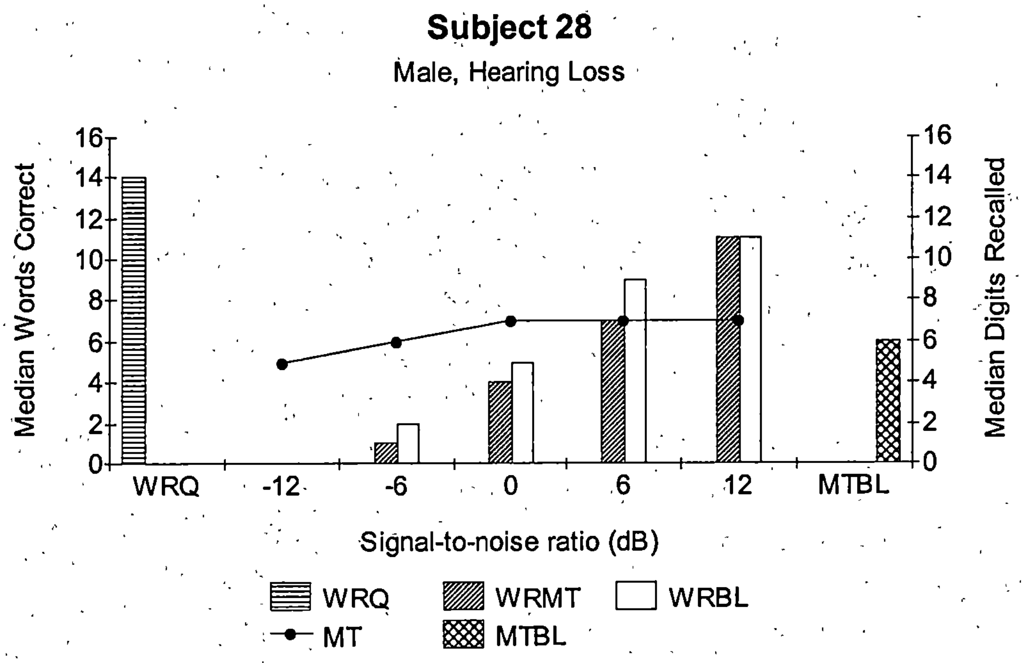
	Quiet	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	15	-	0	2	5	10	13
Trial 2:	14	-	0	1	2	9	10
Trial 3:	12	-	0	2	7	9	11
Median:	14	-	0	2	5	9	11

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	-	0	3	3	6	12
Trial 2:	-	0	1	6	7	11
Trial 3:	-	0	0	4	10	9
Median:	-	0	1	4	7	11

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	6	-	5	6	8	6	7
Trial 2:	6	-	8	8	7	10	7
Trial 3:	6	-	3	5	4	7	5
Median:	6	-	5	6	7	7	7



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 29

Gender: Female **Age:** 52**Test Ear:** Right **Hearing Classification:** Hearing Loss

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	20	25	30	35	45	40	40	45	30	70
LE	20	20	25	35	45	45	40	45	25	

