5-6-1977

Processing Demands During Auditory Learning Under Degraded Listening Conditions

David Wayne Downs

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of The University of New Mexico in partial fulfillment of the requirements for the degree of

Master of Science in Communicative Disorders

PROCESSING DEMANDS DURING AUDITORY LEARNING UNDER DEGRADED LISTENING CONDITIONS

Title

David Wayne Downs

Candidate

Department of Communicative Disorders

Department

Bernard Spolsky

Dean

May 6, 1977

Date

Committee

Chairman

Richard B. Hood

Max E. McClellan

Wayne E. Swisher

PROCESSING DEMANDS DURING AUDITORY LEARNING

UNDER DEGRADED LISTENING CONDITIONS

BY

DAVID WAYNE DOWNS

B.A., University of New Mexico, 1975

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Communicative Disorders
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico
May, 1977

ACKNOWLEDGEMENTS

During the past year, several individuals have made contributions to this thesis. Their aid is greatly appreciated.

First, I would like to thank my parents for their support; both in encouragement, and in preparation of materials. Thanks are also extended to the members of my committee.

Certainly, deepest appreciation is for my advisor, Michael Crum. His comments contributed greatly to the completion of this thesis. They were always offered in a manner that provided direction without directing. Moreso, his freely given time, enthusiasm and interest in the project, and confidence in my abilities were invaluable.

PROCESSING DEMANDS DURING AUDITORY LEARNING

UNDER DEGRADED LISTENING CONDITIONS

BY

David Wayne Downs

ABSTRACT OF THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Master of Science in Communicative Disorders
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico
May, 1977

ABSTRACT

Downs, David Wayne (Masters Degree, Communicative Disorders)

PROCESSING DEMANDS DURING AUDITORY LEARNING UNDER DEGRADED LISTENING CONDITIONS

Directed By Michael A. Crum

(Words in Abstract: 458)

Recent research has demonstrated that auditory learning can be adversely affected when performed under degraded listening conditions. Perhaps the most common of these degraded listening conditions are environments of moderate intensity noise, such as found in the classroom or in the home. A second degraded listening condition occurs when the speech signal is heard at a reduced intensity. This situation is experienced by the hearing impaired individual. That reduced speech intensity and/or noise can have detrimental effects upon learning has been almost exclusively attributed, by audiologists, to impaired signal intelligibility. The present study (which controlled for high speech intelligibility) investigated whether the added processing demands of auditory learning under degraded listening conditions could account for learning deficits. Specifically, the question examined was whether processing demands during auditory learning were greater under noisy versus quiet listening conditions and/or when the learning signal was presented at a reduced intensity level.

To assess processing demands during auditory learning, a double stimulation procedure was employed. The double stimulation procedure allows the experimenter to simultaneously measure both processing accuracy (i.e., performance) and ease (i.e., attention or effort) during a learning task. In the present study, processing accuracy was determined using a paired associate learning task where 10 couplets of spondee words served as the learning stimuli. Processing ease was assessed with a probe reaction time task presented simultaneously during the learning task. The rationale for this procedure is that as the processing demands of the primary learning task increase, there will be a concomitant increase in reaction time during the secondary probe task.

Forty-nine normal hearing undergraduates were randomly assigned to 7 experimental groups. Each of the groups heard the learning signal through the sound field under different listening conditions. These listening conditions represented the primary variables, and included: 1) Signal presented in quiet or noise (+6 dB S/N), and 2) Signal presented at 50, 35, or 20 dB sensation level. Six of the experimental groups performed both the learning and probe reaction time tasks. The seventh group only performed the learning task, and thus served as a control condition.

Results of the study indicated that neither of the primary variables exerted an effect upon learning accuracy. Rather, the results indicated a significant difference in learning ease between the noise

and quiet listening conditions. Specifically, subjects in the noise conditions required greater effort to perform the learning task. No difference in learning ease was evident between groups at the different signal presentation levels.

These results have important implications for: 1) The present listening conditions found in educational settings, 2) Hearing aid selection, 3) Education of the hearing impaired, and 4) Future audiological research and clinical procedures where multiple measures of auditory processing may be warranted.

TABLE OF CONTENTS

CHAPTER PAGE

I. INTRODUCTION.. 1

II. REVIEW OF THE LITERATURE.................................... 6

Effects of Reduced Signal Intensity on Learning......... 6

Effects of Noise on Learning............................ 9

The Limited Capacity Processor.......................... 12

Bottleneck Models of Attention...................... 13

Capacity Models of Attention........................ 15

Selective Attention..................................... 19

Cocktail Party Phenomenon........................... 20

Theories of Selective Attention..................... 22

Arousal, Noise and Selective Attention.............. 25

Physiological Correlates of Selective Attention..... 27

Application of Research on Selective Attention...... 28

Measurement of Processing Demands....................... 31

Physiological Measurement Techniques................ 32

Measurements of Speed, Accuracy and Ease of Processing.................................... 32

Bases of Probe Reaction Time Technique.............. 34

Safeguarding the Primary Task....................... 37

Probe Reaction Time During Verbal Learning Tasks..... 38

CHAPTER PAGE

III. EXPERIMENTAL DESIGN.. 41

Subjects.. 41

Learning Paradigm... 42

Stimulus Material and Presentation................................ 43

Learning Stimuli.. 43

Noise Stimulus.. 46

Learning Signal Presentation Level................................ 47

Signal-to-Noise Presentation Level................................ 50

Probe Reaction Time Signal Presentation........................... 50

Apparatus... 54

Instrumentation for Auditory Signal Presentation.................. 54

Instrumentation for Probe Reaction Time Testing................... 55

Procedure... 58

Experimental Design Matrix.. 60

Statement of Experimental Questions............................... 63

IV. RESULTS AND INTERPRETATION.................................... 67

Preliminary Results... 69

Baseline Reaction Time Performance................................ 69

Exposure Trial Intelligibility Performance........................ 72

Primary Results... 76

Learning Performance.. 76

Expended Processing Capacity Performance.......................... 78

Processing Demands Index.. 85

CHAPTER PAGE

Decisions Regarding the Experimental Hypotheses......... 86

Hypothesis One... 86

Hypothesis Two... 88

Hypothesis Three....................................... 88

Hypothesis Four.. 89

Findings of Additional Interest........................ 90

Implications... 92

Effects of Noise Upon Processing Demands During Auditory Learning.. 93

Effects of Signal Intensity Upon Processing Demands During Auditory Learning................................. 98

Importance of Multiple Measurements When Studying Auditory Processing................................... 101

Plans for Future Research.............................. 102

V. SUMMARY.. 105

REFERENCES.. 110

APPENDIX.. 117

LIST OF FIGURES

FIGURE		PAGE
I.	Single Channel Model of Attention	14
II.	Parallel Processing Model of Attention	16
III.	Supply of Effort as a Function of Demands of the Primary Task	18
IV.	The Yerkes-Dodson Law	26
V.	Spectral Analysis of Multiple Talker Noise	49
VI.	Instrumentation for the Presentation of Speech Material	56
VII.	Instrumentation for Probe Reaction Time Task	57
VIII.	Experimental Design Matrix	62
IX.	Intelligibility of Stimulus Words During Exposure Trial for Seven Experimental Groups	73
X.	Number of Unintelligible Words in Each Word Pair for the 7 Subjects in Group VI	75
XI.	Learning Performance Curves for Experimental Groups I - VI	77
XII.	Expended Processing Capacity for 6 Experimental Conditions During Different Probe Presentations	83
XIII.	Effects of Signal-to-Noise Ratio on Processing Demands Index at Three Presentation Levels	87

FIGURE PAGE

XIV. Subjective Assessment of Learning Task Difficulty for 7 Experimental Groups.................................. 91

LIST OF TABLES

TABLE PAGE

I. Relative Intelligibility of Twenty Spondee Words Used as Learning Stimuli.......................... 45

II. Temporal Parameters During Exposure Trial................ 47

III. Temporal Parameters During Anticipation Trials........... 48

IV. Temporal Parameters of Probe Signals..................... 52

V. Baseline Reaction Time Data for 42 Subjects in Groups I - VI.. 70

VI. Summary Table of Analysis of Variance Utilized to Test the Independent and Interactive Effects of Primary Variables and Probe Presentation Stages.......... 80

VII. Multiple Comparison Table Illustrating Expended Processing Capacity Difference (In Milliseconds) for Signal Presentation Level, Signal-to-Noise Ratio and Probe Presentation Stages............................ 81

CHAPTER I

INTRODUCTION

Learning is among the most basic activities that place demands upon the auditory system. Consequently, if there is a breakdown in auditory processing, a corresponding decline in learning performance is expected. The most basic breakdown that can occur in audition is a reduction in sensitivity to the intensity of an auditory signal. Such a situation exists with the hearing impaired population where the hearing loss acts as an attenuator of the sound signal. It is now recognized that prolonged attenuation of important sound signals by as little as 15 decibels (as is found with minimal hearing losses) can result in deficits in language, speech, speech perception, and educational achievement. An additional type of auditory breakdown is imposed by the presence of noise. While the immediate effect of noise is a masking out of the relevant sound signal, continued exposure to noise may also result in similar impaired performances in the previously mentioned areas. Finally, as might be predicted, the combined effects of reduced signal intensity and noise can compound to produce the same detrimental results.

The assumption has just been made that deficits in language, speech, speech perception, and educational achievement is reflective of reduced learning performance. Unfortunately, there are very few studies which directly measure the effects of reduced signal intensity on learning under highly controlled experimental conditions. Probably the most important research to date in this area has been conducted by Gaeth (1966). In a carefully controlled series of experiments, Gaeth compared the learning performances of hearing impaired children on a paired associate learning task presented either visually, auditorially, or bimodally (i.e., audition and vision combined). Among the many findings were that children with hearing losses from 26-70 dB HL (ANSI-1969) performed similarly on visual and bimodal presentations, but showed significant learning deficiencies on auditory only presentations. With children who had hearing losses between 71-85 dB HL, the bimodal and auditory presentations resulted in poorer learning rates than the visual presentation alone. The ten years since Gaeth's studies have yielded little further research in this area. Because of the lack of laboratory investigations, the effects of reduced speech intensity upon learning has been inferred from the delayed language and speech development, the poor achievement test scores, and the low academic achievement of the hearing impaired.

With regard to experimental studies on the effects of noise on learning, the audiologist must turn to the psychological literature. While the psychology research can yield useful information, the overall emphasis of these studies is not directed toward the audiologist. For this reason, the implications of the psychologist's findings are not always apparent for the problems faced and the questions pondered by the audiologist. Finally, laboratory investigations concerned with the combined effects of noise and reduced signal intensity upon learning have not received attention in either the audiological or psychological literature.

For the moment, we are left with language and speech development, speech perception abilities and educational achievement to serve as indexes of learning performance. If we do indeed accept these indexes as valid indications of learning performance, why is it then that noise or reduced speech intensity can result in learning performance deficits? Within the field of audiology the common scenario for answering this question has been as follows: noise and/or the reduction in signal intensity tends to lower the overall intelligibility, redundancy, and meaning of the speech signal. Because so much learning (particularly of speech and language) is done through the auditory modality, any interference in speech intelligibility will result in a concomitant decrease in learning performance. In fact, Gaeth (1966) pointed out that the hearing impaired children, who showed poorer learning performance bimodally than visually, did so because the auditory signal was unintelligible and, consequently, confusing and distracting for learning.

For audiologists, the ability to discriminate speech has become the major criterion for predicting how well an individual will perform under "degraded listening conditions".* Certainly, tests of speech

---

*"Degraded listening conditions" refers to communication situations where the relevant auditory signal is received by the listener under less than optimum conditions.

intelligibility are a basic tool in the armament of the audiologist. Among the many uses of speech intelligibility scores are to assess: the functional severity of a hearing loss, the effects of noise on a speech signal, and to choose the best type of amplification during hearing aid fittings. However, with the strong emphasis placed upon speech intelligibility, audiologists may have inadvertently overlooked other factors which may affect learning performance under degraded listening conditions.

Broadbent (1958) demonstrated that similar speech intelligibility scores could be obtained under various conditions of distorted speech (i.e., frequency transposition and low frequency filtering of the speech signal). However, he also found that the equal scores were obtained at the expense of unequal amounts of effort exerted by the listener. Broadbent concluded that these experimental results provide:

> "...Very strong evidence of the need for multiple criteria in assessing communication channels. It seems desirable to consider not only the intelligibility obtainable from a given speech system, but also the extent to which other tasks can be performed while using that system". (p. 74)

The background research, underlying assumptions, and experimental techniques utilizing a secondary task for measuring speech processing demands will be explained later in this paper.

With reference to cognition, Rabbitt (1966) expounded on Broadbent's ideas. He proposed that the extra effort used by a listener to correctly discriminate speech under degraded listening conditions can reduce the remaining effort reserves required to perform cognitive operations on the speech material. To test this assumption, Rabbitt utilized a memory recognition task for words heard correctly in noise. His results revealed that:

> "Levels of degradation which do not affect intelligibility may nevertheless affect the efficiency with which subjects carry out certain operations on words transmitted through the circuit. Memory tested by recognition, is shown to be a case in point". (p. 384)

The findings of Broadbent and Rabbitt hasten speculation that intelligibility per se may not be the sole contributing factor to learning performance deficits under degraded listening conditions. Instead, the auditory processing demands during learning are important factors requiring further investigation. The purpose of this paper is to assess processing demands during auditory learning under degraded listening conditions. Specifically, this investigation will focus on auditory learning processing demands when the speech signal is presented at a reduced intensity and/or in noise; yet at a highly intelligible level.

CHAPTER II

REVIEW OF THE LITERATURE

A growing body of research indicates that noise and reduced signal intensity can have detrimental effects upon learning performance. To better understand the seriousness of this problem, a review of the literature was undertaken with regard to (1) the effects of reduced signal intensity upon learning performance, and (2) the effects of noise upon learning performance.

For the audiologist, the study of processing demands during auditory learning is a relatively uninvestigated area of research. Consequently, a review of relevant research in this area is warranted. To better understand processing demands during auditory learning, the review of the literature continues by exploring the following areas: (3) the limited capacity processor, (4) selective attention, and (5) measurement of processing demands.

I. EFFECTS OF REDUCED SIGNAL INTENSITY ON LEARNING PERFORMANCE

Over fifty years ago, Pintner and Paterson (1917) reported severe educational retardation among deaf children. Since then, it has become widely documented that children with significant hearing losses (i.e., greater than 26 dB HL: ANSI-1969) show decrements in learning performance, as is reflected in delayed language and speech development, poor speech discrimination, and educational achievement deficits

(Kodman, 1963; Mindel and Vernon, 1971; Reis, 1963; Schein and Bushnaq, 1962; Wrightstone, Aranov, and Markowitz, 1972; and Young and McConnell, 1957).

While most studies undertaken in this area have dealt with children possessing moderate to profound sensorineural hearing losses, recent attention has been focused upon the effects of minimal hearing impairments upon language, speech, and educational performance. Minimal hearing loss hereafter in this paper will refer to hearing losses within the range of 15-30 dB HL (ANSI-1969) (Northern and Downs, 1974). Quigley (1970) found that children with hearing losses between 15-26 dB HL scored significantly lower on language related subtests of the Stanford Achievement Tests compared to children with hearing 15 dB or better.

Ling (1972) compared the achievement test results of hearing impaired and normal hearing children matched for age, intelligence, and environmental factors. The control group consisted of children with hearing thresholds better than 15 dB HL, while the experimental group was composed of children with hearing losses of 15 - 45 dB HL due to otitis media. Ling found a positive correlation between degree of hearing loss and performance on achievement tests. Delays of 15 months in reading skills, 19 months in problem arithmetic, and 16 months in mechanical arithmetic were evident by the time the child reached 9 - 10 years old.

Kaplan (1973) followed the progress of 489 Alaskan Eskimo children for the first ten years of their lives. Seventy-six percent of the children had one or more episodes of otitis media since birth. He reported a significant loss of verbal ability and delays in reading, math, and language among children with hearing losses greater than 26 dB HL who contracted otitis media before age two. Equally important, however, was a second finding that children with an early onset of otitis media who retained a conductive component (i.e., 15 dB air-bone gap) had lower verbal and achievement scores than normal hearing children.

Holm and Kunze (1969) studied the effects of fluctuating conductive hearing loss due to otitis media on performance of the following language and speech tests: Illinois Test of Psycholinguistic Abilities, Peabody Picture Vocabulary Test, Templin-Darley Picture Articulation Screening Test, and the Mecham Verbal Language Development Scale. The control group had no history of hearing loss, while the matched experimental group was composed of children aged 5 - 9 years with documented histories of fluctuating hearing losses due to otitis media. On all auditory processing and verbal production tasks (except the auditory decoding subtest of the ITPA) the experimental group was significantly delayed in language skills.

These studies lend support to the belief that minimal hearing loss due to middle ear pathology can result in educational, language, and speech deficits. The significance of these findings becomes more dramatic when the incidence of middle ear impairment is realized. While potentially significant hearing losses of greater than 25 dB HL have been reported between 1.7 percent (Eagles, 1963) to 4.1 percent (Hull, et al, 1971) of preschool and school-age children, the incidence of middle ear pathology is considerably higher. Eagles (1972) found evidence of middle ear disease among 24.4 percent of five-to-ten year old children. Brooks (1969) found an inverse relationship between middle ear disease and age. While the presence of middle ear fluid was found in only 2 - 3 percent of the 9 - 11 year old children, it increased to 20 percent of the five year old children. In addition, there is evidence that the incidence of middle ear pathology among children from minority and low socio-economic groups (particularly Native Americans and Eskimos) is substantially higher (Beal, 1972; Fey, et al., 1970; Haymon and Kester, 1956; Reed, et al., 1967).

Unfortunately, these children may go through their early childhood and education without detection of their hearing impairments. Holm and Kunze (1969) state that under favorable listening conditions children with minimal hearing losses should not experience particular difficulty understanding normal conversational speech. However, as will be pointed out in the next section, a child does not grow up living in favorable listening environments.

II. EFFECTS OF NOISE UPON LEARNING PERFORMANCE

Whether at home, in the classroom, or on the playground, a child must live in environments bombarded with noise. Even the newborn baby confined to an incubator begins his life in noise levels of 70-75 dB(C) (Peltzman, et al., 1970). A recent Environmental Protection Agency (1974) survey indicated that about ten million people in the United States live in areas with environmental noise levels above 60-70 dB, and an additional five million where levels exceeded 70-80 dB. Levels inside these residences averaged between 45-65 dB, depending on whether the windows were open or closed.

While the optimum noise levels for classrooms should not be in excess of 35-40 dB SPL (Knudsen and Harris, 1950), noise levels have been reported 20-30 dB higher in a number of educational settings (Paul, 1967; Sanders, 1965). These noise levels were particularly higher in the elementary schools compared to the upper grades.

More critical to speech understanding than the absolute noise levels is the speech-to-noise ratios in the classroom. There is evidence that children require higher signal-to-noise ratios in order to obtain comparable speech perception performances to adults (Goldman, et al., 1970; Marsh, 1973). Unfortunately, these high signal-to-noise ratios do not exist in the classroom. Sanders (1965) reported an average speech-to-noise ratio of from +1 dB in kindergarten classrooms to +5 dB in elementary and high school classrooms. Paul (1967) found a similar speech-to-noise ratio of +3 dB in the classrooms he studied. While these speech-to-noise ratios can result in reduced speech discrimination for normal hearing children, the deleterious effects of noise are compounded for the hearing impaired (Gengel, 1971).

An additional complication that school children encounter during audition in the classroom results from the reverberation of sound. For both normal and hearing impaired listeners, there exists an inverse relationship between reverberation time and speech intelligibility performance (Crum, 1974; Finitzo-Hieber, 1975). That is, as reverberation time increases, speech intelligibility decreases. John (1960) suggests 0.5 seconds as the maximum allowable reverberation time for classrooms designed for the hearing impaired, while Niemoller (1968) places this value at 0.4 seconds for small classrooms and 0.6 for larger classrooms. In actuality, reverberation times for classrooms have ranged from 1.2 seconds (Tolk, 1961) to as high as 3.4 seconds (Thomas, 1960).

Absolute noise levels, reduced speech-to-noise ratios, and excessive reverberation times all combine to produce the adverse listening conditions in which children must do their auditory learning. The consequences of prolonged exposure to noise can thus have its most far reaching effects during the critical developmental periods of early childhood. Here noise can produce delays in speech and language development, as well as impairments in reading and listening skills (Miller, 1974; Mills, 1975).

As mentioned during the introduction, direct laboratory studies on the effects of noise on learning have been reported in the psychological literature. Several of these studies have been concerned with the processing demands during learning in a background of noise. To provide better continuity, this research will be described in later sections of the review of the literature.

III. THE LIMITED CAPACITY PROCESSOR

"I can do only so much at a time" is an appeal heard every day emphasizing one of man's many inadequacies. Man is not omniscient -- all seeing, all knowing. Instead, he is limited in the amount of information that he can process at any given instant. During the past twenty-five years, there has been increasing interest in the idea that man possesses a central mechanism of limited capacity for the processing of information (such as learned material). Numerous theories have been designed to explain how the limited capacity processor works. Kerr (1973) pointed out that while these theories may differ in their explanations, they share one common assumption:

> ". . .under some conditions two signals which simultaneously require access to the limited capacity system will interfere with each other. Interference is a reduction in the efficiency of processing a signal that is measured by changes in the speed or accuracy of responses to the signal." (p. 401)

It is not the purpose of this paper to review all of the many theories that have been proposed to explain the limited capacity processor. Instead, two of the more general models of the limited capacity processor are investigated. A simple understanding of these two models is vital; for they form the theoretical bases for the experimental design and procedures used later in this study. It should always be kept in mind, however, that these explanations are only theories, and that the question as to how man processes information still goes unanswered.

<u>Bottleneck Models of Attention</u>: The question of how the limited capacity processor operates is really one of how attention is allocated. Most of the modern theories of attention have focused upon the establishment of a "bottleneck" somewhere in the organization of the processing mechanism. A "bottleneck" is "a stage of internal processing which can operate only on one stimulus or one response at a time" (Kahneman, 1973, p. 5). The locus of where the bottleneck lies in the internal organization of the information processor has been a matter for considerable debate. From this debate have sprung two bottleneck models; a single channel processor and a parallel processor.

The bases for the single channel model (also called the filter theory of attention) was originally generated by Welford (1952) and Broadbent (1958), and later refined by Broadbent (1971). The single channel model suggests that the bottleneck is located prior to a stage of perceptual analysis of a stimulus (See Figure 1). According to this model, man possesses a single channel processor; such that if two signals are presented simultaneously, only one can be transmitted throughout the remaining processing system. The second signal is either filtered out or held in storage until the response to the first signal has been selected. Therefore, in this model, attention controls perception (Kahneman, 1973).

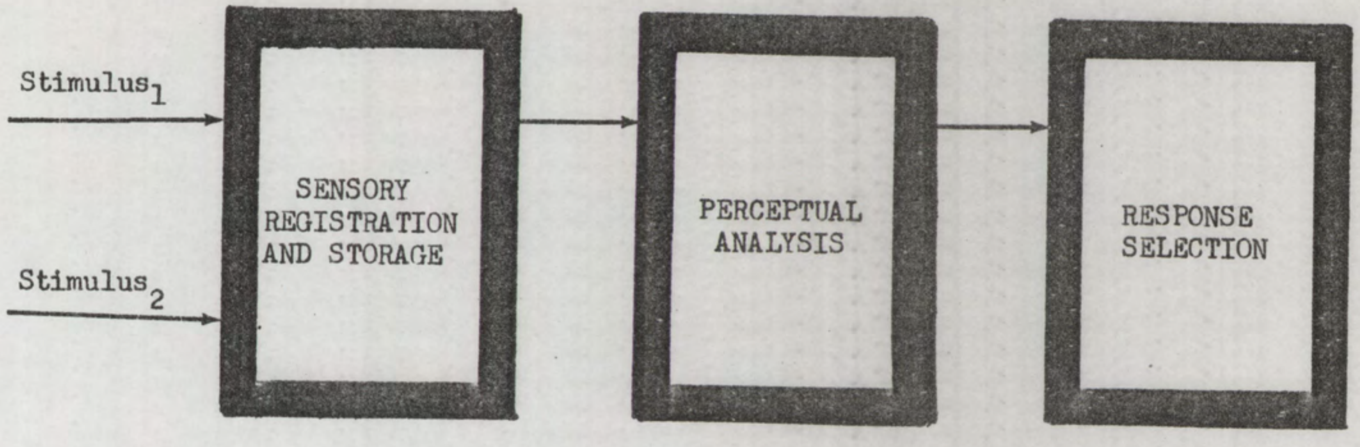


Figure 1. Single channel model of attention. (From Kahneman, 1973, p. 6)

In practice, the single channel model of attention requires that the time to perform two different tasks should be equal to or exceed the amount of time to perform each task separately (Kerr, 1973). However, this has not always been found to be true. Keele (1967) showed that the time to perform a single task can, in fact, be longer than the time required to perform the same task in conjunction with a different task. Such findings have directed suspicion toward a single channel theory, and resulted in another model which reestablished the locus of the bottleneck.

The parallel processing model (Deutsch and Deutsch, 1963) places the bottleneck following the stage of perceptual analysis, but preceding the response selection stage (See Figure 2). According to this model, more than one stimuli simultaneously make demands upon the central processing mechanism (Posner and Keele, 1970). When the two stimuli reach the response stage, only one response is selected at a time; that response being the one that best fulfills the situation requirements at that moment in time (Kahneman, 1973).

The parallel processing model has also been received with criticism. The bulk of this criticism centers upon the fact that our perceptual analysis can be affected by how we selectively attend to simultaneously presented stimulus inputs. More information will be presented concerning this matter in the section concerned with selective attention.

Capacity Models of Attention: Within the past ten years, a capacity (also called a variable-allocation) model of attention has been proposed

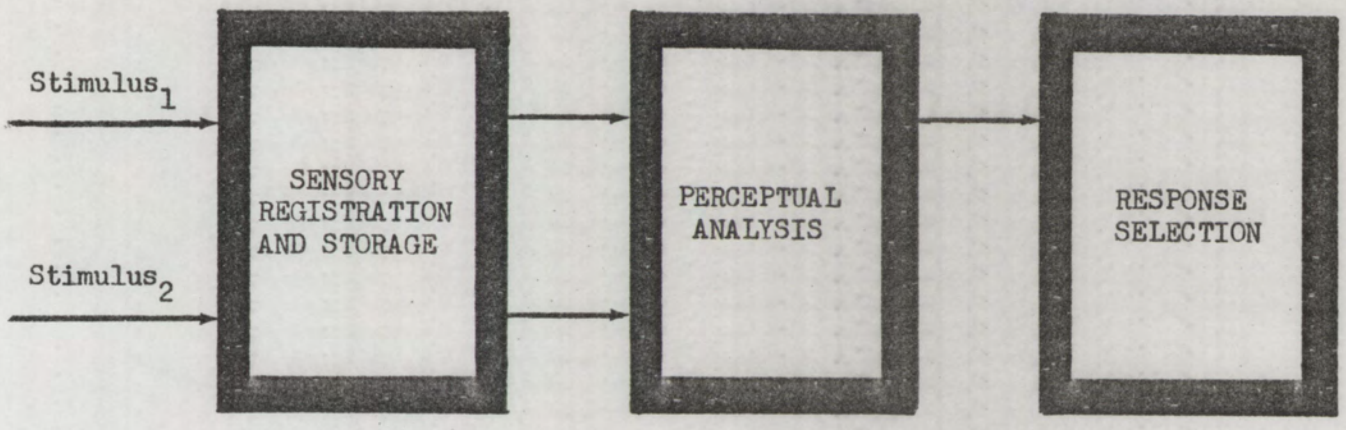


Figure 2. Parallel processing model of attention. (From Kahneman, 1973, p. 6)

(Moray, 1967; Kahneman, 1973) to explain the workings of the limited capacity processor. In a capacity model, the existence of a bottleneck is not recognized. Instead, the model envisions a limited capacity processor which allocates attention (or effort)* to meet the demands of a given task (Kantowitz, 1974). With reference to this model, Kahneman (1973) points out several ways in which performance on a task (such as learning) can breakdown: (1) As the task becomes more difficult, it will require more effort. However, if the supply of effort is not adequate to meet the task demands, the performance on the task will falter. (2) If less effort is allocated than is required for a task, the result will be performance deterioration. (3) Performance can falter because effort is allocated to the performance of other activities. (4) Performance may break down because the input information of a signal was insufficient to direct our attention to that signal.

The allocation of effort in the capacity model is not linear. That is, there is not a one-to-one relationship between the capacity of effort demanded by a task and the capacity supplied (See Figure 3). This discrepancy becomes more significant as the demands of the task increase, until a state of effort overload is approached.

In order to understand this discrepancy, the concept of "spare capacity" was introduced. Even when a task's demands are zero, some

---

*In the capacity model, effort is synonomous with attention; therefore, the terms are used interchangeably.

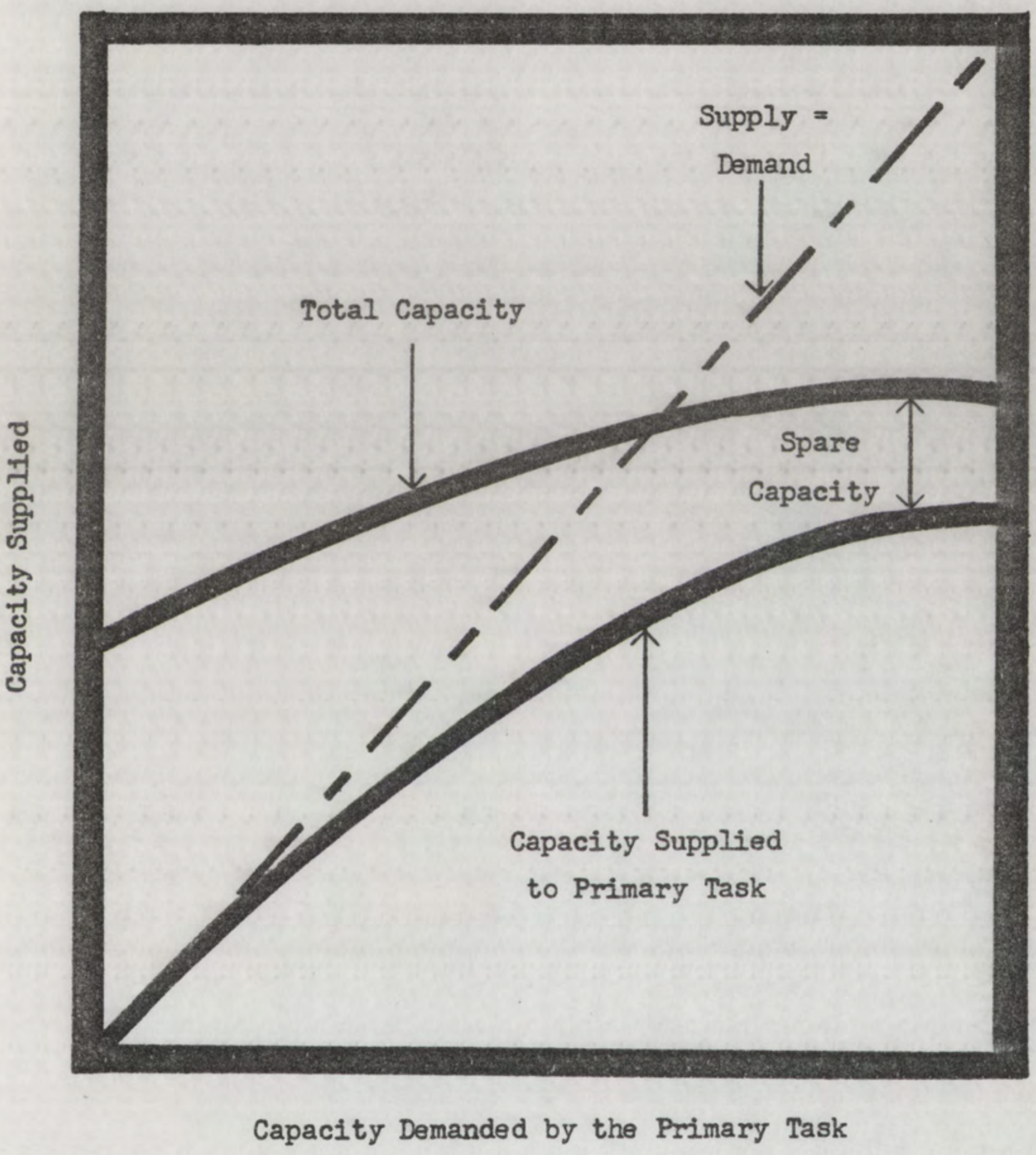


Figure 3. Supply of effort as a function of demands of a primary task. (From Kahneman, 1973, p. 15)

attentional capacity is still being supplied for the continuous monitoring of our environment. This is referred to as spare capacity. As the demands of a task increase, there is a reciprocal decrease in the amount of spare capacity available for the perceptual monitoring of our surroundings.

It is possible to quantify the amount of spare capacity available at a given instant of time when performing a task. By measuring the amount of spare capacity, an assessment can thereby be made about the processing demands of the task (e.g., auditory learning). The techniques for measuring spare capacity are explained in the section on measurement techniques.

The bottleneck and capacity models of attention are only two of several models which attempt to explain how man processes information. Both models are rather general in their approach which can be held as a criticism (See Kantowitz, 1974, p. 94). For this reason, further extensions of these theories is provided in the following section concerned with selective attention. However broad in scope these theories may be, it still remains essential that the bottleneck and capacity theories be understood in order to continue an investigation of processing demands during auditory learning.

IV. SELECTIVE ATTENTION

As a child sits in the classroom, he is overwhelmed by stimuli which collide with his senses. While trying to engage in an auditory learning activity, he must contend with the teacher's instructions, dropping of books, whispers of fellow students, the hum of the air conditioning, the whine of the wind, the commotion of traffic outside, shuffling of feet, etc. From this rubble a child must selectively attend to the relevant auditory message in order to perform the learning task. With such an onslaught of distraction, it is not unusual to expect reduced learning performance.

The Cocktail Party Phenomenon: Psychologists have studied the subject of selective attention since the early part of the twentieth century. As early as 1916, it was reported that stimuli presented to the same sensory modality can have greater distractibility effects than stimuli arriving at different sense modalities (Evans, 1916). Since then the literature has increased remarkably in its investigations of selective attention both within a single modality and between different modalities.

With respect to audition, the classic work on selective attention was performed by Cherry (1953). Cherry simultaneously presented two prose messages to subjects; one message through each earphone. The subjects were instructed to "shadow"* the message presented to a predesignated ear. In subsequent questioning the subjects were able to correctly repeat the message presented to the ear shadowed but could not recall the message presented to the other unattended ear. Speith,

---

*The term "shadowing" is used in the psychological literature, referring to attending to one auditory signal in preference to another auditory signal presented simultaneously.

Curtis, and Webster (1954) performed a similar experiment presenting two simultaneous messages through separate loudspeakers. While the subjects experienced difficulty in distinguishing the messages when the loudspeakers were placed in adjoining positions, they were able to shadow the designated message effectively when the speakers were separated spatially.

Cherry (1957) labeled the ability to select stimulus inputs by focusing attention on signals with specific acoustical properties or originating from a designated sound source as the "cocktail party phenomenon". He likens his experimental findings to the situation where a person can focus his attention upon a particular conversation in preference to several other loud conversations carried on simultaneously at a cocktail party.

Initially, the findings of Cherry suggesting that selective attention to specific inputs is affected by a perceptual analysis would seem to support the single channel bottleneck theory and discount a parallel processing bottleneck theory (Kahneman, 1973). However, Moray (1959), using a shadowing task similar to Cherry's, found that the unattended message was more likely to be recalled if it was preceeded by the subject's name. Such an experience occurs at a cocktail party when a person may shift his attention to a previously ignored conversation if his name is spoken in that conversation.

Treisman (1964) devised an ingenious experiment to test whether two messages can be processed simultaneously. Using French-English bilinguals in her experiment, she simultaneously presented a message in English in one earphone to be shadowed by the subject. A second message in French was presented to the unattended ear. At first, the context of two messages was different. The French message was later switched into a direct translation of the English message so that it lagged slightly behind the English message in time. When the context of the two messages was different, the subjects were not able to recall the unattended message. However, when the message was switched to a French translation, the subjects became aware that the two messages had the same meaning. Such an experiment supports a parallel processing model, suggesting that it is possible to divide attention among two concurrent stimulus inputs.

Theories of Selective Attention: Several additional theories have been put forth to explain the discrepancies between the single channel and parallel processing models. With closer analysis of these theories, it becomes apparent that they are in essence merely modifications or extensions rather than denials of the original single and parallel processing models.

Treisman (1960) modified Broadbent's filter theory to account for the occurrence of meaningful material sometimes being recognized within the unattended message. She proposed that the filter attenuated the material in the unattended message rather than eliminating it altogether. To reduce the processing load, the material in the unattended message is processed in a hierarchical manner such that while all inputs are recognized and identified, only those parts of the message that bear special importance receive further attention (Egeth and Bevan, 1973). Treisman concludes that parallel processing is possible if the two concurrent inputs reach different analyzers. This can account for recognition of changes in the characteristics of the unattended message; since the unattended message would reach a different analyzer than the attended message. However, Treisman still retained Broadbent's idea that if more than one input reached the same analyzer, the inputs must be processed serially (i.e., one input at a time) (Kahneman, 1973). This modified theory is currently referred to as the Broadbent-Treisman filter model of selective attention.

Norman (1968) extended the parallel processing model of Deutsch and Deutsch by suggesting that the message that is selected depends on both the importance as well as the strength of the input. A similar theory has been reported by Morton (1969) who views selective attention as occurring when a criterion level of activation is reached as information gradually increases. The rate of increase is controlled by the strength of the stimulus input as well as by the strength between the input and a memory unit which accumulates information.

Niesser (1967) suggests that selective attention begins with an initial sorting and organization of sensory inputs performed by a passive receptive process. According to Niesser (1967), this passive process is:

> ". . . normally supplemented by an active process of analysis-by-synthesis in which the listener produces inner speech (at

> some level of abstraction) to match the input. I suggest that this constructive process is itself the mechanism of auditory attention. On this hypothesis, to follow one conversation in preference to another is to synthesize a series of linguistic units which match it successfully. Irrelevant, unattended streams of speech are neither "filtered out" nor "attenuated"; they fail to enjoy the benefits of analysis-by-synthesis." (p. 213)

The capacity model has also addressed the issue of selective attention. With this model, capacity is allocated to the processing of specific perceptual units in preference to others. Kahneman (1973, p. 129) states that, "According to this analysis, attention is focused by selecting among available perceptual units (objects or events) those units to which most capacity should be allocated". While capacity can be allocated quite effectively to the relevant stimuli (figural selection), it is not a perfect situation. That is, some capacity is allocated to the processing of irrelevant stimuli. For this reason, the processing of relevant stimuli is much more effective in a "quiet" than in a "noisy" situation.*

The monitoring of irrelevant stimuli is provided by the allocation of spare capacity. As previously stated, the amount of spare capacity available for perceptual monitoring is inversely proportional to the demands of the primary task (e.g., auditory learning). Therefore, when the primary task requires a great deal of effort, the perceptual monitoring of irrelevant stimuli will be reduced. Kahneman (1973, p. 135) sums up the capacity theories with regard to selective attention

---

*"Quiet" and "noisy" are used generically in this sense to refer to an environment without or with distracting stimuli.

when he states, "The distinctive predictions of the present theory are that the effectiveness of selection depends on the ease with which relevant stimuli can be segregated at the stage of unit formation, and that the effectiveness of rejection of irrelevant stimuli depends on the amount of capacity demanded by the primary task".

Arousal, Noise, and Selective Attention: Continuous noise can increase a person's arousal level and, consequently, improve one's ability to selectively attend to certain stimulus inputs. The result of such focusing can be an improvement on primary task performance at the expense of poorer performance on a simultaneously presented secondary task to which little attention is directed (Keele, 1973). In actuality, quality of performance and arousal level do not always function so linearly. In order to explain the relationship between arousal and performance, the Yerkes-Dodson law was proposed (Yerkes and Dodson, 1908). According to this model, performance varies as an inverted U-shaped function with arousal. A third variable introduced into the Yerkes-Dodson Law states that the quality of performance will also fluctuate with task complexity at increasing arousal levels (See Figure 4).

Using the Yerkes Dodson Law, it is possible to make predictions about the performance of a task in a background of noise. As already mentioned, background noise can increase arousal level. Thus, the Yerkes-Dodson Law would predict better performances on simpler than difficult tasks in a background of noise. Such predictions have been borne out in the literature (Kahneman, 1973).

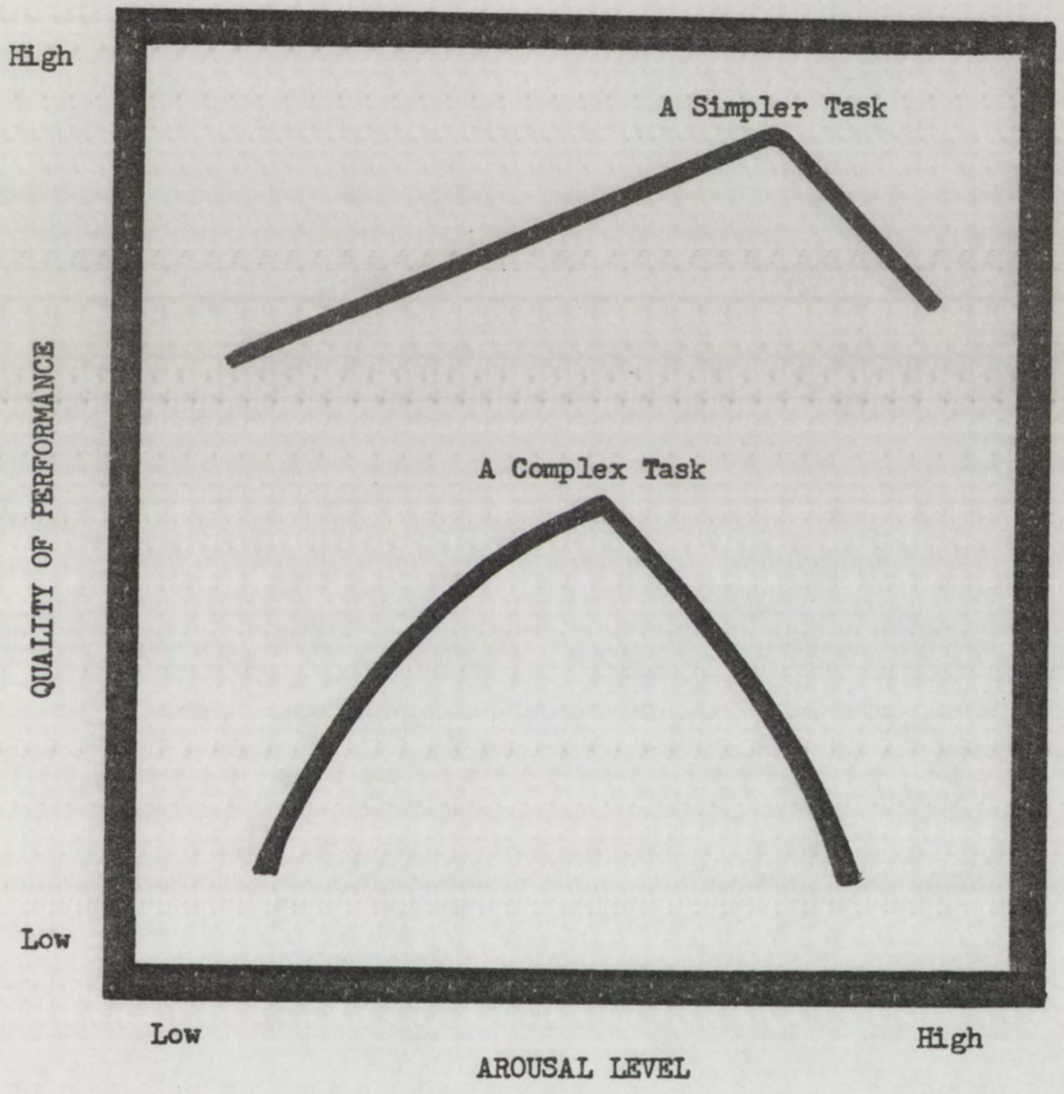


Figure 4. The Yerkes-Dodson Law. (From Kahneman, 1973, p. 34)

It should be mentioned that the bulk of the studies on the effects of noise on arousal level and performance have been conducted using high noise levels (i.e., 90 dB SPL or more). Keels (1973), therefore, emphasizes the urgency for studying the effects of low level noise (such as is found in everyday environments) upon arousal and ultimately upon performance.

Physiological Correlates of Selective Attention: The research, thus far, presented on selective attention has to some extent been confirmed by physiological studies. It is now commonly accepted that intense, novel, unexpected, or important stimuli cause an orienting reaction accompanied by a marked change in the electrical activity of the brain. If this stimuli does not maintain its significance, habituation my occur. The processing of this stimuli thus becomes less effective with a concomitant reduction in the magnitude of the evoked potentials (Grossman, 1973).