Baseline Words Correct at Each Signal/Noise Ratio

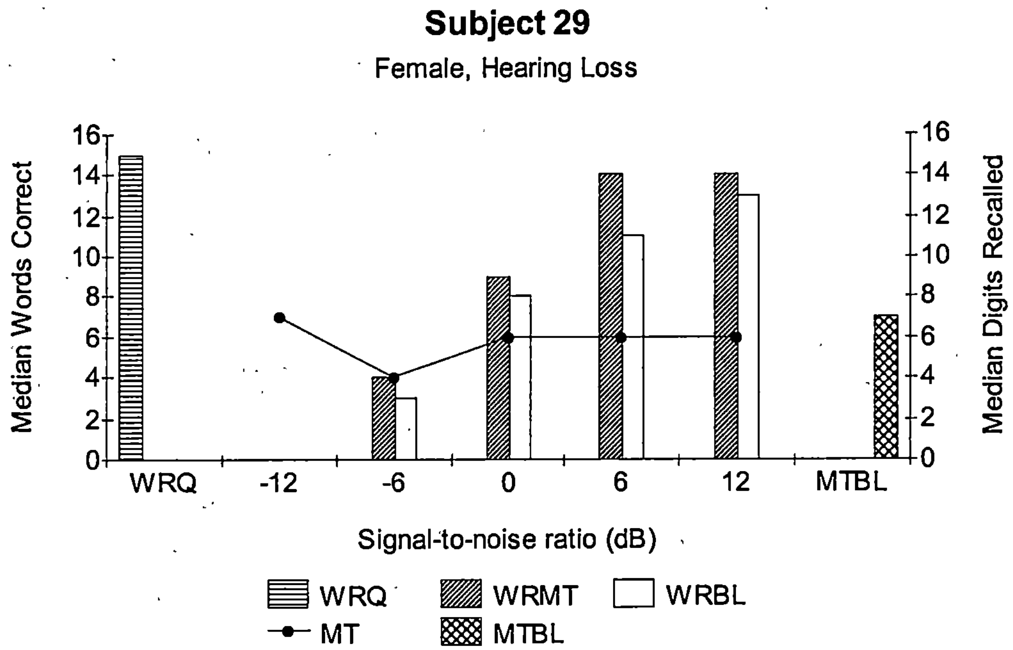
	Quiet	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	14	-	0	7	5	10	13
Trial 2:	15	-	0	3	8	11	13
Trial 3:	15	-	0	3	9	12	15
Median:	15	-	0	3	8	11	13

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	-	0	4	6	14	15
Trial 2:	-	0	4	9	14	11
Trial 3:	-	0	2	11	9	14
Median:	-	0	4	9	14	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	8	-	6	3	3	6	6
Trial 2:	6	-	8	4	7	5	5
Trial 3:	7	-	7	5	6	6	7
Median:	7	-	7	4	6	6	6



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 30

Gender: Male **Age:** 54 **Test Ear:** Right **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	5	5	0	5	15	25	20	10	50
LE	10	5	5	5	10	20	15	25	10	

Baseline Words Correct at Each Signal/Noise Ratio

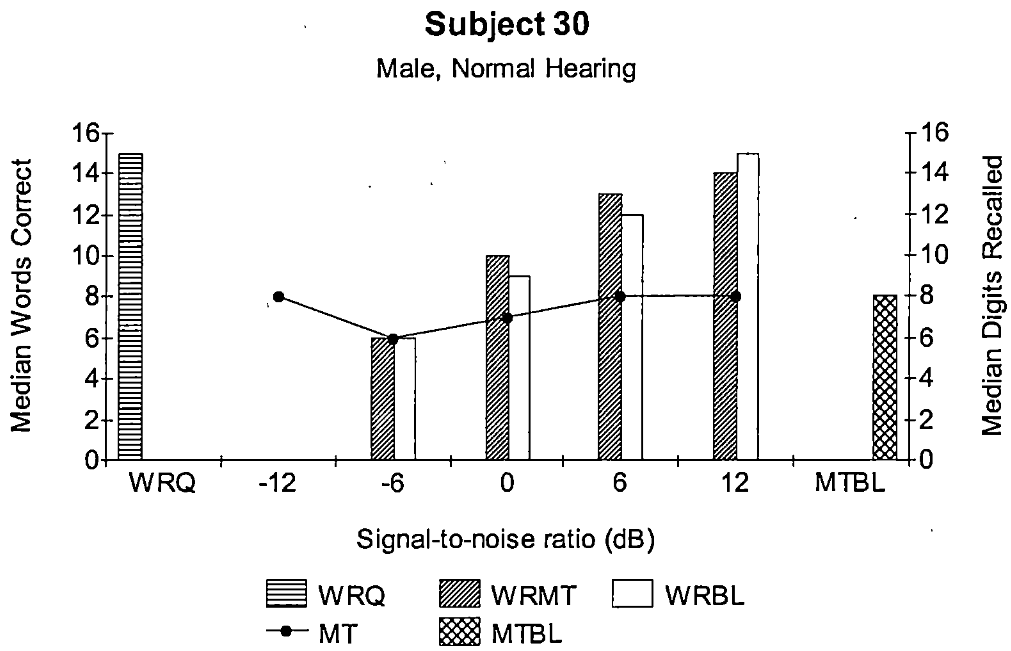
	Quiet	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	15	-	0	8	7	13	15
Trial 2:	15	-	0	6	10	12	13
Trial 3:	15	-	0	4	9	12	15
Median:	15	-	0	6	9	12	15