Man's general arousal level, as well as his selection of stimuli, is determined largely by the following brain structures: the reticular formation, the nonspecific thalamic projection system, the basal forebrain, and the hippocampus. It is at these levels that excitatory and inhibitory influences interplay to determine the organism's overall responsiveness to certain types of stimuli. Milner (1970) stated that lesions in this neurological network can have "deleterious effects upon attention and result, in extreme cases, in complete failure to pay attention to anything", (p. 295).

While the physiological evidence can begin to account for how intensity reductions and/or background noise can affect signal processing, the biological mechanisms for selective attention still remains an area in great need of further research.

Application of Research on Selective Attention: Utilizing the research already presented in the theories on selective attention, it is possible to address the question of processing demands during auditory learning under degraded listening conditions. An auditory learning task, like any other human activity, places demands upon the limited capacity processor. If the only processing during a task was of the auditory learning signal, the difficulty of performing the task would be minimized. However, as has been previously mentioned, auditory learning is almost exclusively performed under degraded listening conditions, especially for the hearing impaired. Consequently, for a high level of auditory learning performance to be maintained, the listener must selectively attend to the relevant signal.

With regard to the degraded listening condition of reduced signal intensity, the past research would suggest that as intensity decreases there would also be a decrement in learning performance. As Norman and Morton have pointed out, a message is selected for processing depending on the importance, as well as the strength of the input signal. The physiological data just presented also provide evidence that more intense stimuli can maintain orienting responses toward a signal better than weaker stimuli.

Tracing the effects of noise on auditory learning is slightly more complicated. In this case, the limited capacity processor must sort through the available input stimuli and select the auditory signal required for learning. Research suggesting that selective attention allows for focusing on the auditory learning signal in a background of noise is summarized below:

1. Single Channel Theory (Broadbent, Welford): Background noise is filtered at the level of perceptual analysis, allowing the auditory learning signal to be further processed.
2. Attenuator Theory (Treisman): The single channel processor attenuates the background noise while the message bearing special significance (i.e., the auditory learning signal) will receive further processing.
3. Cocktail Party Phenomenon (Cherry): The auditory learning signal receives selective attention in the noise background by focusing upon message context, localization of sound signal, and by message frequency characteristics.
4. Parallel Processing Model (Deutsch and Deutsch): Though both the auditory learning signal and the background noise are processed in parallel, a response is selected on the signal depending on the situational requirements.
5. Message Significance (Norman): As an extension of the parallel processing model, the auditory learning signal is processed in preference to the noise background because of its importance and signal intensity.

6. Criterion Model (Morton): The auditory learning signal is processed when a criterion of activation is reached as the informational content of the message increases.
7. Analysis-by-Synthesis (Niesser): The auditory learning signal is selected over the background noise because it has the advantage of analysis-by-synthesis.
8. Capacity Model (Kahneman, Moray): The auditory learning signal is attended to by the allocation of capacity to this signal in preference to the background noise.
9. Increases in Arousal: As the noise level and, consequently, the arousal level is increased, the auditory learning signal is focused upon while other distracting material may be ignored.
10. Physiological Correlates: The auditory learning signal maintains higher cortical processing, while inhibition of the noise may occur at lower neurological levels.

Obviously, selective attention during auditory learning under degraded listening conditions can be explained in several ways. It is apparent that man does not process an auditory learning signal in only one manner; or according to the explanation of any single model or theory. Rabbitt (1971, p. 262) is in agreement when he writes:

> "My view is that the evidence leads to no conclusion, but rather to doubt about the value of trying to distinguish between serial and parallel processing as a guide to the development of models and to experiments."

In formulating an experiment on processing demands during auditory learning it is, therefore, advantageous to look for what the several theories or models have in common. One common assumption is that while auditory learning can proceed under degraded listening conditions, maintenance of a high performance level requires that increased demands be placed upon the limited capacity processor. For example, the processing demands during learning are far less for a student in a small conference room than in a large auditorium containing hundreds of other students. The student in the quiet conference room can be seen sitting leisurely back in his chair during the learning process. Conversely, the pupil sitting in the back row of the more reverberent, noisy auditorium leans forward in his chair as he strains to listen to the professor below. For both students it is possible to maintain high learning performance. However, for the student in the auditorium, this is only possible at the expense of exerting increased effort. A procedure for measuring such increased processing demands is advanced in the next section of this paper.

V. MEASUREMENT OF PROCESSING DEMANDS

There have been numerous methods proposed for measuring processing demands during mental operations such as learning. While several of these techniques will be mentioned, a greater part of the remaining review of the literature will be devoted to the method that will be utilized in the present investigation.

Physiological Measurement Techniques: The two most widely accepted physiological techniques for quantifying processing demands have been: (1) Measurement of pupil dilation, and (2) Measurement of increases in skin conductance during the performance of a task (Colman and Paivio, 1969; Kahneman, Tursky, Shapiro, and Crider, 1969). Of the two techniques, pupil dilation measurements are the more promising for research. Kahneman (1973) states that measurement of the pupil diameter is more sensitive to both between task and within task variations, as compared to other physiological techniques. However, he concedes that there remain fundamental difficulties in using any physiological technique (including pupil dilation) for the measurement of processing demands. The problem is that physiological techniques, which record the arousal levels of persons performing the task, not only measure the amount of effort invested in the task, but also the amount of stress the person exhibits. Therefore, when the results are interpreted, it becomes difficult to separate the effects of effort from that of stress.

Measurement of Speed, Accuracy, and Ease of Processing: Johnston, Wagstaff and Griffith (1972b) suggested three variables which can be used to assess processing demands during learning. They write, "Viewed as an enhancement in information flow, learning should show up on at least three dimensions of information processing: speed, accuracy and ease" (p. 307).

In the past, speed and accuracy of information processing has received the greatest amount of attention. Accuracy of processing demands is reflected in just about every learning activity that a child performs in the classroom. For example, when a student takes an examination, he obtains a score which is intended to be indicative of how well he has learned the subject matter. Several types of tests for children (particularly IQ tests) introduce a time limit, such that speed of information processing becomes a major factor in measuring learning performance. The rationale is that processing of any information requires time; even if it is merely a few milliseconds. Therefore, the speed of performing a task is reflective of the processing demands of that task.

Within the area of verbal learning, the dimension of ease (i.e., effort or attentional allocation requirements) of information processing has not been as systematically examined. Using a free recall verbal learning task, Johnston, Griffith, and Wagstaff (1972a) revealed the importance of adding the dimension of ease as a factor in evaluating processing demands. They found that speed, accuracy, and ease were not redundant in the information that they yielded concerning processing demands during learning. For example, the learning task was performed under low and high signal-to-noise ratios. The researchers found that one of the learning variables (i.e., serial position) they examined was only sensitive to different signal-to-noise ratios in the case of ease, but not speed or accuracy of processing.

Finally, Johnston, et al (1972a) suggest that even if there were redundancy in these three dimensions of information processing, the techniques used for quantifying ease of processing still would offer one important virtue. That advantage is that, when studying ease, processing demands can be assessed at any instant of time during the performance of a learning task. This is exceedingly important since, during a learning task, processing demands are constantly varying.

The technique that was used by Johnston and his fellow researchers in several learning experiments is known as probe reaction time measurements. This is also the basic technique which will be used to access processing demands during auditory learning in the present investigation. The theoretical bases, historical references and procedures for the probe reaction time experiment will now be discussed.

<u>Bases of the Probe Reaction Time Technique</u>: For nearly 80 years psychologists have studied the ability of individuals to perform two tasks simultaneously. A biologist named Jacques Loeb advanced the theory that mental operations could be studied by evaluating the degree of interference provided by a secondary task (Kerr, 1973). Welch (1898), a student of Loeb's, demonstrated this technique by having subjects attempt to maintain a hand pressure while performing secondary mental task operations such as arithmetic, counting, and reading tasks.

The advent of behaviorism during the first half of the twentieth century resulted in a decline of double stimulation studies. However, during the 1950's interest was redirected toward double stimulation experiments in order to investigate processing demands during mental operations (Bahrick, Noble, and Fitts, 1954; Brown 1958; Garvey and Taylor, 1959; Peterson and Peterson, 1959). Finally, during the past ten years, experimenters have begun to use the double stimulation paradigm to pinpoint processing demands at various points during performance of cognitive tasks.

The basic premise for the double stimulation experiment is the following: Because man has a limited capacity for processing information, any task that requires space in the processing mechanism will interfere with any other task that also requires space. Therefore, if two tasks are performed simultaneously, the amount of effort invested in a primary task can be assessed by viewing the performance on a secondary task. An interesting experiment illustrating this paradigm was conducted by Brown and Poulton (1961). These researchers used a memory and classification activity as a secondary task. The primary task was driving a car in a residential area versus a shopping area. The results of the study indicated that more errors were performed on the secondary task while driving in the shopping area as opposed to the residential area. It was, therefore, suggested that driving in the shopping area required more processing capacity. For further information on the double stimulation paradigm, the reader is referred to Kantowitz (1974).

While different techniques have been used as a secondary task, one of the most useful has been the probe reaction time task. Commonly in this technique a light or a tone is presented by the experimenter at various intervals during the performance of a primary task. The subject must then turn the probe signal off (usually by pushing a switch). A measurement can thereby be made of the subject's reaction time from the point when the probe is presented till it is turned off. Depending on the relative length of the reaction time, a judgement is made concerning the processing demands of the primary task. That is, the longer the reaction time, the greater the processing demands of the task.

The bases for the probe reaction time technique coordinates very well with the capacity models of Moray and Kahneman. The capacity invested in monitoring the probe is synonomous with the spare capacity reserved for perceptual monitoring of the environment. As the demands of the primary task increase, the amount of spare capacity decreases. Similarly, in the reaction time paradigm, as the primary task demands increase there is a proportional change in the reaction time to the probe signal.

As early as 1879, Obersteiner recognized the utility of using this technique for measuring processing demands. He wrote, "retardation of the reaction stands in an inverse proportion to the intensity of attention" (p. 439). Woodrow (1914, p. 8) commented (rather strongly) that the relationship between reaction time and degree of attention is "so overwhelming that it is unnecessary to argue the matter". More recently, Kantowitz (1974, p. 124) concluded, "The probe reaction time task will become an increasingly more useful tool for the study of attention".

Safeguarding the Primary Task: Basic to the double stimulation experiment is the premise that the performance on the secondary task must only reflect (but not affect) primary task performance. Therefore, certain safeguards must be instituted to insure that the probe reaction time task does not alter the performance of the primary task. The precautionary tasks that have been found to be effective in safeguarding the primary task are:

1. Kahneman (1973) has stated that the expectations of a secondary task probe by the subject, in itself, requires processing capacity; thus reducing attention directed toward the primary task. To offset this expectancy set on the part of the subject, probes should be at variable rather than fixed intervals during the primary task (Posner and Keele, 1970).

2. Kerr (1973) emphasizes the importance of maintaining consistency in the use of secondary tasks. She writes:

> ". . . processing demands are most accurately assessed within one specific paradigm using the same secondary task to evaluate various levels or points within one primary task. Within one paradigm, the structural interference should remain more constant, allowing the comparison of relative processing demands across the primary task". (p. 405)

3. The subject should be instructed to "protect" the primary task in favor of the secondary task. This can be done by emphasizing in the instructions the importance of the primary task in relation to the secondary task. Another effective technique has been to use tangible payoffs; with larger rewards for primary task performance than for secondary task performances (Johnston, Griffith, and Wagstaff, 1972a); Kahneman, 1970; Kerr, 1973).

4. A final technique is to use a single stimulation no probe control condition in the experiment. If this primary task only condition yields a comparable performance to a double stimulation similar condition, then it can be safely assumed that the probe reaction time task did not affect primary task performance (Kantowitz, 1974).

Probe Reaction Time During Verbal Learning Tasks: As previously mentioned, one of the unique advantages of the probe reaction time technique is that processing demands can be measured at any instant during a mental activity. This feature has become particularly valuable in studying processing demands of the various components of a verbal learning task. Among the important findings that the research has yielded are:

1. Executing a movement to a physical stop does not require processing capacity (Posner and Keele, 1969; Ells, 1972). This becomes increasingly important in designing instrumentation for probe reaction time experiments.
2. Encoding* does not increase processing demands during a learning task. (Johnston, et al, 1970, 1972a, 1972b; Kerr, 1973; Posner and Boies, 1971).

---

*Kerr (1973) defines: Encoding as "the operations required as one stimulus item is received and contacts its representation in memory". (p. 406)

3. The three components of learning which do require processing capacity are multiple input, rehearsal, and response selection* (Johnston, et al., 1970, 1972a, 1972b; Martin, 1970; Posner and Boies, 1971). Of the three components, response selection requires the most capacity while multiple input requires the least. Kerr (1973) concludes that "Multiple input processing is affected by physical presentation variables such as signal-to-noise ratio rather than by linguistic or organizational variables, while recall and rehearsal processing demands reflect the organization and nature of the material to be recalled" (p. 411).

4. Johnston, et al. (1972a) found that expended processing capacity was increased at low compared to high signal-to-noise ratios. Unfortunately, the values of these signal-to-noise ratios was not stated, and the strict control for signal intelligibility was not totally apparent. Finally, the absolute intensity of the signal was not examined as a variable in this or any other similar study.

---

*Kerr (1973) defines: Multiple input as "a series of operations associated with receiving a group of stimuli, such as a list of words or a sentence. In this case, one must both encode one stimulus and retain or comprehend the meaning of previously presented items." Rehearsal as, "mental operations that 'maintain' an item or list of items in memory for later use." Response selection as, "a number of operations associated with 'producing' answers in a variety of settings, such as recall tasks or tasks requiring the execution of a discrete or continuous motor response." (p. 406)

These research findings indicate that processing demands during learning are constantly switching in degree during the performance of a verbal learning task. This emphasizes the importance of using a technique, such as probe reaction time, which can reflect these fluctuations. For this reason, the probe reaction time technique is the method of choice for the present investigation measuring processing demands during auditory learning under degraded listening conditions.

CHAPTER III

EXPERIMENTAL DESIGN

The current investigation was designed to study processing demands during auditory learning under degraded listening conditions.

I. SUBJECTS

The subjects in this study were 49 undergraduate students (12 males and 37 females) who fulfilled the following selection requirements:

1. 18-25 years of age.
2. No significant visual defects. Corrected vision was not considered to be a significant visual defect.
3. Pure tone air conduction thresholds equal to or better than 10 dB HL (ANSI-1969) at octave frequencies from 250-4000 Hz.
4. No history of fluctuating hearing sensitivity or otologic disease.

It is appropriate, at this time, to mention the rationale behind using normal hearing subjects in preference to hearing impaired individuals for a study of reduced signal intensity. When using hearing impaired subjects, it is extremely difficult to control for the effects of fluctuating and progressive hearing loss upon past learning experiences. If hearing impaired subjects had been employed in this study, a normal hearing group of individuals would have been required to serve as a control group. However, when making comparisons between the learning performances of normal versus hearing impaired individuals, the results would be dubious because the two groups would have brought different learning experiences into the experimental situation. Secondly, no past research using normal hearing subjects has been conducted specifically investigating processing demands during auditory learning under degraded listening conditions. Such normative data is essential before similar research is carried out with the hearing impaired.

II. LEARNING PARADIGM

A paired associate learning task was chosen as the learning paradigm to be used in this experiment. In paired associate learning, it becomes the task of the subject to form associations between a given response and a stimulus word; such that, when the stimulus word is presented again, a subject can anticipate the correct response. For this reason, this particular paradigm is referred to as the anticipation method of paired associate learning.

There are several reasons why the paired associate learning paradigm was chosen in preference to other learning paradigms. Ellis (1972) reported that paired associate learning involves at least ten different types of information processes and subprocesses; among which are: stimulus discrimination, response integration, stimulus selection and encoding, association formation, mediation, and organizational processes. During paired associate learning, there is a rapid switching between these processes. Using the probe reaction time task, the processing demands of these processes can be estimated. The paired associate learning task also offers flexibility in interpretation of results. With this procedure the experimenter can either view learning performance after a specified number of trials; or he can study the number of learning trials that are required for the subject to reach a designated criterion (usually one or two trials of 100 percent correct response to the stimulus words). In addition, learning curves can be constructed to visualize the progress of learning under different experimental situations. Finally, the paired associate learning task can be structured so that the difficulty of the task can be varied by the number and the complexity of the stimulus and response words.

III. STIMULUS MATERIAL AND PRESENTATION

Learning Stimuli: To assess the processing demands of auditory learning under degraded listening conditions, it was imperative that the learning stimuli be 100 percent intelligible. The reasoning for this was that if the intelligibility of the speech material were reduced, the task would become one primarily of intelligibility rather than of learning. To insure the intelligibility of the learning material used, twenty W-1 spondee words were chosen as the learning stimuli. Hirsh, et al. (1952), found that these words required only a 20 dB range to rise from a zero to a 100 percent articulation function score. Throughout the 20 to 80 percent range, the words rise in intelligibility at about eight percent per decibel. While there is a gradual tapering in slope above the 80 percent point, the authors noted that 100 percent intelligibility of words could be obtained at +14 dB sensation level. This was important since the lowest presentation level of learning stimuli in this experiment was +20 dB sensation level (i.e., 6 decibels higher).

Homogeneity among the twenty spondees was also a requirement for learning material selection. Curry and Cox (1966) published data on the relative intelligibility of the 36 spondees used in the W-1 list. The researchers determined the mean sensation level at which fifty normal hearing subjects correctly identified individual spondee words. These results were very similar to that found by Bowling and Elpern (1961) suggesting high consistency in intelligibility among spondee words. The twenty words chosen for the present investigation had a mean sensation level range of from 3.8 dB SL ("Hotdog") to 7.0 dB SL ("Inkwell"). Stated differently, there was only a 3.2 dB difference in mean sensation level between the most and the least intelligible spondee. This allowed for high intelligibility and homogeneity among the learning stimuli. The twenty spondee words used in this study and their mean sensation levels of intelligibility (as found by Curry and Cox) are presented in Table I.

The twenty spondees were randomly assigned into ten, two-word pairings. The first word in each pairing served as the stimulus word, while the second acted as the response word. For an initial exposure trial the words were tape recorded on track 1 from a 33-1/3 rpm disc recording of the W-1 list. Each pairing of words was subsequently

TABLE I

RELATIVE INTELLIGIBILITY OF TWENTY SPONDEE WORDS USED AS LEARNING STIMULI

Spondee Word	Mean Sensation Level in dB
Hotdog	3.8
Iceberg	4.0
Airplane	4.2
Armchair	4.4
Playground	4.6
Drawbridge	4.8
Woodwork	4.8
Hardware	4.9
Cowboy	5.0
Birthday	5.6
Greyhound	6.0
Eardrum	6.1
Sunset	6.2
Northwest	6.2
Sidewalk	6.5
Railroad	6.5
Daybreak	6.6
Doormat	6.8
Schoolboy	6.9
Inkwell	7.0

Source: (Curry and Cox, 1966, p. 421)

spliced according to the temporal parameters illustrated in Table II. The exposure trial was followed by 12 anticipation trials. Again, words were tape recorded on track 1 from the same disc recording. Words were spliced onto the tape such that the pairings were randomly varied from trial to trial to eliminate serial position serving as a learning cue. The temporal parameters for presentation of words in a learning trial is shown in Table III. The ten pairings in the exposure trial and for the 12 anticipation trials are presented in Appendix A. A 1000 Hz calibration tone was added at the beginning of the learning stimulus tape, such that spondee word intensity peaks corresponded to 0 VU.

Noise Stimulus: The competing message signal was composed of a multiple talker noise recorded on a separate magnetic tape. This tape was prepared by the Northwestern University Auditory Research Laboratory, and contains four male and four female speakers reading a prose passage with a minimum of inflection and intonation. The speakers participating were students with previous experience in monitoring spoken materials. A 1000 Hz calibration tone was added to this tape, such that the level of the most frequent peaks of the noise corresponded to 0 VU. A spectral analysis of the noise signal is shown in Figure 5.

Learning Signal Presentation Level: The speech signal containing the paired associate learning task was presented at 50, 35, and 20 dB sensation levels. Because all subjects participating in this study were required to have pure tone averages equal to or better than 10 dB HL, a 50 dB sensation level was considered appropriate as a level

TABLE II

TEMPORAL PARAMETERS DURING EXPOSURE TRIAL

Stimulus Word 1	1 Second Pause	Response Word 1
	5 Second Pause	
Stimulus Word n	1 Second Pause	Response Word n
	5 Second Pause	
Stimulus Word 10	1 Second Pause	Response Word 10

TABLE III

TEMPORAL PARAMETERS DURING ANTICIPATION TRIALS

Stimulus Word 1	3 Second Pause for Subject Response	
Stimulus Word 1	1 Second Pause	Response Word 1
	4 Second Pause	
Stimulus Word n	3 Second Pause for Subject Response	
Stimulus Word n	1 Second Pause	Response Word n
	4 Second Pause	
Stimulus Word 10	3 Second Pause for Subject Response	
Stimulus Word 10	1 Second Pause	Response Word 10

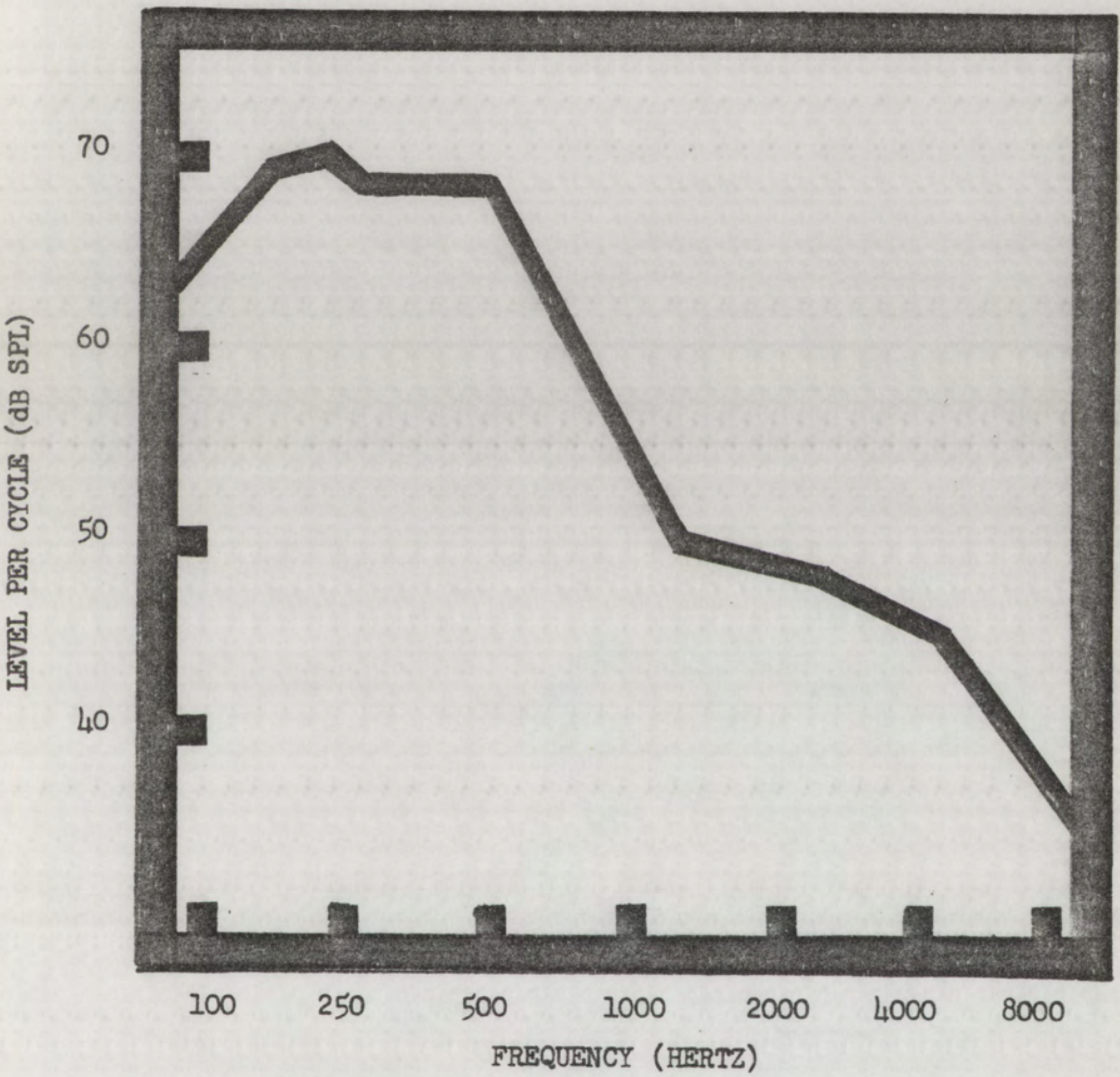


Figure 5. Spectral analysis of multiple talker noise.

of normal conversational speech. With 50 dB SL thus representing the optimum intensity level, the presentation at 35 dB SL served as a 15 dB attenuation of normal conversational speech; while 20 dB SL was a 30 dB attentuation of normal conversational speech. If 15 and 30 dB attenuation is thought of in terms of hearing loss, the two levels represented the lower and upper values, respectively, of minimal hearing impairment (Northern and Downs, 1976).

Signal-to-Noise Presentation Level: A +6 dB signal-to-noise ratio was chosen to be used in the present investigation. A pilot study using 10 normal hearing subjects was conducted to determine a signal-to-noise ratio that was capable of yielding at least a 90 percent correct discrimination of the stimulus material. In this preliminary investigation (testing different subjects than in the main study), the 10 stimulus word pairs of the exposure trial were presented through the sound field at 20 dB SL at varying (0, 3, 4, and 6 dB) signal-to-noise ratios. The +6 signal-to-noise ratio was found to be the lowest level satisfying the previously stated criterion for understanding the stimulus material. It is important to note that if a misunderstood word was repeated immediately following the error, upon retest the subjects could attain a 100 percent correct intelligibility of all 20 words.

Probe Reaction Time Signal Presentation: Two probe signals were randomly* presented during each learning trial. One probe signal was

*As was previously mentioned, randomization of secondary task probe signals is an effective technique for protecting the primary task performance.

presented during the response selection (RS) stage, while a second probe was presented during either the multiple input (MI)* or the rehearsal stage. The multiple input and rehearsal probes were alternated between learning trials, such that if the multiple input probe was presented on the odd number trials, the rehearsal probes would be presented on all of the even number trials, and vice versa. Overall, four of the subjects in each experimental group received multiple input probes on odd number trials and rehearsal probes on even number trials; while three of the subjects in each experimental group received rehearsal probes on odd number trials and multiple input probes on even number trials. Table IV illustrates the temporal placements of these probes. The response selection probe was placed immediately after the presentation of the stimulus word in accordance with Johnston et al. (1972a), who found that this temporal placement was most indicative of expended processing capacity. The multiple input probe followed immediately after the response word; while the rehearsal probe was presented three seconds after the response word. In addition, twice as many response selection probes, as opposed to multiple input or rehearsal probes, were used because the response selection stage has

---

*Johnston, et al. (1972a) refer to the multiple input placement as an encoding stage. However, in accordance with Kerr's (1973) definition of multiple input as "encoding a stimulus item while simultaneously remembering previously presented items" (p. 407), the term multiple input seems more appropriate and will therefore be used in the present study.

TABLE IV

TEMPORAL PARAMETERS OF PROBE SIGNALS

Response Selection Probe: (RS)	Stimulus Word	3 Second Pause for Subject Response		
		PROBE (RS)		
	Stimulus Word	1 Second Pause		Response Word
Multiple Input Probe: (MI)	3 Second Pause		+	1 Second Pause
Rehearsal Probe: (R)	PROBE (MI)*			PROBE (R)*

*Multiple input and rehearsal probes were alternately presented on every other trial.

been found to utilize the most processing capacity. To allow the experimenter time to record the subject's reaction time and reset the timer, only a single probe was ever presented per word pairing.

To insure that probes were consistently presented to all subjects, they were always triggered at the same point during the learning trials. For the response selection stage, stimulus words on track 1 of the learning tape signalled the experimenter to trigger the probe. In the case of the multiple input probe, response words were used as signals. Since neither stimulus nor response words immediately preceded the rehearsal probe (so that they could not be used as signals), a separate verbal instruction (i.e., "start now") was synchronized on track 2 of the tape so that it coincided with the temporal placements of the stimulus and response words on track 1. This technique has been found to be effective in insuring constant probe presentations (Johnston et al., 1972a). Additionally, the protocol sheet which recorded subject responses during the learning trials also warned the experimenter when a probe presentation would be coming up on the tape. The exact placement of all probes for the 12 anticipation trials is included in Appendix A.

An additional tape recording was made with probe presentation signals heard by the experimenter when establishing a baseline performance for the subjects on a single stimulation, reaction time only task. A voice on the tape instructed the experimenter when to trigger a probe signal. The tape was divided into two five-minute segments, with the probe signals ordered in the same random time sequences as during the probe presentations during the anticipation trials.

IV. APPARATUS

Instrumentation for the Auditory Signal Presentations: The test environment used in the experiment consisted of a double-walled IAC auditory test suite. Pure tone thresholds were obtained using a Beltone 10-D portable audiometer calibrated to ANSI, S3.6-1969 Standards. Pure tone stimuli were presented through TDH-39 earphones mounted in MX-41/AR cushions.

The learning material was delivered from channel 1 of an Akai 1710 stereo tape recorder to the external A input of a Grason-Stadler 1704 audiometer. The noise stimulus was delivered from a Sony TC-377 stereo tape recorder to the external B input of the same audiometer. The speech and noise signals were subsequently channelled to a loudspeaker in the subject's sound-treated test booth. The speech and noise signals were calibrated with the measurement microphone at a distance of 3 feet from the loudspeaker, at a height of 3-1/2 feet from the floor (i.e., the average position that was assumed by the seated subject's head during the testing situation). The calibration equipment consisted of a 1/2 inch condenser microphone coupled to a Bruel and Kjaer 2209 sound level meter. Calibration checks of pure tone, speech, and noise stimuli were performed weekly to assess any change in the calibration of the instrumentation. The responses of the subjects were monitored by the experimenter through a microphone at an average distance of six inches from the subject's lips. The arrangement of the instrumentation used for signal and noise presentations is shown in Figure 6.

There are two reasons why the speech and noise signals were chosen to be presented through the loudspeaker in preference to through earphones. First of all, one seldom ever listens through earphones. Secondly, Kahneman (1970) in a personal communication from Broadbent pointed out that "The deleterious effects of noise on longterm performance are reduced when the noise comes over earphones, in comparison to the case where noise of the same intensity is perceived as 'room noise'" (p. 126).

Instrumentation for Probe Reaction Time Testing: The instrumentation for probe reaction time testing is illustrated in Figure 7. A Standard Electric Time Company (Model S-1) reaction timer was used in this experiment. The unit recorded reaction time in 10 millisecond increments and could be activated by either the experimenter or the subject. The experimenter used a toggle switch mounted in a control box for activating a probe light. Also mounted on the control box was a panel light which could signal any false responses made by the subject. The subject used a pushbutton switch held in the preferred hand. This type of switch was chosen in accordance with the previously stated finding that executing a movement of a switch to a physical stop does not require processing capacity.

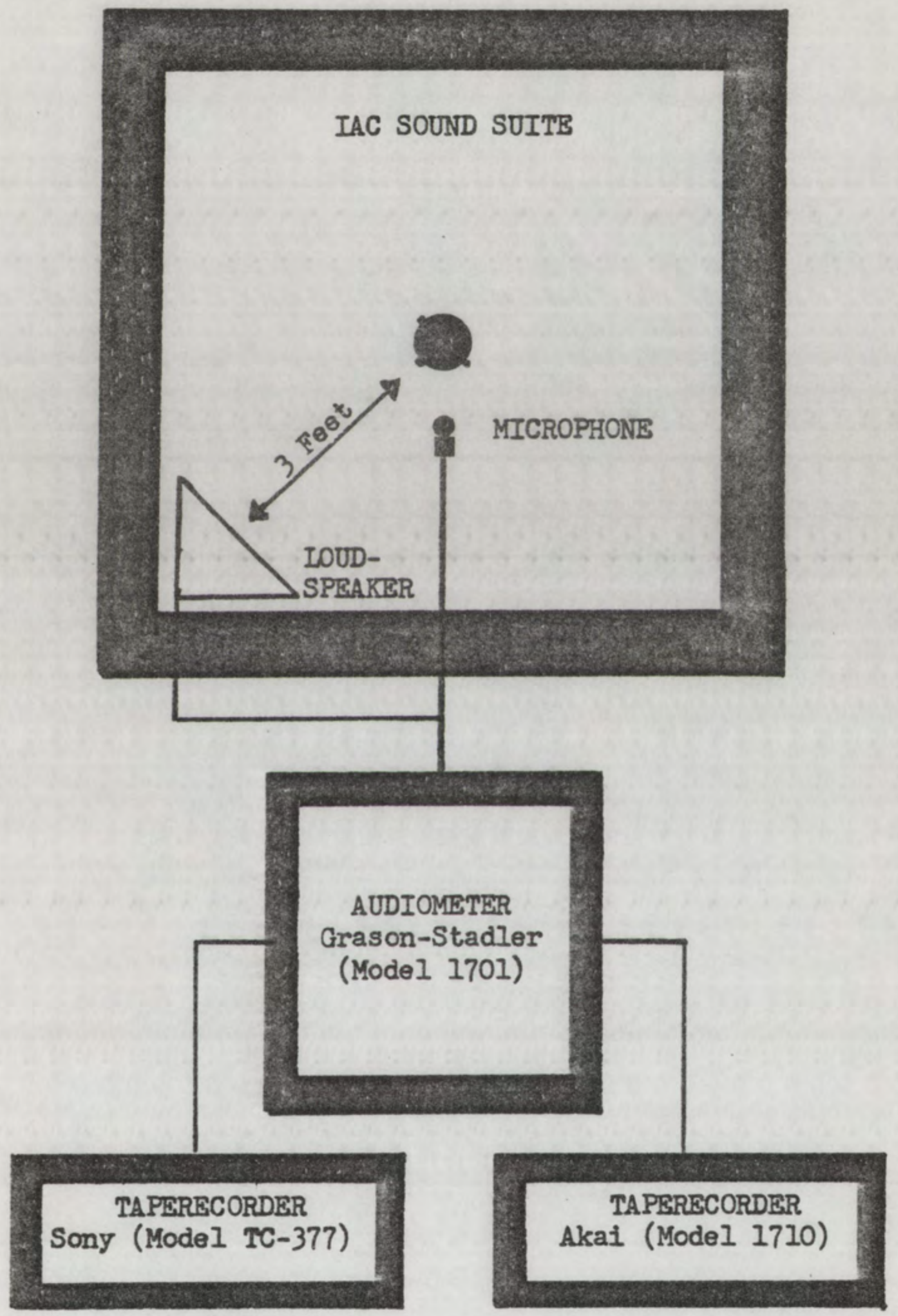


Figure 6. Instrumentation for the presentation of speech material.

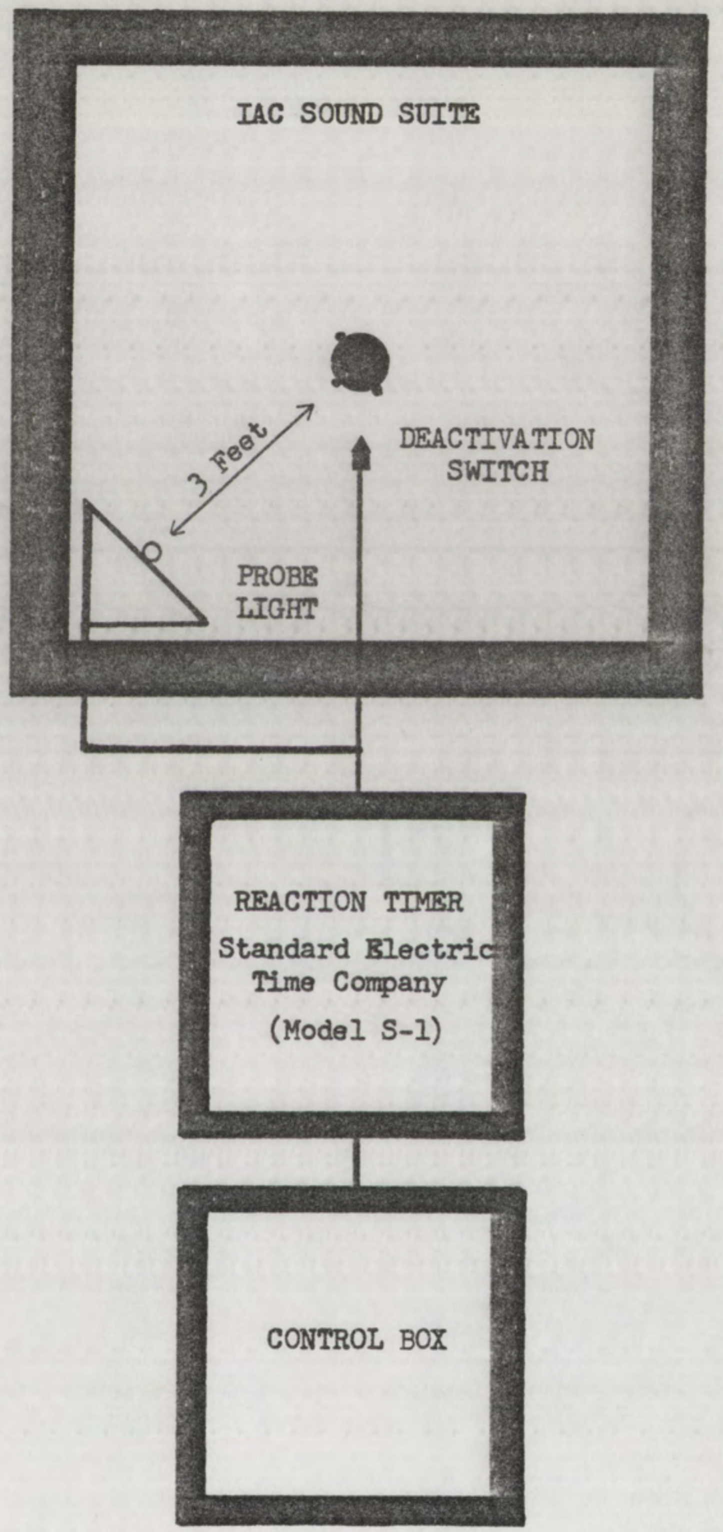


Figure 7. Instrumentation for Probe Reaction Time Task.

The light unit consisted of a 7-1/2 watt white lightbulb (one inch in diameter) mounted on a six inch square brown wooden background. The light was centered on top of the loudspeaker at a height of 3-1/2 feet, at a distance of three feet from the subject. The light could be simultaneously activated or deactivated with the reaction timer. In this experiment, it was the responsibility of the experimenter to trigger the light and reaction timer, and the duty of the subject to turn them both off.

V. PROCEDURE

Initially all subjects received a pure tone air conduction evaluation at the octave frequencies between 250-4000 Hz inclusively. The subjects who met the previously stated criteria for selection were randomly sorted into one of seven experimental conditions. Because there were considerably more female than male subjects participating in this study, all seven experimental groups were randomly assigned at least one male subject; with five of the groups having two male subjects.

Baseline data was obtained on the subject's performance on the probe reaction time task. The experimenter simultaneously activated the light and reaction timer at six preprogrammed points. These points, as previously mentioned, were recorded on two five-minute tapes heard only by the experimenter. The subject was instructed to push the button whenever the light appeared. Baseline data was obtained for five minutes both preceding and following the paired associate learning task.

The exposure trial of the learning task was presented to the subjects under the listening conditions to be mentioned in the subsequent section of this paper. The subjects were instructed to repeat aloud the word pairs in order to insure their discrimination of the speech signal was at a high level. In the event that a word pair was not understood initially by the subject, the experimenter immediately repeated the word pair through the talk through system of the audiometer.

Following the exposure trial, the subjects were given instructions concerning the response requirements for the anticipation trials of the paired associate learning task. All subjects who were in the double stimulation experimental conditions were also instructed to devote as much attention as needed to the learning task, using only their "left over" attention to perform the reaction time task. An additional step was taken to "protect" the primary task. While the subject was told to do well on the reaction time task, he was informed that the duration of the experiment was dependent upon performance on the paired associate learning task. The text of these instructions is included in Appendix B. The learning task was completed when the subject either reached a 100 percent criterion of 10 correct responses for one complete trial, or until the subject completed the 12 trials.*

---

*An upper limit was placed on the number of anticipation trials presented before the experiment was terminated. This limit was instituted to prevent a single subject with an extremely poor learning performance from adversely biasing the overall group results.

Following the paired associate learning task, the subject once again participated in the five minute reaction time only task to establish a baseline performance. This concluded the experiment. However, in order to obtain a subjective assessment of the learning task, the subjects were questioned about their opinion of the difficulty of the paired associate learning task. For this purpose, a semantic differential scale was used. The subjects were asked to rate the demands of the learning task on the seven point scale from (1) Very Easy -to- (7) Very Difficult. This semantic differential scale is illustrated in Appendix C.

VI. EXPERIMENTAL DESIGN MATRIX

The 49 subjects were randomly divided into seven experimental groups of 7 subjects per group. The following six double stimulation groups all performed the probe reaction time task in addition to the primary learning task under the following experimental conditions:

Group I: Speech signal presented at 50 dB SL.*

Group II: Speech signal presented at 35 dB SL.

Group III: Speech signal presented at 20 dB SL.

Group IV: Speech signal presented at 50 dB SL in background of noise (+6 S/N).

---

*All sensation levels were relative to the subject's pure tone average for 500, 1000, and 2000 Hz.

Group V: Speech Signal presented at 35 dB SL in background of noise (+6 S/N).

Group VI: Speech signal presented at 20 dB SL in background of noise (+6 S/N).

An additional single stimulation no-probe reaction time condition was added to assess whether the secondary probe task limited the processing of the primary task in the latter six experimental groups. The single stimulation task condition was performed under the following condition:

Group VII: Speech signal presented at 20 dB SL in background of noise (+6 S/N).

An apriori judgement was made that a speech signal of 20 dB SL in a background of noise would be most difficult of the experimental conditions. For this reason, the single stimulation control condition was performed at this level. The assumption was made that if an interaction between primary and secondary tasks was to take place, the condition chosen should be one that reflected both listening variables (i.e., reduced signal intensity and noise).

Figure 8 illustrates the experimental design matrix used in this study; visually displaying the seven conditions and the factors under consideration. An additional group of factors which are not included in this design matrix are the learning stages of response selection, multiple input, and rehearsal. Because it is not critical to this investigation to understand the processing demands of these stages

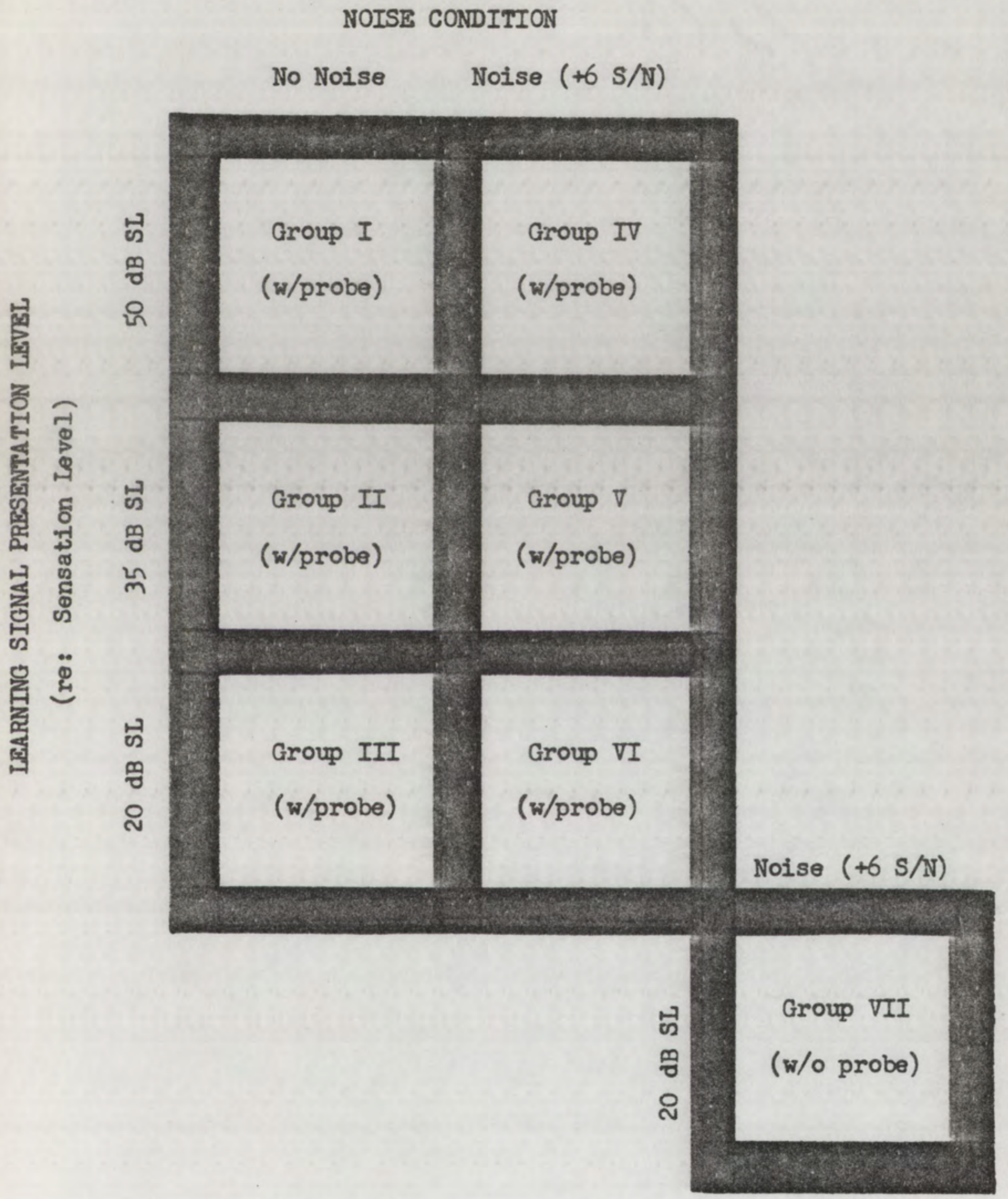


Figure 8. Experimental design matrix.

separately, they were not instituted as primary variables. However, the structure of the present experiment still allowed for an examination of how processing demands during these stages changed under degraded listening conditions. Therefore, as a matter of extra interest, these additional variables will be examined.