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	-	0	7	9	13	15
Trial 2:	-	0	6	12	13	14
Trial 3:	-	0	3	10	10	13
Median:	-	0	6	10	13	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	**-15**	**-12**	**-6**	**0**	**+6**	**+12**
Trial 1:	3	-	1	6	8	10	8
Trial 2:	8	-	8	9	7	8	5
Trial 3:	9	-	10	6	7	8	9
Median:	8	-	8	6	7	8	8



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 31

Gender: Male **Age:** 57 **Test Ear:** Right **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	0	15	10	0	0	15	15	15	55
LE	5	5	15	10	5	20	35	40	15	

Baseline Words Correct at Each Signal/Noise Ratio

	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	5	11	12	14
Trial 2:	13	-	0	2	9	10	14
Trial 3:	14	-	0	3	6	14	14
Median:	14	-	0	3	9	12	14

Words Correct With Memory Task at Each Signal/Noise Ratio

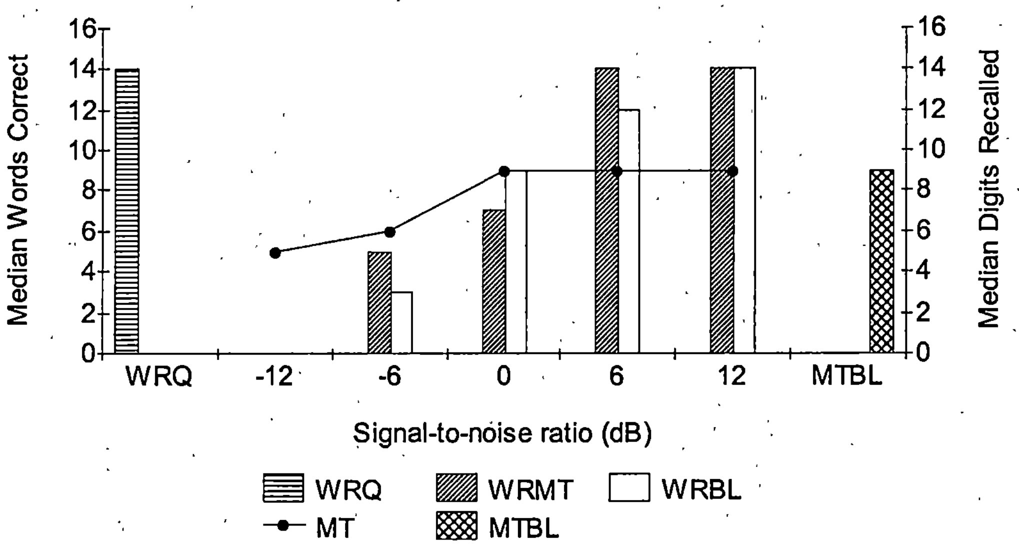
	-15	-12	-6	0	+6	+12
Trial 1:	-	1	5	10	14	14
Trial 2:	-	0	6	6	14	15
Trial 3:	-	0	3	7	13	14
Median:	-	0	5	7	14	14

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	9	-	5	6	9	9	6
Trial 2:	9	-	5	5	11	10	11
Trial 3:	6	-	5	6	6	8	9
Median:	9	-	5	6	9	9	9

Subject 31

Male, Normal Hearing



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

DATA SHEET SUBJECT 32

Gender: Male **Age:** 56 **Test Ear:** Left **Hearing Classification:** Normal

Hearing Thresholds (dB HL)

	250 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHZ	6 kHz	8 kHz	SRT	MCL
RE	10	5	5	5	15	25	20	30	5	
LE	10	0	5	10	15	10	25	35	10	50