VII. STATEMENT OF THE EXPERIMENTAL QUESTIONS

Pertinent questions regarding the processing demands during auditory learning under degraded listening conditions include the following:

1. Does reduced speech intensity have an effect upon processing demands during auditory learning?

2. Does the introduction of noise into the listening situation have an effect upon processing demands during auditory learning?

3. What are the interaction effects of noise and reduced speech intensity upon processing demands during auditory learning?

4. Do the learning stages of response selection, multiple input, and rehearsal reflect different changes in processing demands during auditory learning under degraded listening conditions?

The null hypotheses pertaining to these experimental questions are stated below:

H_{0_1} Changes in speech intensity over a range from 0 - 30 dB exert no effect upon processing demands during auditory learning.

H_{0_2} The introduction of noise into the listening situation exerts no effect upon processing demands during auditory learning.

H_{0_3} Noise and reduced speech intensity do not interact so as to exert an effect upon processing demands during auditory learning.

H_{0_4} Processing demands during the learning stages of response selection, multiple input and rehearsal are not affected differently under degraded listening conditions.

Prior to conducting this experiment, a significance level of $P \leq 0.05$ was chosen for any statistical analysis. That is, decisions regarding the rejection of the null hypotheses were based upon a 0.05 level of confidence. The 0.05 level of confidence was selected in preference to a 0.01 level of confidence in lieu of committing a Type I rather than a Type II error. It should be recalled that the Type I error occurs when a null hypothesis is rejected that actually is true. Conversely, a Type II error is committed when a null hypothesis is accepted that actually is false.

One possible implication of rejecting the null hypothesis would be that costly noise controls would be instituted within various learning environments. The rationale would be that by controlling excessive noise, processing demands during auditory learning would be reduced, thus facilitating learning. With regard to primary and secondary task interference, a Type I error would be indicating that there is an interaction between primary and secondary tasks when none actually exist.

A far more damaging result would occur if the null hypothesis were accepted when, in fact, it is false. In this case, parents and educators would continue to ignore the added demands that are placed upon a child who must do his auditory learning under degraded listening conditions.

Consequently, unacceptable acoustical environments would be maintained with detrimental effects to the child. This would be especially harmful to the hearing impaired who must perform their learning at reduced speech intensity levels. In addition, a Type II error would suggest that no interaction exists between primary and secondary tasks when one is actually present. This certainly is an undesirable situation. Thus, in the present study, committing a Type I error would be much less harmful. For this reason, the less stringent 0.05 level of confidence was selected over the 0.01 level. Consequently, a null hypothesis that actually is false might mistakenly be accepted at the $P \leq 0.01$ confidence level, but could be rejected at the $P \leq 0.05$ level.

The statistical procedure adopted for determining significant differences in data obtained from Groups I - VI was an analysis of variance. This technique can be used when the effects of two independent variables are investigated. With regard to this experiment, the ANOVA procedure can assess the effects of noise and reduced signal intensity upon processing demands during auditory learning; as well as determine differences between the response selection, multiple input and rehearsal signal presentations. In addition, any interaction of these variables also can be assessed. However, this procedure does not allow the investigator to pinpoint the locus of significant differences between experimental conditions. For this purpose, Duncan's Multiple Range Test also was conducted when significant differences were found between experimental conditions using the ANOVA procedure. Finally, in order to determine if an interaction existed between the primary and secondary probe reaction time tasks, a t-test was utilized.

CHAPTER IV

RESULTS AND INTERPRETATIONS

The purpose of this study was to investigate processing demands during auditory learning under degraded listening conditions. Forty-nine undergraduates with pure tone averages equal to or better than 10 dB HL (ANSI-1969) were randomly divided into 7 listening groups. All 7 groups performed the same paired associate learning task presented auditorially under the different listening conditions. These listening conditions included the two primary variables in this study, which were: 1) Learning signal intensity level (50, 35, or 20 dB SL), and 2) Presentation of learning signal in quiet ($+\infty$ dB S/N) or in noise (+6 dB S/N). In addition, subjects in experimental groups I - VI simultaneously performed a secondary, probe reaction time task to measure the expended processing capacity (i.e., attention or effort) during the primary learning task. Group VII was added as a control condition to assess whether the probe reaction time task had any significant effect upon the learning task.

Prior to presenting the results which provide answers to the experimental hypotheses, data will be offered concerning the baseline reaction time performance and the exposure trial intelligibility performance of the subjects. This information is put forth initially for two reasons. First, it is presented to aid in understanding the relative strengths of the procedures used in this study. Secondly, by including this data early in the results section, added credibility is afforded other experimental findings.

Following this preliminary data, the primary results directly concerned with processing demands will be presented. The reader will recall that processing demands during an activity can be assessed by viewing the accuracy and/or ease with which the activity is performed. In this study, results associated with accuracy and ease are reported in the sections on learning performance and expended processing capacity, respectively. In addition, an overall processing demands index is computed, which combines the results of these two measurements. Within each of these sections, the primary experimental variables (i.e., signal intensity level and signal-to-noise level) and their possible interactions are explored. With respect to expended processing capacity, differences are analyzed between the three types of probe presentations; response selection, multiple input, and rehearsal. The results concerned with any interference between primary and secondary tasks are also included. Finally, decisions regarding the experimental hypotheses are provided to put the aforementioned results into better perspective.

Several findings of additional interest conclude the results section. These findings include the semantic differential scale of learning task difficulty, as well as relevant comments made by the subjects about this experiment. Hopefully, this will provide the reader with interesting comparisons between the subjective and objective findings of this study.

PRELIMINARY RESULTS

Baseline Reaction Time Performance: The strength of the results found in any experiment are, in part, dependent upon the power of the procedures used in obtaining them. While audiologists are acquainted with several of the procedures implemented in this study, the use of the probed reaction time technique is relatively unfamiliar to those in this profession. For this reason, baseline reaction time data is provided as an indicator of the stability of this procedure.

Baseline reaction time data was obtained on every subject in Groups I - VI.* During each 5 minute segment, 6 probes were presented. A mean reaction time score on each subject was computed for the first 5 minute presentations ($Baseline_1$), the second 5 minute presentations ($Baseline_2$), and the total 10 minutes ($Baseline_T$). Baseline results were finally combined for all 42 subjects in Groups I - VI. The overall means, range, range difference, standard deviation (SD) and SD range for these subjects is listed in Table V. As is shown, the mean $baseline_T$

---

*Because group VII did not perform the probe reaction time task during the learning task, it was not necessary to obtain a baseline performance score for these subjects. However, to insure that group VII performed the paired associate learning task under similar conditions to group VI, they did participate in the first 5 minute baseline reaction time task.

TABLE V

BASELINE REACTION TIME DATA
FOR 42 SUBJECTS IN GROUPS I - VI

Result	Milliseconds
Mean $Baseline_1$ Reaction Time...........................	343
Mean $Baseline_2$ Reaction Time...........................	333
Mean $Baseline_T$ Reaction Time...........................	338
$Baseline_T$ Reaction Time Range....................	222 - 495
$Baseline_T$ Reaction Time Range Difference...............	273
$Baseline_T$ Reaction Time Standard Deviation (SD)........	56
$Baseline_T$ Reaction Time - One SD Range...........	282 - 394
$Baseline_T$ Reaction Time - Two SD Range...........	227 - 449

reaction time to the light was 338 msecs., with an overall range of 222 - 495 msecs. The range difference between the fastest baseline reaction time by a subject and the slowest baseline reaction time by a subject was 273 msecs. More important, one standard deviation from the mean equals 112 msecs. Stated differently, theoretically 68 percent of the subjects should be within 1/20 of a second from the mean, while 95 percent should be be within 1/10 of a second from the mean for the baseline reaction time task. These results suggest little variability between subjects in performing the reaction time task--an obvious strength in using this technique.

An additional comparison can be made between the $baseline_1$ and $baseline_2$ performances of the 42 subjects. The mean differences between the $baseline_1$ (i.e., 343 msecs.) and $baseline_2$ (i.e., 333 msecs.) is 10 msecs. (i.e., 1/100 of a second). A t-test performed on these data indicated that these mean differences were not significant, (df= 82, $P > 0.05$). This result suggests four points about the stability of the reaction time task: 1) A practice effect is not present--repeated performance of the task does not result in lower reaction times. 2) A fatiguing effect is not present--repeated performance of the task does not result in higher reaction times. 3) The reaction time technique is highly reliable--repetition of the task will produce similar results. 4) Finally, by having a stable baseline reaction time, the validity of the probe reaction time task results are enhanced, when used as a measure of processing demands during the learning task.

Exposure Trial Intelligibility Performance: To assess the processing demands during auditory learning under degraded listening conditions, it is imperative that the learning stimuli be highly intelligible. To insure this, the exposure trial served as an intelligibility index. During the exposure trial, each subject was scored on the percentage of 20 stimulus words which they could correctly repeat. This group intelligibility data are compiled and averaged for the seven experimental conditions (See Figure 9). As can be seen, the mean intelligibility score for 3 of the groups is equal to or better than 98 percent; and for 6 of the groups it is better than 90 percent. Only group VI (i.e., the learning signal presented at 20 dB SL in a background of noise) has a mean intelligibility score below 90 percent (i.e., 86 percent). An analysis of variance conducted on the results from groups I - VI reveals that these differences are significant for both signal presentation level, $F(2,36)$, $P < 0.05$; and signal-to-noise level, $F(1,36)$, $P < 0.05$. A Duncan's Multiple Range Test further identifies these mean differences to be significant only between group VI and the other 6 experimental groups ($r=6$, $df=36$, $P < 0.05$). This suggests that the intelligibility for the exposure trial stimulus words was significantly poorer only when presented at 20 dB SL in a background of noise.

At first, this finding would seem to imply that subjects in group VI were placed at an unfair advantage when performing the paired associate learning task. This assumption is untrue for several reasons.

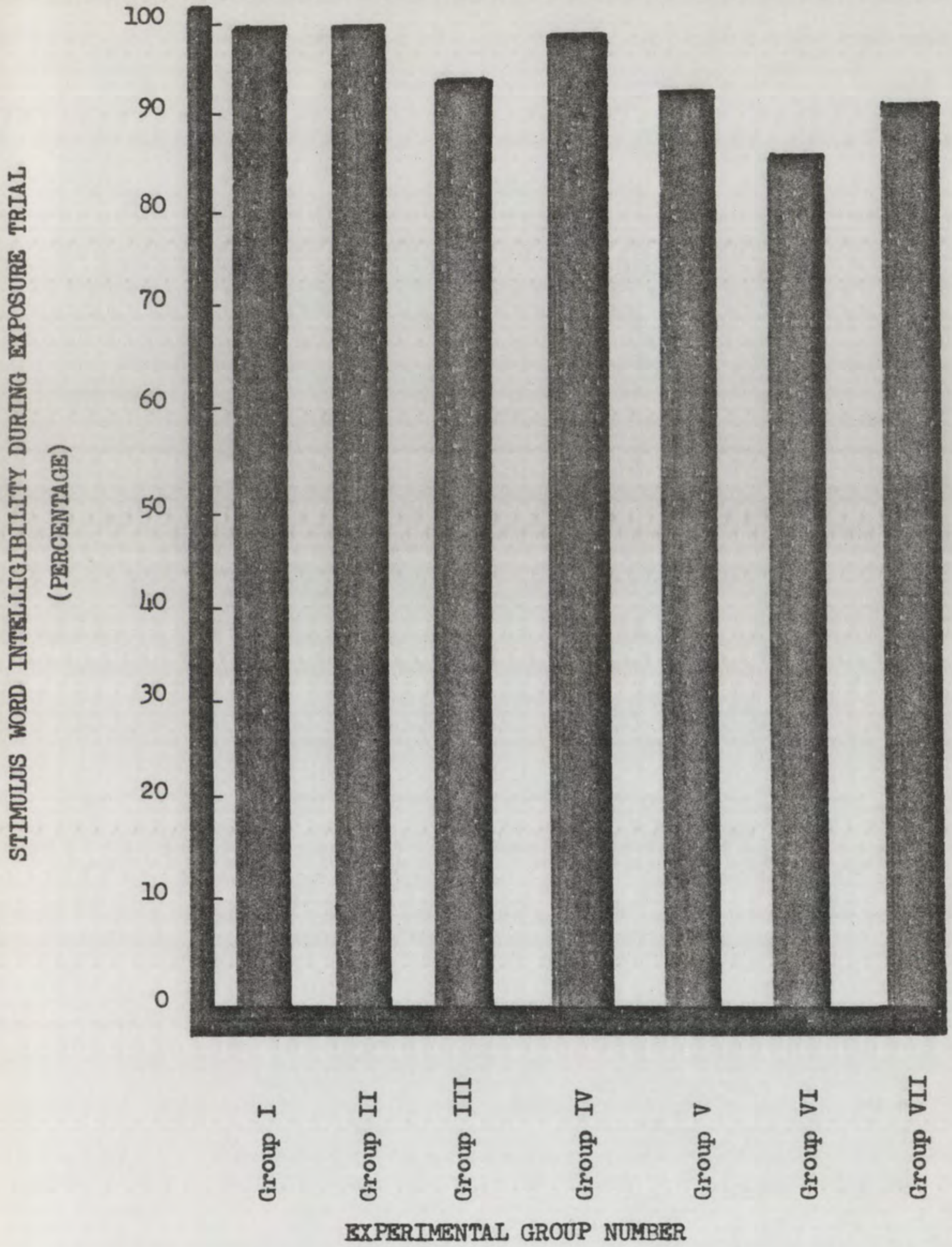


Figure 9. Intelligibility of stimulus words during exposure trial for seven experimental groups.

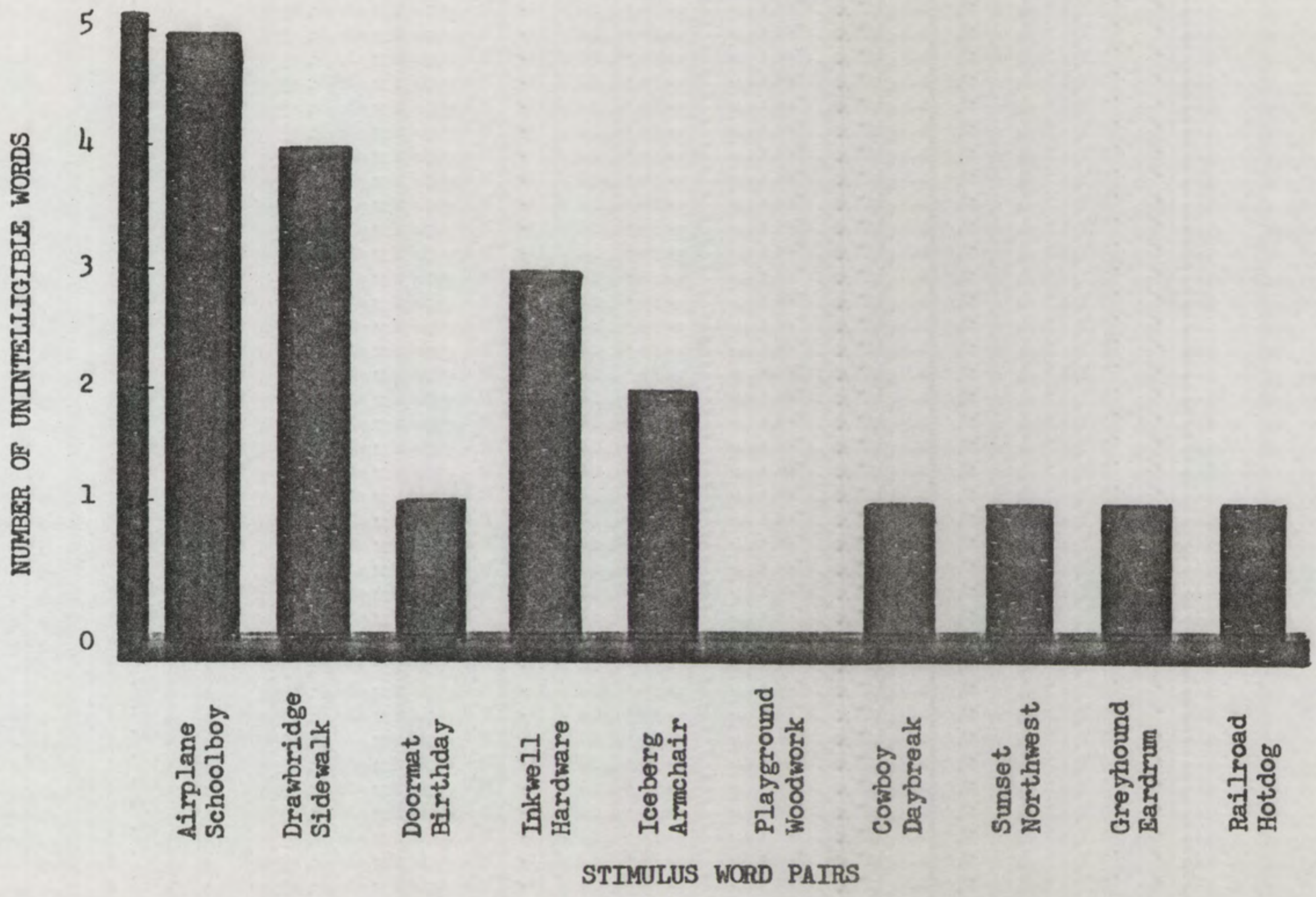
First, the reader will recall that whenever a word was not understood during the exposure trial, the experimenter immediately repeated that word pair through the talkthrough system for the subject. During the pilot study this technique was found to yield 100 percent correct discrimination on subsequent trials. This was also borne out in the main study by questioning the subjects at the conclusion of the experiment about the intelligibility of the learning material. All the subjects reported that they experienced no difficulty in understanding the stimulus words during the anticipation trials.* They further stated that the single repetition of any misunderstood word during the exposure trial was adequate for the later correct intelligibility of that word.

By analyzing the errors made by subjects in group VI, it is apparent that the intelligibility was poorest for the early word pairings, becoming progressively better for later pairings (See Figure 10). A possible explanation is that the subjects in group VI took slightly longer than the other experimental groups to adapt to their unfamiliar listening condition. However, once they became adapted, the intelligibility was as high as for the other conditions. In conclusion, after reviewing the exposure trial data and the subjects'

---

*The experimenter made an interesting observation concerning this point. Often during the early anticipation trials the subjects would rehearse the word pairings to themselves in a soft whisper, which could be heard by the experimenter through the talkback speaker. By monitoring the subjects voice, the experimenter became aware that the subjects were hearing the words at a highly intelligible level.

Figure 10. Number of unintelligible words in each word pair for the 7 subjects in Group VI.



comments it can be stated that the learning stimulus material was, in fact, at a high intelligibility level for all test groups.

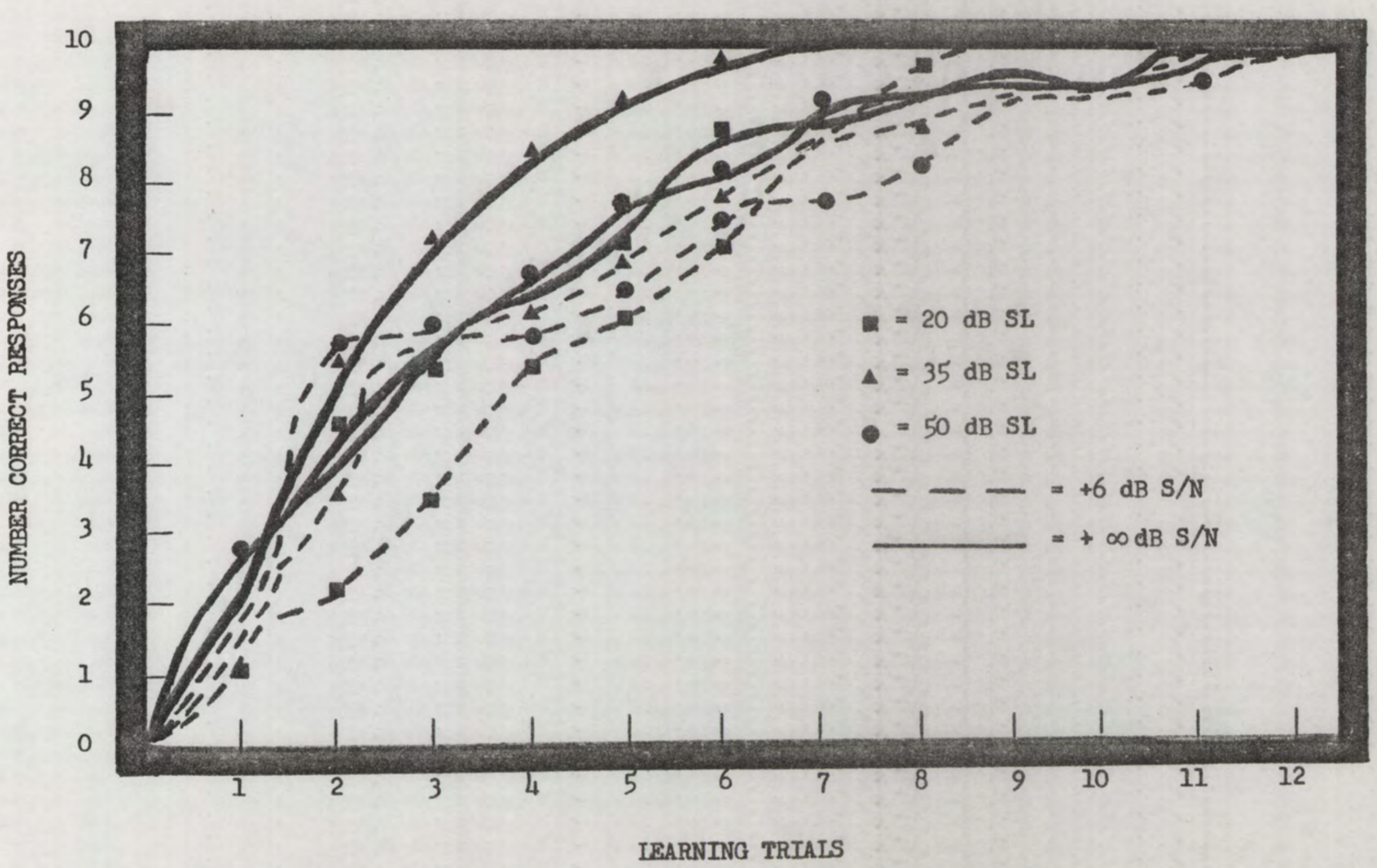
PRIMARY RESULTS

Learning Performance: Learning performance was assessed by the number of anticipation trials required to obtain a 100 percent learning score (i.e., 10 correct responses) for a single trial.* The individual learning performance data is provided in Appendix D for all 49 subjects. An analysis of variance, comparing mean differences for groups I - VI indicated no significant differences between experimental conditions, $P > 0.05$. This suggests that the experimental variables of signal intensity level and signal-to-noise level had no significant effects upon learning performance. This is illustrated in Figure 11 where the learning curves for groups I - VI are presented. Notice that the six curves are characterized by similar curvilinear configurations. The only deviation is the initial slow rise for group VI. Eventually, however, performance for this group reaches that of the other five groups. This early gradual sloping may be due to the subjects adapting to their listening condition. Finally, while Figure 11 shows slightly poorer performance for the noise conditions (i.e., groups IV, V, and VI), this tendency is not significant.

---

*2 of the 49 subjects never obtained a 100 percent learning score within the 12 trial limit of this experiment. Both of these subjects had only reached the 90 percent level at this point. However, in accordance with the procedural guidelines, these subjects were credited with performing the task in 12 trials.

Figure 11. Learning performance curves for experimental groups I - VI.



A t-test was performed to identify any significant difference in learning performance between group VI and group VII. The t-test reveals no significant difference ($df = 12$, $P > 0.05$) between these two groups. This finding indicates that the addition of the probe reaction time task in group VI exerted no effect on the primary learning task. It also implies that the precautionary measures implemented in this experiment to protect the primary task were effective. Finally, it lends support to past research which used the probe reaction time task. An example would be the previous investigations by Posner and Keele (1969) and Ells (1972) who reported that executing a movement to a physical stop does not require processing capacity.

Expended Processing Capacity Performance: In addition to learning performance, processing demands can be measured by viewing expended processing capacity performance. Again, the rationale for this measurement is as follows: If a great deal of attention is required for performing a primary task (i.e., the paired associate learning task), there will be a concomitant reduced performance on a secondary task (i.e., the probe reaction time task). Expended processing capacity is computed for each subject in groups I - VI by determining the mean difference between probe reaction time and baseline_T reaction time.*

---

*A 2000 msec. limit was placed on all probe reaction times, such that any reaction time greater than this limit was only scored as 2000 msec. This limit was instituted to control for any exceptionally long reaction time from biasing the overall test results.

These raw data are presented in Appendix E. Because there were three types of probe presentations, expended processing capacity can be calculated for the response selection, multiple input and rehearsal stages.

To determine the effects of signal presentation level and signal-to-noise level, an ANOVA model R-III was used. This analysis of variance procedure is required for a three-way mixed design where there is a repeated factor, and two fixed factors. In this experiment, the repeated factor was the probe presentation, and the fixed factors were the independent variables. A summary of the analysis of variance is represented in Table VI. This table indicates that no significant differences were present in expended processing capacity between the three presentation levels of the stimulus material, $F(2,36)$, $P > 0.05$. However, a significant difference, $F(1,36)$, $P < 0.05$, was found between the noise (+6dB S/N) and the quiet ($+\infty$dB S/N) conditions. Significant differences $F(2,72)$, $P < 0.05$, are also present between the probe presentation stages. Finally, no significant interaction is present between any of these conditions.

A Duncan's Multiple Range Test was performed on this data to further specify the conditions under which these differences were present. A multiple comparison table (Table VII) is included to illustrate the expended processing capacity differences. In addition,

TABLE VI

SUMMARY TABLE OF ANALYSIS OF VARIANCE UTILIZED TO TEST THE INDEPENDENT AND INTERACTIVE EFFECTS OF PRIMARY VARIABLES AND PROBE PRESENTATION STAGES

Source of Variation	Sum of Squares	df	Mean Squares	F-Ratio	Critical F (0.05)
Between Subjects	2,929,961	41			
Sensation Level (SL)	21,910	2	10,955	0.17	3.32
Signal-to-Noise Level (N)	406,189	1	406,189	6.13*	4.17
(SL) X (N)	115,516	2	57,758	0.87	3.32
Error for (SL)	2,386,345	36	66,287		
Within Subjects	1,112,879	84			
Presentation Stages (PS)	219,525	2	109,762	10.32*	3.15
(SL) X (PS)	63,880	4	15,970	1.50	2.52
(N) X (PS)	26,497	2	13,248	1.25	3.15
(SL) X (N) X (PS)	37,523	4	9,381	0.88	2.52
Error for (PS)	765,454	72	10,631		

*Result significant at $P < 0.05$

TABLE VII

MULTIPLE COMPARISON TABLE ILLUSTRATING EXPENDED PROCESSING CAPACITY DIFFERENCES (IN MILLISECONDS) FOR SIGNAL PRESENTATION LEVEL, SIGNAL-TO-NOISE RATIO AND PROBE PRESENTATION STAGE.

		20,Q,R	20,Q,RS	20,Q,MI	35,Q,R	35,Q,RS	35,Q,MI	50,Q,R	50,N,R	50,Q,MI	20,N,R	50,N,MI	35,N,R	35,N,MI	20,N,MI	50,Q,RS	35,N,RS	50,N,RS	20,N,RS
		94	139	155	161	177	184	185	186	193	203	277	278	301	317	327	329	341	408
20,Q,R	94											*	*	*	*	*	*	*	*
20,Q,RS	139											*	*	*	*	*	*	*	*
20,Q,MI	155													*	*	*	*	*	*
35,Q,R	161													*	*	*	*	*	*
35,Q,RS	177														*	*	*	*	*
35,Q,MI	184														*	*	*	*	*
50,Q,R	185														*	*	*	*	*
50,N,R	186														*	*	*	*	*
50,Q,MI	193															*	*	*	*
20,N,R	203																*	*	*
50,N,MI	277																		*
35,N,R	278																		*
35,N,MI	301																		
20,N,MI	317																		
50,Q,RS	327																		
35,N,RS	329																		
50,N,RS	341																		
20,N,RS	408																		

20 = 20dB SL
35 = 35dB SL
50 = 50dB SL

N = Noise (+6 S/N)
Q = Quiet (+∞ S/N)

RS = Response Selection
R = Rehearsal
MI = Multiple Input

*Expended Processing Capacity differences are significant, $P < 0.05$, ($r = 18$, $df = 72$), Duncan's Multiple Range Test

the data shown in Table VII are visually displayed in Figure 12.*
The most striking finding evident in Table VII and Figure 12 is the much better performance by subjects in the quiet versus the noise conditions. Of the 18 possible measurements (9 in noise and 9 in quiet), the 7 fastest expended processing capacity times were under quiet listening conditions. Conversely, 9 of the 11 slowest expended processing capacity times were under noisy listening conditions. Specifically, subjects in groups IV, V, and VI (i.e., signal-in-noise) had significantly slower expended processing capacity times than for the subjects in groups II and III (signal-in-quiet). This difference is not significant when compared against group I.

Under closer examination, the differences between the noise and quiet conditions are significant for all the response selection probes presented in noise, and for two of the multiple input probes presented in noise. These differences are quite evident in Figure 12, where there is a dramatic separation between the curves for the quiet and noise conditions. That the response selection probe should more clearly differentiate between the expended processing capacity of the noise and quiet conditions is not surprising; but expected. The reader will recall that past research has found this probe presentation stage to be most indicative of expended processing capacity (Kerr, 1973). The

---

*While Figure 12 illustrates the important differences more clearly than Table VII, it does not show which of these differences are significant. For this purpose, Table VII is included.

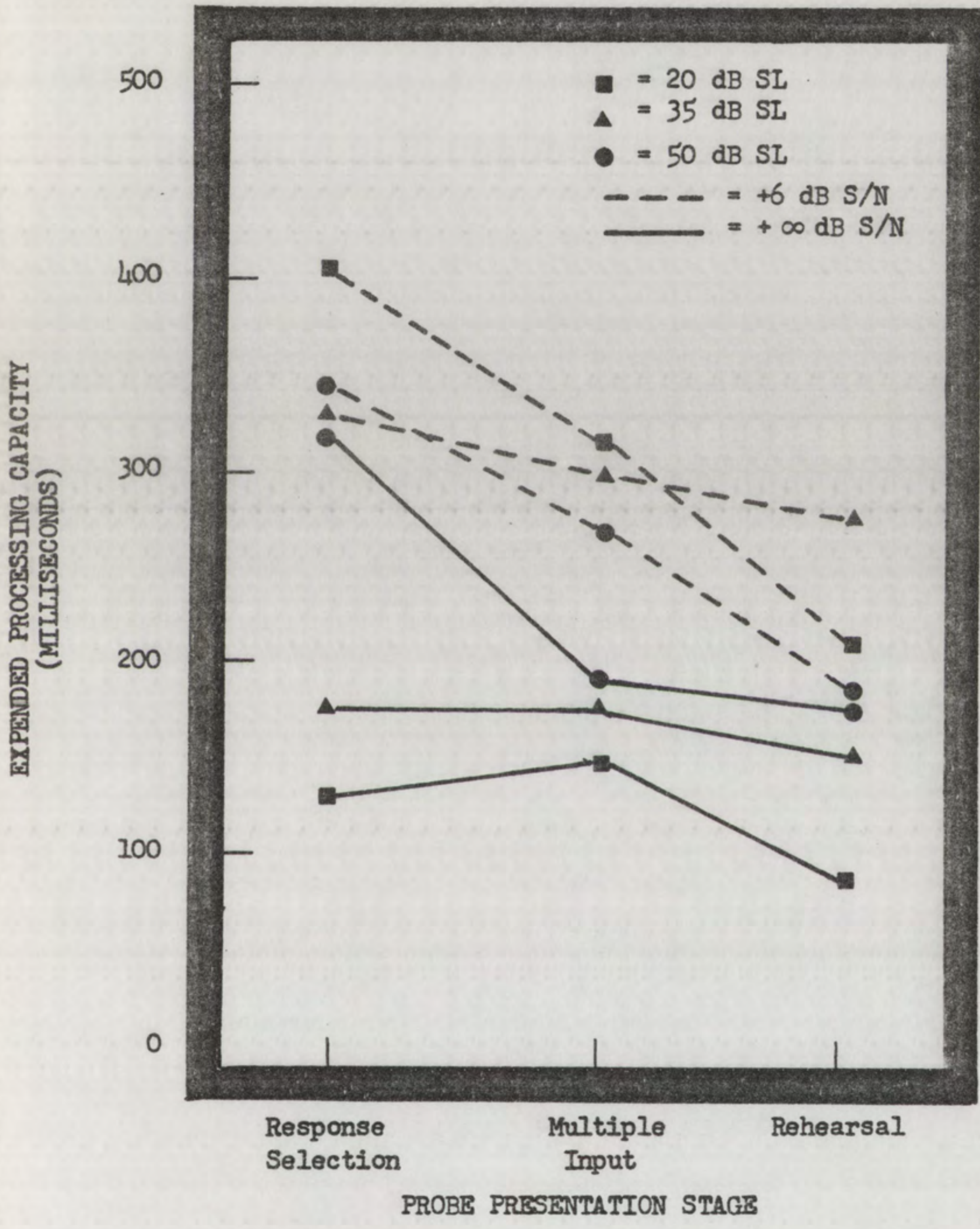


Figure 12. Expended processing capacity for 6 experimental conditions during different probe presentations.

present study confirming this finding, reinforces the procedure used in this experiment of having twice as many response selection as other probes.

Table VII shows that the four slowest expended processing capacity times involve response selection probes. Overall for the 18 possible measurements, expended processing capacity is greatest (i.e., slowest reaction time speed) for the response selection probes and least for the rehearsal probes. This relationship is portrayed by the downward slopes in Figure 12. However, Duncan's Multiple Range Test indicates that differences in expended processing capacity are only significant for the response selection probes versus the other two probe stages ($r = 18$, $df = 72$), $P < 0.05$. No significant difference is present between the rehearsal and multiple input probes.

Before concluding this section, mention should be made regarding the experimental error found for the expended processing capacity results (See Table VI). The reader is reminded that total variance in a study is equivalent to between-groups variance plus within-groups variance. The between-groups variance reflects the differences between group means as a result of experimental manipulation. The within-groups variance (also called error variance) refers to the difference between individual scores and their respective group means; and is indicative of experimental error. In the present study, while this experimental error in no way negates the significance of the previously stated findings, it does account for a proportion of the total expended processing capacity variance between experimental conditions. The reader is thus cautioned to not accept the absolute mean differences (i.e., variance) of expended processing capacity as being only reflective of the effects of the primary variables.

By viewing individual expended processing capacity data, one of the factors possibly contributing to the experimental error becomes apparent (See Appendix E). The reader will notice that considerable variability exists between individual processing capacity scores and their respective group means. This is true for all 6 experimental groups; and results in certain subjects listening in the noise conditions actually having better expended processing capacity scores than other subjects listening under quiet conditions. Such variability is, of course, not uncommon in studies using human subjects. The importance of this variability is later recognized in the section concerned with future research.

Processing Demands Index: A processing demands index was computed which combined the results of learning performance and expended processing capacity into one single measure. This was done for each subject by computing and subsequently combining a Z-score for learning capacity and expended processing capacity.* A mean Z-score was then calculated for each of the experimental groups I - VI. The results of

---

*The expended processing capacity score is represented by a value equal to: 2(response selection) + (multiple input) + rehearsal)/3 - baseline_T reaction time.

the processing demands index are graphically displayed in Figure 13. Again, notice the downward trend between the noise and quiet conditions. An analysis of variance indicates that differences due to signal presentation level are not significant, $F(2,36)$, $P > 0.05$. Conversely, the differences between the noise and quiet conditions are significant, $F(1,36)$, $P < 0.05$. Duncan's Multiple Range Test reveals that the differences are significant ($r = 6$, $df = 36$), $P < 0.05$, between groups IV, V, and VI (i.e., the three noise conditions) and group II. Greater significant differences could possibly have been pinpointed had the expended processing capacity Z-score included results from only the response selection probes.

DECISIONS REGARDING THE EXPERIMENTAL HYPOTHESES

To put the previously mentioned findings into better perspective, the results as they relate to the null hypotheses will now be presented.

Hypothesis H_{0_1}: Changes in speech intensity over a range of from 0 - 30 dB exert no effect upon processing demands during auditory learning.

Processing demands during auditory learning for experimental groups I - VI were assessed by three measurements: 1) Learning performance--the number of anticipation trials a subject required to attain a 100 percent performance on the paired associate learning task. 2) Expended processing capacity--the reaction time to a secondary task presented simultaneously during the learning task. 3) Processing demands index--a measurement combining the results of learning performance and

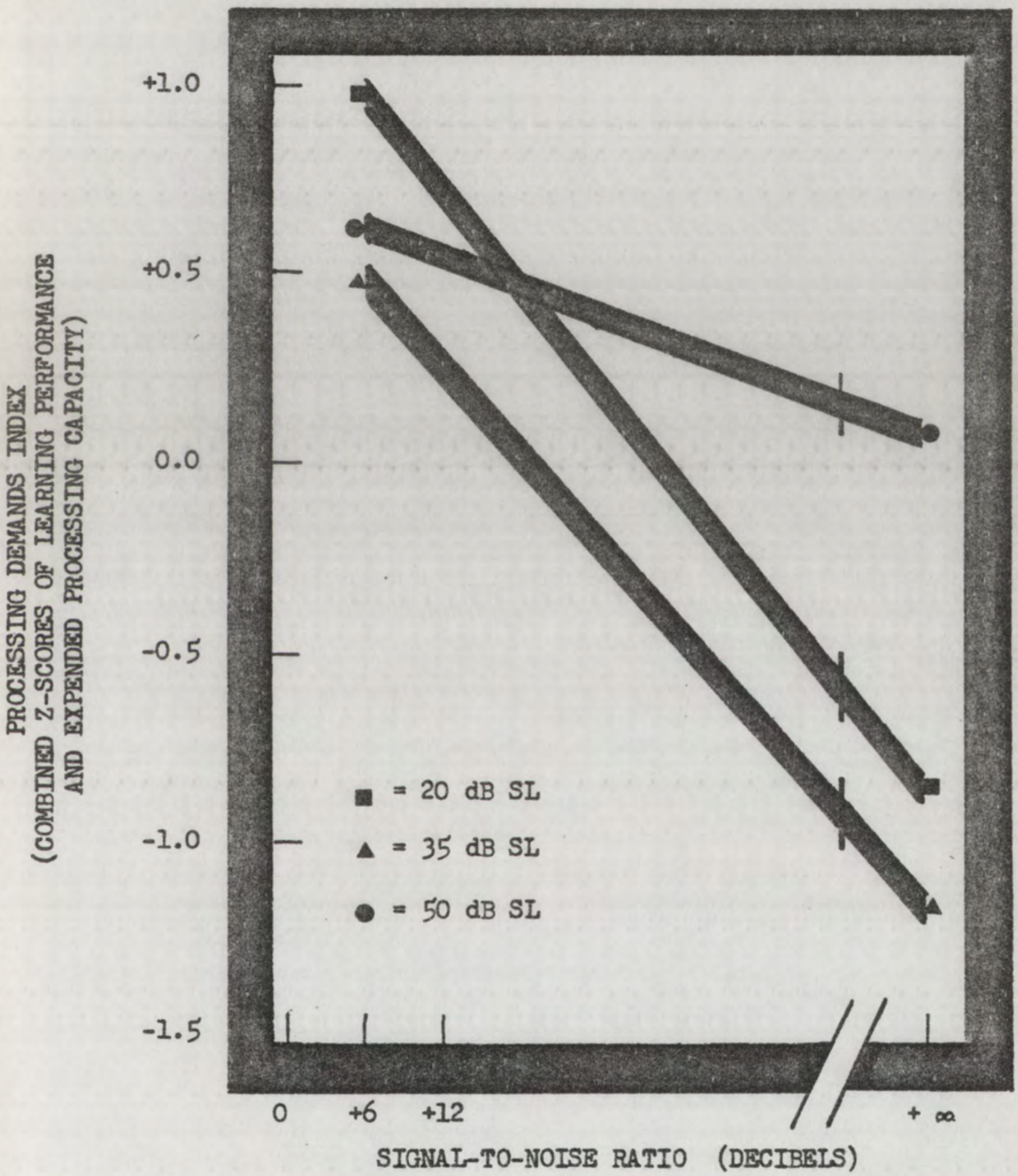


Figure 13. Effects of signal-to-noise ratio on processing demands index at three presentation levels.

expended processing capacity. An analysis of variance reveals that the results of these measures are not significantly different for the three signal presentation levels at 50, 35 and 20 dB SL. These results fail to reject the null hypothesis that changes in speech intensity over a range of from 0 - 30 dB exert no effect upon processing demands during auditory learning.

Hypothesis H_{0_2}: The introduction of noise into the listening situation exerts no effect upon processing demands during auditory learning.

The effects of noise upon processing demands during auditory learning was assessed by each subject's learning performance, expended processing capacity and processing demands index. An analysis of variance indicates that the introduction of noise does not exert a significant effect upon learning performance; but does so on the expended processing capacity measurement and the processing demands index. This effect is present for all three noise conditions (i.e., groups IV, V and VI). With respect to expended processing capacity, the greatest differences between the noise and quiet conditions are found during all of the response selection probe presentations, and one of the multiple input presentations. In conclusion, this null hypothesis is rejected. That is, the introduction of noise into the listening situation does exert an effect upon processing demands during auditory learning.

Hypothesis H_{0_3}: Noise and reduced speech intensity do not interact so as to exert an effect upon processing demands during auditory learning.

An analysis of variance reveals no significant interaction between noise and reduced speech intensity for the three measurements: learning performance, expended processing capacity, and processing demands index. Thus, the null hypothesis is not rejected. Noise and reduced speech intensity do not interact so as to exert an effect upon processing demands during auditory learning.

<u>Hypothesis</u> $^{H}0_4$: Processing demands during the learning stages of response selection, multiple input and rehearsal are not affected differently under degraded listening conditions.

The effects of degraded listening conditions upon probe presentation is determined by viewing differences in expended processing capacity. An analysis of variance indicates that the expended processing capacity for the response selection probes are significantly longer than for the other probes (particularly under the noise conditions). This finding is consistent with Kerr's supposition that the response selection probe is most indicative of expended processing capacity. However, no significant differences are apparent between the multiple input and rehearsal probes, as has been previously reported in the literature (Johnston, et al., 1972a; Kerr, 1973). When the overall data are considered, hypothesis four is rejected. Processing demands during the learning stages of response selection, multiple input and rehearsal are affected differently by presentation under degraded listening conditions.