Baseline Words Correct at Each Signal/Noise Ratio

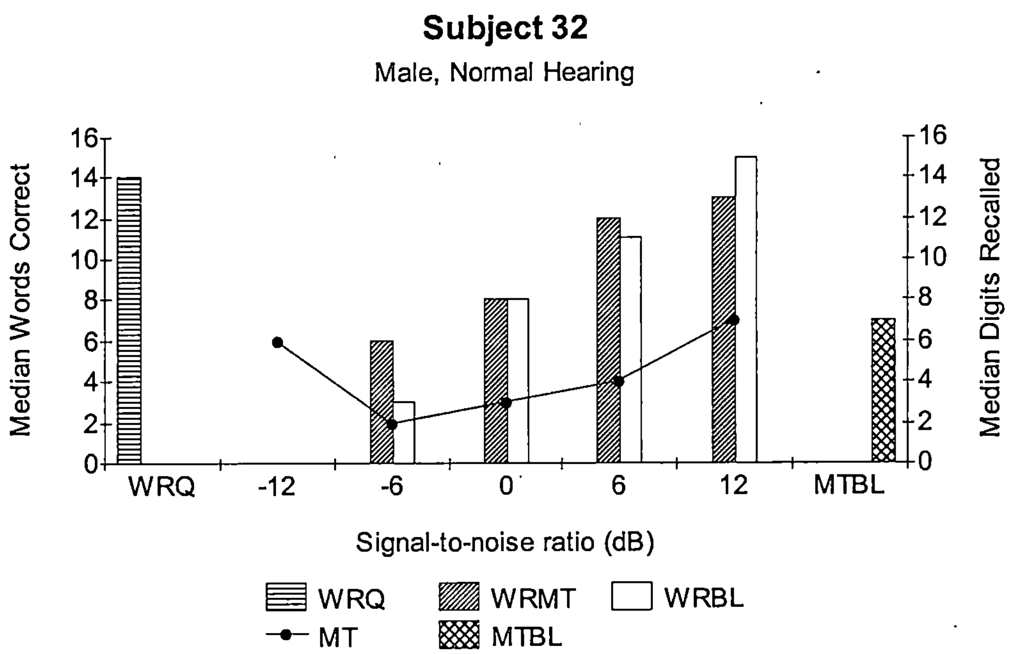
	Quiet	-15	-12	-6	0	+6	+12
Trial 1:	15	-	0	3	11	13	15
Trial 2:	13	-	0	3	8	11	15
Trial 3:	14	-	0	2	6	10	11
Median:	14	-	0	3	8	11	15

Words Correct With Memory Task at Each Signal/Noise Ratio

	-15	-12	-6	0	+6	+12
Trial 1:	-	0	7	8	12	13
Trial 2:	-	0	6	9	14	12
Trial 3:	-	0	5	7	10	14
Median:	-	0	6	8	12	13

Digits Remembered Baseline and at Each Signal/Noise Ratio

	Baseline	-15	-12	-6	0	+6	+12
Trial 1:	8	-	7	2	4	6	7
Trial 2:	6	-	4	4	1	3	5
Trial 3:	7	-	6	2	3	4	7
Median:	7	-	6	2	3	4	7



WRQ - Words Correct in Quiet
WRMT - Words Correct in Noise with Memory Task
WRBL - Words Correct in Noise Baseline (no memory task)
MT - Memory Task (digits recalled with auditory task)
MTBL - Memory Task Baseline (no auditory task)

VITA

Robert Edwin Moore was born in Athens, Tennessee on December 17, 1946. He attended elementary school in Maryville, Tennessee and graduated from Everett High School there in 1964. His Bachelor of Arts degree was in Speech and Hearing from the University of Tennessee-Knoxville in 1975. He received a Master of Arts degree in Audiology from the University of Tennessee-Knoxville in 1976. After working at the Shea Clinic in Memphis, Tennessee as an audiologist for three years, he returned to the University of Tennessee-Knoxville as an Instructor in the Department of Audiology and Speech Pathology in 1979. He was there until 1985. After working at two hospitals in Knoxville, Tennessee he began working at the Baptist Ear Center as an audiologist in 1989. In 1992, he began his doctoral studies as a part-time student at the University of Tennessee-Knoxville and received a Doctor of Philosophy degree in Audiology in 2000. He continues to work as an audiologist at the Baptist Ear Center in Knoxville, Tennessee.