FINDINGS OF ADDITIONAL INTEREST

Now that the objective experimental results have been presented, it may be interesting to compare them with the subjective impressions of the subjects. Following termination of the experiment, a seven point semantic differential scale was completed by each subject in the 7 experimental groups. The subjects were asked to rate the difficulty of the learning task from (1) Very Easy - (7) Very Difficult. Figure 14 illustrates the results of this scale for the groups. Notice that the mean scores are very close in value; with a range of 4.0 to 4.6 units. An analysis of variance was conducted to compare the subjective assessments of learning difficulty between groups I - VI. No significant differences, $P > 0.05$, are evident among the 7 groups, indicating that neither noise nor signal presentation level exerts an effect on the subject's assessment. This corraborates the objective learning performance results where no significant differences were found among groups. Conversely, the subjective assessments conflict with the expended processing capacity results, where significant differences were present between the noise and quiet listening conditions. This suggests that while the subjects were good judges of learning accuracy (i.e, performance), they were poor judges of learning ease (i.e., attention or effort).

It is interesting to note that several of the subjects in groups IV, V and VI reported that the presence of noise did not affect their learning performance. A common statement was that they became "unaware"

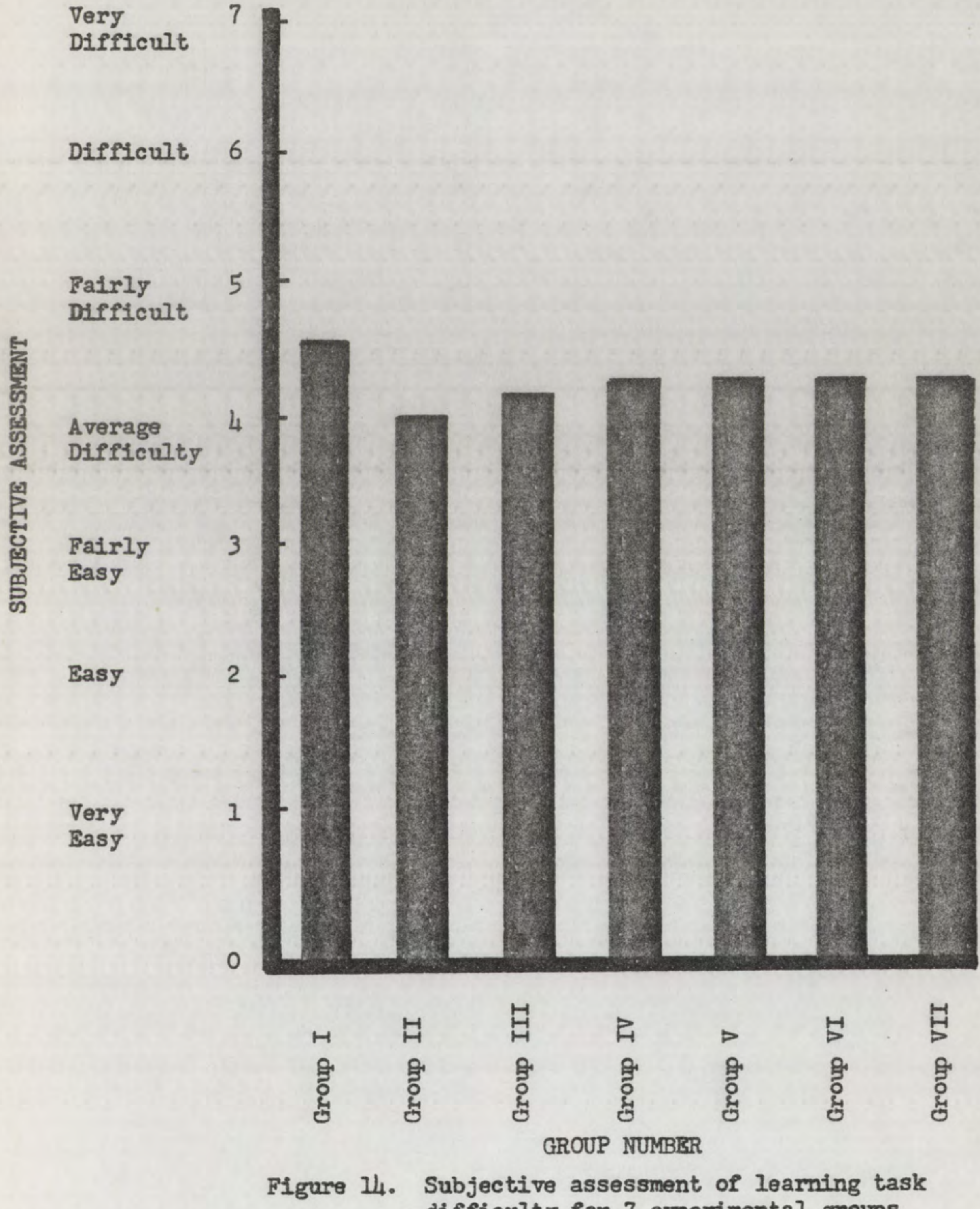


Figure 14. Subjective assessment of learning task difficulty for 7 experimental groups.

of the noise as the experiment progressed. However, the experimenter observed that the subjects participating in the noise conditions showed greater concentration on the learning task. These subjects tended to lean forward in their chairs and demonstrated more overt rehearsing of the learning material.

Figure 14 also portrays equivalent subjective assessment values (i.e., 4.4 units) between group VI and group VII. This finding is in agreement with the objective experimental result of no significant difference in learning performance between these two groups. It thus supports that the introduction of the probe reaction time task did not exert an effect upon the primary learning task.

The findings presented in this section are, of course, only subjective impressions of the subjects and experimenter. That, in some cases, they tend to confirm the objective experimental results is of interest. They should not, however, be interpreted as definitive indicators of processing demands during auditory learning.

IMPLICATIONS

Implications of the previously presented results will now be reviewed. To aid in this discussion, the implications are divided into three general sections. Section one is concerned with the effects of noise upon processing demands during auditory learning. Section two involves the effects of signal intensity upon processing demands during auditory learning. Finally, section three examines the importance of multiple measurements when studying auditory processing.

Effects of Noise Upon Processing Demands During Auditory Learning: Previous research has demonstrated that prolonged exposure to noise can produce delays in speech and language development, as well as impairments in reading and listening skills (Miller, 1974; Mills, 1975). In the field of audiology, past research has cited reduced speech intelligibility in noise to account for these learning difficulties. Granted, reduced intelligibility for speech can impair learning performance. However, the present investigation suggests that other factors are involved. Though all speech signals used in this study were highly intelligible, experimental results still indicated that processing demands during auditory learning were significantly greater under noise conditions. This difference was reflected in the ease with which the learning task was performed. Specifically, the amount of attention (or effort) required for performance of the learning task was greater when the learning signal was presented in a background of noise.

This finding suggests that the noise present in educational settings (e.g., at home or in school) may have deleterious effects upon the learning performance of children. This would be due to increased processing demands invoked by auditory learning under noisy listening conditions. For the child in a noisy classroom, increased effort would be required to selectively attend to an auditory learning signal. If this effort is not expended, there will be a concomitant decrease in learning performance. Similarly, if the effort is allocated, but is not adequate to fulfill the attentional demands of the learning task, learning performance also will falter.

A counterargument to the above suggestions would be that in the present experiment no significant difference in learning performance was present between noise and quiet conditions; and after all, isn't learning performance (i.e., accuracy) the result that is important. Upon review of the double stimulation procedure, this argument is seen to be unfounded. The reader will recall that the subjects in the experiment were instructed not to allow the secondary probe reaction time task to detract from performance on the primary learning task. The primary task performance also was protected by having the duration of the experiment dependent upon learning performance. These precautions are, of course, essential for the precise measurement of learning performance accuracy and ease.

These experimental stipulations are not placed upon a child during his everyday learning activities. Subjects in the present experiment probably exhibited their best learning performance (i.e., the accuracy performance). However, the child in a noisy classroom can sacrifice optimal learning performance if the processing demands of a learning task are increased. This tradeoff relationship could be summed up with the statement, "Learning is just not worth the effort". Or, as previously mentioned, he may provide maximum effort which still cannot meet the requirements for optimum learning performance.

These two possibilities are quite reasonable with respect to the noise conditions in many educational environments. The reader will recall from the review of literature that signal-to-noise ratios in school classrooms have been reported to be even lower than the +6 dB signal-to-noise level used in this study (Paul, 1967; Sanders, 1968). In addition, long reverberation times present in many classrooms may further compound processing demands.

The present experiment also has demonstrated that the detrimental effects of noise were evident whether the learning signal was presented at 50, 35, or 20 db SL. With the signal-to-noise ratio held constant at +6 dB, the respective noise levels were 44, 31, and 14 dB SL. That only a 14 dB SL of background noise could effect processing demands, is of considerable interest. A possible explanation for this is that processing demands during auditory learning are dependent upon the relationship of signal to noise, rather than the absolute level of the noise. If the reduced signal presentation levels of 35 and 20 dB SL are thought of in terms of hearing loss below normal conversational speech, it can be proposed that no listener (i.e., normal hearing or hearing impaired) is immune from the deleterious effects of noise on auditory learning.*

---

*The generalization of these results to the hearing impaired is done with caution. As will be suggested in the section concerned with future research, similar processing demands studies should be performed with hearing impaired listeners.

These findings have important implications for environments in which learning is conducted. The home where a child develops speech and language, and the classroom where a child continues his education, contain unacceptable levels of noise. With the recent emphasis upon open classroom environments in our schools, this situation is sure to become worse. That these noise levels can produce increased processing demands during auditory learning indicates that greater attention should be focused upon classroom and home acoustical design, and/or noise reduction in our learning settings.

A second area of concern to the audiologist, where the results of this study are applicable, is in the area of amplification for the hearing impaired. These experimental findings would suggest that an important consideration in hearing aid fitting is how much a hearing aid amplifies ambient noise. Certainly, audiologists have been aware that noise can have detrimental effects upon hearing aid performance, as well as hearing aid acceptance. This generally is attributed to the reduced intelligibility for speech as a result of noise distortion. The present study would suggest that many of the patients' complaints may also be due to increased auditory processing demands as speech and noise are both amplified.

With regard to young hearing impaired children, questions are prompted concerning the feasibility of using a personal hearing aid in preference to an auditory training unit in educational settings. Because speaker-to-microphone distance is reduced with an auditory training unit, the signal-to-noise ratio generally is more favorable than for a personal hearing aid. The use of an auditory training unit by a hearing impaired child may reduce processing demands during auditory learning in the classroom. Thus, as with adults, selection of the proper amplifying system for children should include careful consideration of the effects of background noise.

Up to this point, the hearing impaired have been considered as individuals with reduced hearing sensitivity. The present findings may also have special relevance for those persons with auditory perceptual disorders. There is accumulating evidence that these individuals have particular difficulty with figure-ground relationships; such as, signal-in-noise (Katz and Illmer, 1972). The present study indicated that processing demands during auditory learning were increased for normal hearing subjects listening in a background of noise. It is not unwarranted to speculate that the processing demands may be even greater in noisy situations for the person with an auditory perceptual disorder. This area is certainly in need for continued research.

In conclusion, it is unfortunate that with a recent emphasis upon the damaging effects of high level noise (i.e., $\geq$ 90 dB SPL), only limited attention has been focused upon the more common, moderate intensity noise. The present study would indicate that noise levels, such as encountered in homes and schools, can produce serious effects upon processing demands during auditory learning.

Effects of Signal Intensity Upon Processing Demands During Auditory Learning: The effects of signal intensity upon auditory learning also may have important implications for the audiologist. Such a suggestion is rather contradictory since the present investigation indicated no significant differences in processing demands during auditory learning between the three signal presentation levels. This finding initially was unexpected. Before this investigation was conducted, the experimenter speculated that if either of the two primary variables would have an effect upon processing demands, it would be signal intensity, not noise. The reasoning behind this apriori assumption was that the normal hearing subjects in this study were accustomed to auditory learning in noise, but not where signal intensity is presented at a reduced level. That this assumption was not borne out by the experimental results is important. First, it suggests that prior experience with auditory learning under degraded listening conditions (such as in noisy environments) does not necessarily result in reduced processing demands during that learning. Secondly, it implies that the attentional requirements of auditory learning in a background of noise are different than auditory learning at reduced signal intensity levels. Specifically, the processing demands of attending to an auditory signal in a background of noise involves an an act of selective attention. However, the present experiment would indicate that attending to a highly intelligible auditory signal at reduced intensities does not involve the same processes.

Moray (1969) provides physiological information which raises objections to the apriori judgement that reduced signal intensity should result in increased processing demands. While Moray is referring to high intensity sound, his statements have applicability for the moderate intensities used in this study. Moray writes:

> "Because most signals from the real world are highly redundant there is no reason to think a priori that such a reduction in overall signal magnitude as can be recorded from nervous pathways necessarily corresponds to an effective loss of information. It is apparent, for example, that if the intensity of stimulation received by an individual nerve cell is signalled as a frequency of firing which is proportional to the logarithm of the stimulus strength, and if the output of a particular nucleus where such a transform occurs is compared with the input then there will be an overall decrease in the number of spike potentials recorded, because of the arithmetic to logarithmic transformation. Summing over the entire pathway we would record an apparent decrease in signal strength, but there would be no loss in information, merely a recoding." (p. 161-162)

The finding that processing demands during auditory learning at different signal intensities are comparable has considerable applicability for hearing aid selection. These results reveal that when the learning signal is highly intelligible, a mere increase in intensity is not essential for a good learning performance. Stated differently, a normal conversational speech level (i.e., approximately 50 dB SL) need not be attained to insure a high level of learning.

With regard to hearing aid selection, these results imply that high gain amplification (re: hearing threshold) is not a prerequisite for the hearing impaired. This is in accord with recent research, as well as comments by hearing aid users, that "use-gain" need not be 40 - 50 dB SPL above the individual's hearing threshold. In many cases, the hearing aid is rejected at these levels. This finding is commonly explained in terms of loudness comfort and discomfort levels. However, the present research would indicate that the hearing aid user may actually be offering us additional information. That is, this person might be suggesting that increased intensity is not a necessary requirement for functioning in different auditory learning situations.

A second (but closely related) implication of these findings concerns education of the hearing impaired. The present findings again imply that learning through the auditory modality does not necessitate a speech signal being presented at a normal conversational speech level. This offers an explanation as to why profoundly hearing impaired children (using amplification), with limited dynamic ranges, can develop speech and language through audition. However, the question logically is raised as to why minimal hearing impairment (15 - 30 dB HL) can result in delayed speech and language development? If the present experimental findings are valid, should not subjects who received the learning signal at reduced intensities (i.e., a "simulated hearing loss") have shown increased processing demands?

This contradiction is explained in two possible ways. First, it should be restated that in this study the learning material was highly intelligible under all listening conditions. This is not the case for even the minimally hearing impaired. Holm and Kunze (1969, p. 833) sum up the plight of the child with minimal hearing impairment when they write, "...he will understand what is being said only under the most favorable conditions (i.e., when facing a person who speaks fairly loudly at close range) but will not understand much of what is said under less favorable conditions (i.e., as in a classroom)". Thus, the high intelligibility of speech evident in the present study may account for the difference between experimental results and hearing impaired learning performance.

Secondly, the minimally hearing impaired listener must receive a learning signal at a reduced intensity for prolonged periods of time. This, of course, was not the case with the subjects in the present study. Therefore, to conclude that reduced signal intensity will not result in increased processing demands for the hearing impaired would be an unsafe generalization. Certainly, similar processing demands studies using hearing impaired subjects are warranted.

Importance of Multiple Measurements When Studying Auditory Processing: To illustrate the importance of using multiple measurements when studying auditory processing, the present study will be cited as an example. If processing demands had been studied only by examining learning performance, no significant differences would have been found between noise and quiet conditions. The conclusion could have then been drawn that background noise does not effect processing demands during auditory learning. However, by introducing the probe reaction time task as a simultaneous measurement of processing ease, significant differences were revealed between noise and quiet conditions. Obviously, the resultant conclusions are quite different.

This example shows the importance of using multiple measures to assess auditory processing demands. The reader will recall from the introduction, that nearly twenty years ago, Broadbent called for using multiple criteria when studying communication systems. Because auditory processing can be assessed by viewing accuracy, speed, and ease of performance, studying any one of these factors individually may not present a proper picture of the demands of an auditory task. Within the field of audiology, auditory processing demands are examined primarily through accuracy measurements. The present study suggests that these measurements alone may be inadequate when examining auditory processing.

PLANS FOR FUTURE RESEARCH

Future research related to the questions investigated in the present study should be directed primarily toward answering two questions: 1) What are the processing demands of the hearing impaired* during auditory learning under degraded listening conditions, and 2) How can the audiologist assess auditory processing demands in a clinical setting.

---

*With respect to future research, hearing impaired should be thought of in terms of children with auditory perceptual disorders, as well as individuals with reduced hearing sensitivity.

With regard to the first question, the normative data presented in the present study have important implications for the hearing impaired. Certainly, the effects of noise on auditory processing demands pose serious questions about the listening conditions under which normal hearing and hearing impaired individuals attempt learning. In addition, the absence of a significant effect of signal intensity upon processing demands has even broader implications for the hearing impaired than for those with normal hearing. However, the importance of this normative data can only be enhanced if similar studies on auditory processing are performed with both normal hearing and hearing impaired individuals.

The following is provided as an example of such a research study. The audiologist may have observed that many hearing impaired patients report greater listening difficulties than intelligibility test results would indicate. A possible reason may be that these intelligibility tests are only measuring accuracy but not ease of auditory processing. By using a double stimulation procedure, such as the probe reaction time task, processing ease could also be judged, thereby providing a more precise estimate of listening demands for the hearing impaired.

The second question concerned with assessing auditory processing demands in a clinical setting is far more complex and challenging. The primary reason for this is that auditory processing demands in a clinical setting are studied on an individual basis. The present study indicated that there was considerable individual variability, as well as sources of experimental error when assessing expended processing capacity. To insure clinical applicability, future research should be directed toward reducing this variability when measuring expended processing capacity. This warrants clinical investigations using repeated measures designs, so that a subject can serve as his own control. Such auditory processing demands studies are presently possible when implemented with clinical procedures such as intelligibility testing and hearing aid evaluations.

In conclusion, the area of auditory processing demands (where attention and effort are of primary concern) has been totally ignored in the past by audiologists. The present study has shown that areas of interest to the audiologist can be investigated using a double stimulation procedure. Hopefully, this study will foster other investigations by audiologists into the area of auditory processing demands.

CHAPTER V

SUMMARY

Recent research has demonstrated that auditory learning can be adversely affected when performed under degraded listening conditions. Perhaps the most common of these degraded listening conditions are environments of moderate intensity noise; such as found in the classroom or in the home. A second degraded listening condition occurs when the important speech signal is heard at a reduced intensity. This situation is found with the hearing impaired individual. That reduced speech intensity and/or noise can have detrimental effects upon learning has been almost exclusively attributed, by audiologists, to impaired signal intelligibility. The present study (which controlled for high speech intelligibility) investigated whether the added processing demands of auditory learning under degraded listening conditions could account for learning deficits. Specifically, the question examined was whether processing demands during auditory learning were greater under quiet versus noisy listening conditions and/or when the learning signal was presented at a reduced intensity level.

To assess processing demands, a double stimulation procedure was employed. The double stimulation procedure allows the experimenter to simultaneously measure both processing accuracy (i.e., performance) and ease (i.e., attention or effort) during an activity--such as, auditory learning. The rationale for using the double stimulation procedure is as follows. Viewing only the performance of an individual on a particular activity does not give a complete picture of the processing demands of that activity. A more accurate assessment of task demands is provided when the attention or effort expended during a task also is measured. To accomplish this, performance on a secondary task is simultaneously measured while being engaged in the task of primary interest. As processing demands of the primary task increase, there will be a concomitant decrease in performance on the secondary task. In addition, to insure the validity of using a double stimulation procedure, it is imperative that the secondary task reflect but not effect processing demands on the primary task. By protecting the primary task during a double stimulation procedure, this precaution is taken; with the result being valid measures of task accuracy and ease.

In the present study, the primary activity was a paired associate learning task where 10 couplets of spondee words were used as the learning signal. Forty-nine normal hearing, undergraduate students were randomly assigned to 7 experimental groups. Each group performed the same learning task under varying listening conditions. Groups I - III received the learning signal under quiet conditions; while groups IV - VII heard the learning signal presented in a background of multiple talker noise (+6 dB signal-to-noise ratio). In addition, the learning signal was presented at three intensity levels: 50 dB SL for groups I and IV; 35 dB SL for groups II and V; and 20 dB SL for groups

III, VI, and VII. All signal and noise conditions were presented into the sound field of a double walled sound treated booth.

A secondary probe reaction time task was simultaneously performed by groups I - VI to assess processing ease. This task consisted of a probe light being presented to the subjects at varying intervals during the learning task. It was the subjects' responsibility to immediately switch the light off whenever it appeared. A reaction timer registered the latency between the time the light appeared and the time it was turned off. Group VII performed only the primary learning task. This group thus served as a control condition to assess any interference between primary and secondary tasks.

Learning performance was measured by the number of trials required for a subject to reach a 100 percent criterion on the paired associate learning task. Learning ease (referred to as expended processing capacity) was equivalent to the difference between the probe reaction time during the learning task and a baseline performance on a reaction time task. A third measurement, called the processing demands index, was calculated by combining learning performance and expended processing capacity results.

Results of this study indicated that neither of the experimental variables (i.e., signal-to-noise ratio or signal presentation level) exerted a significant effect upon learning performance. However, the expended processing capacity and processing demands index measurements revealed that all three noise conditions (i.e., groups IV - VI) required significantly greater processing demands than the quiet conditions, $P < 0.05$. This was found to be particularly true for the probe presentations made during the response selection and multiple input learning stages. Finally, no significant differences were apparent for the expended processing capacity or processing demands index measurements when comparisons were made between signal presentation levels.

These results suggest that while signal presentation level does not exert an effect upon processing demands during auditory learning, signal-to-noise ratio does. Specifically, the greater processing demands evident under the noise conditions are reflected in the expended processing capacity measurement, but not learning performance. This suggests that while the noise did not affect processing accuracy, it did exert an effect upon processing ease. It is interesting to note that the subjects' own assessment of the difficulty of the learning task was in agreement with the accuracy results, but contradicted the ease results. Finally, no significant difference in learning performance was found between experimental group VI and control group VII. This finding indicates that the secondary probe reaction time task did not interfere with performance on the primary learning task.

These results have important implications for the audiologist. The most obvious implication is that the noise levels present in educational settings may have serious deleterious effects upon learning ease. With respect to the hearing impaired, the results also indicate that hearing aid selection should include a careful evaluation of the noise characteristics of the amplification unit chosen. The lack of significance found between signal presentation levels is equally important. Generally, this finding implies that a mere increase in intensity of a speech signal is not necessarily an advantage for auditory learning. Such a proposition offers one explanation as to why auditory learning is possible with many hearing impaired individuals with limited dynamic ranges. Certainly, these results also question the use of high gain (re: sensation level) amplifying units with the hearing impaired. Finally, this study offers the audiologist evidence for the utility of instituting multiple measurements when assessing auditory processing.

REFERENCES

American National Standard (1969), Specifications for Audiometers, (ANSI S3.6-1969), New York: American National Standards Institute, 1430 Broadway.

Bahrick, H. P., Noble, M., and Fitts, P. M. (1954), Extratask performance as a measure of learning on a primary task, Journal of Experimental Psychology, 48, 298-302.

Beal, D. (1972), Personal communication to David Kessner, In Otitis Media, Glorig, A. and Gerwin, K. S. (Ed.), Charles C. Thomas, Springfield.

Bowling, L. S. and Elpern, P. S. (1961), Relative intelligibility of items on CID Auditory Test W-1, Journal of Auditory Research, 1, 152-157.

Broadbent, D. E. (1958), Perception and Communication, Pergamon Press, London, 68-85.

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

Brooks, D. N. (1969), The use of electro-acoustic impedance bridge in the assessment of middle ear function, International Audiology, 8, 563.

Brown, I. D., and Poulton, E. C. (1961), Measuring the spare "mental capacity" of car drivers by a subsidiary task, Ergonomics, 4, 35-40.

Brown, J. (1958), Some tests of the decay theory of immediate memory, Quarterly Journal of Experimental Psychology, 10, 12-21.

Cherry, E. C. (1953), Some experiments on the recognition of speech with one and two ears, Journal of the Acoustical Society of America, 25, 975-79.

Colman, F. D. and Paivio, A. (1969), Pupillary response and galvanic skin response during an imagery task, Psychonomic Science, 16, 296-297.

Crum, M. (1974), Effects of reverberation, noise and distance upon speech intelligibility in small, classroom size acoustic enclosures. PhD. Dissertation, Northwestern University.

Deutsch, J. A., and Deutsch, D. (1963), Attention: some theoretical considerations, Psychological Review, 70, 80-90.

Eagles, E. L. (1972), Selected findings from the Pittsburgh Study, Transactions of the American Academy of Opthamalogy and Otolaryngology, 76, 343.

Egeth, H. and Bevan, W. (1973) Chapter in Wolman, B. B. (Ed.), Handbook of General Psychology, Prentice-Hall, New Jersey, 395-418.

Ellis, H. C. (1972), Human Learning and Cognition, William C. Brown, Iowa, 38-43.

Environmental Protection Agency Survey (1974), reported in Mills, J. H., (1975), Noise and children: A review of the literature, Journal of the Acoustical Society of America, 58, #4.

Evans, J. E., (1916), The effect of distraction on reaction time, Archives of Psychology, 37, 1-106.

Fey, T. H., Hochberg, I., Smith, C., et al. (1970), Audiologic and otologic screening of disadvantaged children, Archives of Otolaryngology, 91, 311.

Finitzo-Hieber, T. (1975), The influence of reverberation and noise on the speech intelligibility of normal and hard of hearing children in classroom size listening environments, Ph. D. Dissertation, Northwestern University.

Gaeth, J. (1967), Deafness in children, National Symposium on Deafness in Childhood, Freeman, M., and Ward, P. H., (Eds.), Vanderbilt University Press, Nashville, Tennessee.

Garvey, W. D. and Taylor, F. V. (1959), Interactions among operator variables, system dynamics, and task-induced stress, Journal of Applied Psychology, 43, 79-85.

Gengel, R. W. (1971), Acceptable speech-to-noise ratios for aided speech discrimination for the hearing impaired, Journal of Auditory Research, 11, 219-222.

Goldman, R., Fristoe, M., and Woodcock, R. W. (1970), Test of Auditory Discrimination, American Guidance Service, Circle Pines.

Grossman, S. P., (1973), Essentials of Physiological Psychology, John Wiley and Sons, New York.

Hayman, C. R., and Kester, F. E. (1956), Eye, ear, nose and throat infections in natives of Alaska, Northwest Medicine, 56, 423.

Hirsh, I. J., Davis, H., Silverman, S. R., Reynolds, E. G., Eldert, E., Benson, R. W., (1952), Development of materials for speech audiometry, Journal of Speech and Hearing Disorders, 17, 321-327.

Holm, V. A. and Kunze, L. H., Effect of chronic otitis media on language and speech development, Pediatrics, 43, 833-838.

Hull, F. M., Mielke, P. W., Timmons, R. J., et al.,(1971), The national speech and hearing survey: preliminary results, American Speech and Hearing Association, 13, 501.

John, J. E. J., (1960), The efficiency of hearing aids as a function of architectual acoustics, in Ewing, A. W. G. (Ed.), The Modern Educational Treatment of Deafness, Manchester University Press, Manchester, England.

Johnston, W. A., Greenberg, S. N., Fisher, R. P., and Martin, D. W., Divided attention: A vehicle for monitoring memory processes, Journal of Experimental Psychology, 83, 164-171.

Johnston, W. A., Griffith, D., and Wagstaff, R. R., (1972a) Speed, accuracy, and ease of recall, Journal of Verbal Learning and Verbal Behavior, 11, 312-320.

Johnston, W. A., Wagstaff, R. R., and Griffith, D. (1972b), Information processing analysis of verbal learning, Journal of Experimental Psychology, 307-314.

Kahneman, D. (1970), Remarks on Attention control, Acta Psychologica, 33, 118-131.

Kahneman, D., (1973), Attention and Effort, Prentice-Hall, Englewood Cliffs, New Jersey.

Kahneman, Tursky, Shapiro, and Crider, (1969), Pupillary, heart rate and skin resistance changes during a mental task, Journal of Experimental Psychology, 79, 164-167.

Kantowitz, B. H. (1974), Human Information Processing:Tutorials in Performance and Cognition, Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Kaplan, G. J., Fleshman, J. R., Bender, T. R., et al.: Longterm effects of otitis media: a 10 year cohort study of Alaska Eskimo Children, Pediatrics, 52, 577-585.

Katz, J. and Illmer, R. (1972), Auditory perception in children with learning disabilities, in Katz, J. (Ed.), Handbook of Clinical Audiology, Williams and Wilkins Co., Baltimore, 540-563.

Keele, S. W., (1967), Compatibility and timesharing in serial reaction time, Journal of Experimental Psychology, 75, 529-539.

Keele, S. W., (1973), Attention and Human Performance, Goodyear Publishing Company, Pacific Palisades, 147-157.

Kerr, Beth (1973), Processing demands during mental operations, Memory and Cognition, 1:4, 401-412.

Knudsen, V.C., and C. M. Harris (1950), Acoustical Design in Architecture, John Wiley and Sons, New York.

Kodman, F. (1963), Educational status of hard of hearing children in the classroom, Journal of Speech and Hearing Disorders, 28, 297-299.

Ling, D. (1972), Rehabilitation of cases with deafness secondary to otitis media, in Glorig, A. and Gerwin, K. S. (Eds.), Otitis Media, Charles C. Thomas, Springfield, 249-253.

Marsh, D. J. (1973), Auditory figure-ground ability in children, American Journal of Occupational Theory, 27:5, 218-225.

Martin, D. W. (1970), Residual processing capacity during verbal organization in memory, Journal of Verbal Learning and Verbal Behavior, 9, 391-397.

Miller, J. D. (1974), Effects of noise on people, Journal of the Acoustical Society of America, 56, 729-764.

Mills, J. H. (1975), Noise and children: A review of the literature, Journal of the Acoustical Society of America, 58:4, 767-779.

Milner, P. M. (1970), Physiological Psychology, Holt, Rinehart, and Winston Inc., New York, 281-295.

Mindel, E. D., and Vernon, M. (1971), They Grow in Silence, National Association of the Deaf, Silver Spring, Maryland, 87-94.

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

Moray, N. (1967), Where is capacity limited? A survey and a model, _Acta Psychologica_, 27, 84-92.

Moray, N. (1969), _Selective Processes in Vision and Hearing_, Hutchinson Educational LTD. London, 161-162.

Morton, J. (1969), In Keele, S. W., _Attention and Human Performance_, Goodyear Publishing Company, Pacific Palisades, p. 110.

Neisser, U. (1967), _Cognitive Psychology_, Appleton-Century-Crofts, New York.

Niemoller, A. F. (1968), Acoustical design of classrooms, _American Annals of the Deaf_, 113, 1040-1045.

Norman, D. A. (1968), Toward a theory of memory and attention, _Psychological Review_, 75, 522-36.

Northern, J. and Downs, M. (1974), _Hearing in Children_, Williams and Wilkins, p. 32.

Obersteiner, H. (1879), Experimental researches in attention, _Brain_, 1, 439-453.

Paul, R. L. (1967), in Katz, J. (Ed.) (1972), _Handbook of Clinical Audiology_, Williams and Wilkins Co., Baltimore, p. 757.

Peltzman, P., Kitterman, J. A., Ostwald, P. F., Manchester, D., and Heath, L., (1970), Effects of incubator noise on human hearing, _Journal of Auditory Research_, 10, 335-339.

Peterson, L. R., and Peterson, M. J. (1959), Short-term retention of individual verbal items, _Journal of Experimental Psychology_, 58, 193-198.

Pinter, R. and Peterson, D. G. (1917), A measure of the language ability of deaf children, _American Annals of the Deaf_, 62, 211-239.

Posner, M. I., and Boies, S. J. (1971), Components of attention, _Psychological Review_, 78, 391-408.

Posner, M. I. and Keele, S. W. (1970), Time and space as measures of mental operations, Invited address, Division 3, _American Psychological Association_.

Posner, M. I. and Keele, S. W., (1969), Attention demands of movements, _Proceedings of the Seventeenth Congress of Applied Psychology_, Amsterdam, Zeitlinger.

Quigley, S. P. (1970), in Downs, M. P. (1974), Hearing loss: definition, epidemiology, and prevention, Public Health Review.

Rabbitt, P. M. A. (1966), Recognition: memory for words correclty heard in noise, Psychonomic Science, 6:8, 383-384.

Rabbitt, P. M. A. (1971), Times for the analysis of stimuli and for the selection of responses, British Medical Bulletin, 27, 259-265.

Reed, D., Struve, S., and Maynard, J. E. (1967), Otitis media and hearing deficiency among Eskimo children: a cohort study, American Journal of Public Health, 57, 165.

Reis, P. (1973), Academic Achievement Test Results of a National Testing Program for Hearing Impaired Students, Gallaudet College, Washington, D. C.

Sanders, D. (1965), Noise conditions in normal school classrooms, Exceptional Children, 31, 344-353.

Schein, J. D. and Bushnaq, S. (1962), Higher education for the deaf in the U. S.--a retrospective investigation, American Annals of the Deaf, 107, 416-20.

Speith, W., Curtis, J. F., and Webster, J. C. (1954), Responding to one of two simultaneous messages, Journal of the Acoustical Society of America, 26, 391-96.

Thomas, H. (1960), Architectual acoustics as a fundamental factor in the design of schools for the deaf, in Ewing, A. (Ed.) (1960), The Modern Educational Treatment of Deafness, Manchester University Press, Manchester, England.

Tolk, J. (1961), Acoustics, intelligibility of speech and electro-acoustic systems in classrooms, in Katz, J. (Ed.) (1972), Handbook of Clinical Audiology, Williams and Wilkins Co., Baltimore, p. 766.

Treisman, A. M. (1960) Contexual cues in selective listening, Quarterly Journal of Experimental Psychology, 12, 242-48.

Triesman, A. M. (1964), Monitoring and storage of irrelevant messages in selective attention, Journal of Verbal Learning and Verbal Behavior, 3, 449-59.

Welch, J. C. (1899), On the measurement of mental activity through muscular activity and the determination of a constant attention, American Journal of Physiology, 1, 283-306.

Welford, A.T. (1952), the "psychological refractory period" and the timing of high speed performance: A review and a theory, British Journal of Psychology, 43, 2-19.

Woodrow, H. (1914), The measurement of attention, Psychological Monograph, 17:76, p.8.

Wrightstone, J. W., Aronow, M. S., and Maskowitz, S. (1963), Developing reading test norms for deaf children, American Annals of the Deaf, 108, 311-316.

Yerkes, R. M. and Dodson, J. D. (1908), The relation of strength of stimulus to the rapidity of habit formation. Journal of Comparative Neurology of Psychology, 18, 459-482.

Young, C. and McConnell, F. (1957), Retardation of Vocabulary Development in hard of hearing children, Exceptional Children, 368-370.

APPENDIX A

STIMULUS WORD PAIRINGS FOR THE EXPOSURE TRIAL AND 12 ANTICIPATION TRIALS (INCLUDING PROBE PLACEMENTS)

Exposure Trial

Airplane-Schoolboy
Drawbridge-Sidewalk
Doormat-Birthday
Inkwell-Hardware
Iceberg-Armchair
Playground-Woodwork
Cowboy-Daybreak
Sunset-Northwest
Greyhound-Eardrum
Railroad-Hotdog

Anticipation Trials*

Trial I

Doormat-Birthday	(R)
Airplane-Schoolboy	
Drawbridge-Sidewalk	
Inkwell-Hardware	
Sunset-Northwest	(MI)
Playground-Woodwork	
Railroad-Hotdog	
Iceberg-Armchair	
Cowboy-Daybreak	(RS)
Greyhound-Eardrum	

Trial II

Cowboy-Daybreak	
Drawbridge-Sidewalk	
Iceberg-Armchair	
Doormat-Birthday	(R)
Inkwell-Hardware	
Airplane-Schoolboy	(MI)
Playground-Woodwork	
Railroad-Hotdog	
Greyhound-Eardrum	(RS)
Sunset-Northwest	

Trial III

Sunset-Northwest	
Railroad-Hotdog	
Iceberg-Armchair	
Playground-Woodwork	(R)
Inkwell-Hardware	
Airplane-Schoolboy	
Cowboy-Daybreak	
Greyhound-Eardrum	(MI)
Doormat-Birthday	(RS)
Drawbridge-Sidewalk	

Trial IV

Inkwell-Hardware	
Drawbridge-Sidewalk	
Iceberg-Armchair	
Playground-Woodwork	
Airplane-Schoolboy	
Greyhound-Eardrum	(R)
Sunset-Northwest	(MI)
Doormat-Birthday	
Railroad-Hotdog	(RS)
Cowboy-Daybreak	

*While the response selection (RS) probes were presented on every trial, The reader will recall that multiple input (MI) and rehearsal (R) probes were presented on alternate trials.

Trial V

Greyhound-Eardrum	(R)
Railroad-Hotdog	
Airplane-Schoolboy	
Doormat-Birthday	
Drawbridge-Sidewalk	(MI)
Iceberg-Armchair	(RS)
Inkwell-Hardware	
Sunset-Northwest	
Playground-Woodwork	
Cowboy-Daybreak	

Trial VI

Cowboy-Daybreak	(RS)
Iceberg-Armchair	(MI)
Sunset-Northwest	
Greyhound-Eardrum	
Railroad-Hotdog	
Doormat-Birthday	(R)
Inkwell-Hardware	
Drawbridge-Sidewalk	
Playground-Woodwork	
Airplane-Schoolboy	

Trial VII

Railroad-Hotdog	(R)
Iceberg-Armchair	
Cowboy-Daybreak	(MI)
Greyhound-Eardrum	
Sunset-Northwest	
Playground-Woodwork	
Drawbridge-Sidewalk	(RS)
Doormat-Birthday	
Airplane-Schoolboy	
Inkwell-Hardware	

Trial VIII

Sunset-Northwest	
Drawbridge-Sidewalk	
Railroad-Hotdog	(R)
Iceberg-Armchair	(MI)
Doormat-Birthday	
Airplane-Schoolboy	(RS)
Greyhound-Eardrum	
Playground-Woodwork	
Cowboy-Daybreak	
Inkwell-Hardware	

Trial IX

Iceberg-Armchair	
Inkwell-Hardware	(R)
Doormat-Birthday	(MI)
Cowboy-Daybreak	
Drawbridge-Sidewalk	
Railroad-Hotdog	
Greyhound-Eardrum	(RS)
Sunset-Northwest	
Airplane-Schoolboy	
Playground-Woodwork	

Trial X

Sunset-Northwest	
Drawbridge-Sidewalk	
Railroad-Hotdog	
Playground-Woodwork	(RS)
Doormat-Birthday	
Airplane-Schoolboy	(R)
Cowboy-Daybreak	(MI)
Inkwell-Hardware	
Greyhound-Eardrum	
Iceberg-Armchair	

Trial XI

Airplane-Schoolboy	
Inkwell-Hardware	
Cowboy-Daybreak	
Greyhound-Eardrum	
Drawbridge-Sidewalk	
Playground-Woodwork	(RS)
Sunset-Northwest	
Iceberg-Armchair	(R)
Doormat-Birthday	
Railroad-Hotdog	(MI)

Trial XII

Airplane-Schoolboy	
Playground-Woodwork	
Greyhound-Eardrum	
Iceberg-Armchair	(RS)
Cowboy-Daybreak	
Railroad-Hotdog	
Doormat-Birthday	
Drawbridge-Sidewalk	(R)
Inkwell-Hardware	
Sunset-Northwest	(MI)

APPENDIX B

EXPERIMENTAL INSTRUCTIONS

Instructions for Baseline Reaction Time Task:

During the next five minutes, the light on the panel in front of you will be turned on at different time intervals. By pushing this button, it will be your responsibility to turn off the light as quickly as possible whenever it appears. Do you understand these instructions?

Instructions for Exposure Trial:

10 different word pairs will now be spoken through the loudspeaker (experimenter will state under which listening condition). Following the presentation of the two words in each pair, you will have 5 seconds to repeat back both words. Please wait till you hear both words before you say them both back. These same ten word pairs will be used in a learning task later on during the experiment, so that you should begin trying to associate the first word with the second word in each pair. Do you understand these instructions?

Instructions for Anticipation Trials;

You will now hear the first word in each of these word pairs followed by a 3 second pause. During this pause, you should say back the second word in each pair. Immediately after this 3 second pause, both words in the pair will be repeated in order for you to learn whether you were correct or incorrect in your response. This same procedure will be used for all 10 word pairs which constitutes one learning trial. The experiment will continue until you correctly recall all ten of the second words in each pair during a single learning trial. Since you will not be aware of which learning trial you are on, I will instruct you when the experiment is completed. Do you understand these instructions?

Instructions for Probe Reaction Time Task (Groups I - VI):

During this learning task, the light will also come on at different times. When the light appears, you should turn it off as quickly as possible by pushing the button in your hand. However, it is extremely important that you do not let the turning off of the light interfere with your performance on the word learning task. To insure this, while performing the learning task you should devote only your "left over" effort to turning off the light. In addition, I should reemphasize that the duration of this experiment is dependent upon how well you do on the learning task. For this reason, while you should try to turn the light off as quickly as possible, you should not let this task detract from your performance on the learning of the word pairs. Do you understand these instructions?

APPENDIX C

SEMANTIC DIFFERENTIAL SCALE FOR SUBJECTIVE ASSESSMENT OF LEARNING TASK DIFFICULTY

Very Easy	Easy	Fairly Easy	Average Difficulty	Fairly Difficult	Difficult	Very Difficult
1	2	3	4	5	6	7

Directions: Please rate the difficulty of the <u>learning task</u> along this 7 point scale.

APPENDIX D

NUMBER OF ANTICIPATION TRIALS REQUIRED FOR EACH OF THE 49 SUBJECTS TO COMPLETE THE PAIRED ASSOCIATE LEARNING TASK

	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII
Subject 1	3	4	11	9	11	9	6
Subject 2	7	4	3	12	6	7	7
Subject 3	6	7	7	5	9	7	3
Subject 4	12	3	10	9	6	8	6
Subject 5	3	5	5	12	4	7	7
Subject 6	5	4	5	3	3	8	4
Subject 7	11	4	4	5	10	8	12
TOTAL	47	31	45	55	49	54	45
AVERAGE	6.7	4.4	6.4	7.9	7.0	7.7	6.4

APPENDIX E

EXPENDED PROCESSING CAPACITY DATA FOR EACH OF THE 49 SUBJECTS (OVERALL TIMES--MILLISECONDS)*

	Group 1	Group II	Group III	Group IV	Group V	Group VI
Subject 1	441	206	136	241	476	172
Subject 2	403	156	166	96	113	598
Subject 3	122	310	116	286	258	201
Subject 4	148	181	161	151	204	148
Subject 5	292	3	135	561	248	256
Subject 6	230	148	177	528	152	214
Subject 7	181	209	39	157	715	734
AVERAGE	260	173	133	289	309	332

*Overall Time = 2(RS) + (R) + (MI)/3 - $Baseline_T$ Reaction Time

APPENDIX E

EXPENDED PROCESSING CAPACITY DATA FOR EACH OF THE 49 SUBJECTS (RESPONSE SELECTION TIMES--MILLISECONDS)*

	Group I	Group II	Group III	Group IV	Group V	Group VI
Subject 1	599	215	160	178	491	185
Subject 2	548	117	215	78	77	735
Subject 3	165	249	127	274	302	214
Subject 4	175	213	187	211	181	171
Subject 5	362	33	108	712	260	356
Subject 6	249	165	153	807	124	287
Subject 7	194	244	25	130	869	905
AVERAGE	327	177	139	341	329	408

*Response Selection Time = 2(RS)/2 - $Baseline_T$ Reaction Time

APPENDIX E

EXPENDED PROCESSING CAPACITY DATA FOR EACH OF THE 49 SUBJECTS (MULTIPLE INPUT TIMES--MILLISECONDS)*

	Group I	Group II	Group III	Group IV	Group V	Group VI
Subject 1	229	260	124	441	543	180
Subject 2	277	242	158	151	121	791
Subject 3	22	481	109	357	212	174
Subject 4	115	153	188	113	233	245
Subject 5	232	-64	198	461	238	205
Subject 6	258	110	221	230	169	167
Subject 7	216	109	90	189	588	455
AVERAGE	193	184	155	277	301	317

*Multiple Input Time = (MI) - Baseline_T Reaction Time

APPENDIX E

EXPENDED PROCESSING CAPACITY DATA FOR EACH OF THE 49 SUBJECTS (REHEARSAL TIMES--MILLISECONDS)*

	Group I	Group II	Group III	Group IV	Group V	Group VI
Subject 1	309	135	104	130	360	134
Subject 2	234	147	38	78	177	214
Subject 3	135	288	100	224	217	198
Subject 4	126	143	82	72	220	5
Subject 5	202	28	138	359	232	90
Subject 6	180	150	188	260	204	112
Subject 7	110	234	15	177	534	668
AVERAGE	185	161	95	186	278	203

*Rehearsal Time = (R) - Baseline_T Reaction Time