THE EFFECT of NOISE and SYNTACTIC COMPLEXITY on LISTENING COMPREHENSION

by

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ABSTRACT

Twelve normal-hearing subjects (21 to 33 years of age) listened to sentences in the presence of an eight-talker babble background noise in three signal-to-noise (S:N) conditions: 0, -3, -6 dB S:N. Each sentence was one of nine different syntactic complexity types. Subjects were asked to perform an Object Manipulation Task (OMT) by acting out who did what to whom in the sentences by using toy animals. Each subject's manipulations were coded as correct or incorrect; the incorrect manipulations were subdivided into three error categories: syntactic violations, lexical substitutions, and omissions. The latency of each manipulation was measured. The present study investigated the effect of the S:N conditions and the syntactic complexity on accuracy of comprehension and latency of response. Also, the number and types of errors that occurred as S:N conditions became more adverse were examined. It was found that more complex sentences were not comprehended as accurately as less complex sentences and the more complex sentences took more time to act out. The pattern of the relative number of errors across sentence types were similar across S:N conditions, though fewer sentences were comprehended correctly in the -6 dB S:N condition. It was also found that, in general, syntactic-type errors increased as the S:N condition became more adverse. It was shown that similar errors were made in the present study as were made by aphasic patients (Caplan, Baker, and Dehaut, 1985) and by normal young subjects who were perceptually stressed with a visual presentation of sentences at an increased speed (Miyake, Carpenter, and Just, 1994). The results obtained in the present study were used to evaluate the idea that working memory capacity may limit a listener's ability to comprehend.

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INTRODUCTION

"Understanding speech is undoubtedly the most important of human auditory functions. It is also very complex, requiring the integration of auditory, cognitive, linguistic, and communicative skills." (Willott, 1991). Many people experience difficulty in the immediate comprehension of spoken language, especially when it is composed of complex sentences. This trouble is certainly exacerbated when the sentences are presented in noisy conditions. The purpose of this study is to determine how the comprehension of sentences heard in noise varies as the structural complexity of the sentences increases and as the amount of background noise increases.

In the present chapter, perception and comprehension of speech heard in noise will be reviewed as will be the role of working memory in comprehension. The issue of syntactic complexity will receive special consideration. A review of the research on sentence comprehension will be presented along with the specific hypotheses of the current study.

SPEECH PERCEPTION AND LANGUAGE COMPREHENSION

An important factor which differentiates human perception of speech sounds from that of other auditory signals is that the relationship between speech sounds and meaning is arbitrary; that is, the sounds of speech form a complex code; a small set of sounds can potentially produce a countless set of words (Jusczyk, 1986).

Communication though spoken language can be seen as a process of message transfer in which a talker converts a meaning into sound. Specifically, a message is converted into articulatory movements to produce acoustic signals which are transmitted though an environment or medium to the auditory system of a listener. An adult listener receives the sound and matches it against various representations of meanings which are stored as linguistic knowledge. The goal of speech perception is to trigger processes in the listener which retrieve the speaker's meaning. To attain this goal it is necessary that speech sounds be heard by a listener and that the listener possess relevant knowledge and a linguistic processing system. This mapping or translation from input signal to meaning is achieved as a result of various steps in an information-processing model (Fraser, 1992). See Figure 1.

high-level processes →→→ conceptual representation of message

↕

semantic representation

↕

syntactic representation

↕

lexical access

↕

phonological representation

↕

phonetic representation

↕

auditory representation

speechwave →→→

(adapted from Fraser, 1992)

Figure 1. A basic model of speech perception.

Information can flow from the "top" of the model down, as well as from the signal "up". For example, after comprehending a message, a listener's knowledge of syntax can be used to both predict and interpret what will follow. These predictions often impose constraints on further interpretations and, by so doing, guide the subsequent processing of auditory input (Smith, 1988).

Comprehension of spoken language can be considered to result in a representation of the meaning of a talker's intended message. Comprehending is an intricate process which involves a variety of types of knowledge: knowledge of the phonology, morphology, and syntax of the language being spoken, knowledge of the accent, dialect, and vocal characteristics of the speaker, and knowledge of vocabulary, past related discourse, and physical context (Briscoe, 1987).

SPEECH PERCEPTION AND COMPREHENSION IN NOISE

It appears that while comprehension of spoken messages is difficult for people with hearing impairments or for those who are older (for a review, see CHABA, 1988), it may also sometimes be difficult for normal-hearing young adults. We encounter many situations in everyday life which reduce our ability to comprehend. Competing background noise is one such condition. Evidence for the variety of ways in which young normal-hearing adults are affected by adverse listening conditions is provided by Pichora-Fuller, Schneider, & Daneman (1995) who describe a decrease in word identification and working memory performance as competing speech babble becomes more adverse. It also has been shown that, for young normal-hearing subjects, speech reception thresholds are lower when the competing signal is speech, as compared to when it is non-speech noise, even when the noise has the same long-term average spectrum as the speech stimuli (Duquesnoy, 1983). Pichora-Fuller et al. (1995) found that normal-hearing young subjects performed almost perfectly in a word identification task at +2 dB S:N when the noise was eight-talker babble and the words were in a high-context condition; these subjects, however, required a +8 dB S:N condition to perform optimally (approximately 90%) in a low-context condition.

The contribution of visual information to speech intelligibility as a function of S:N and the size of a possible vocabulary set was investigated by Sumby and Pollack (1954). These authors found that more adverse S:N conditions could be tolerated as the size of the message set to be comprehended was reduced. They also found that more adverse S:N conditions could be tolerated if visual cues were presented. They found that the visual contribution to speech intelligibility increased as S:N ratio decreased. Thus, the visual contribution became more important as S:N ratio decreased since the information could no longer be comprehended when the input was solely auditory.

WORKING MEMORY

"Since auditorily presented sentences consist of sequentially presented words, it is a priori reasonable to consider that the short-term-memory system, which stores and allows for retrieval of auditorily presented words, might be involved in sentence comprehension." (Caplan and Hildebrandt, 1988). Working memory is a term used by Baddeley and Hitch (1974) to describe the short-term memory system which is involved in the temporary processing and storage of information. They suggested that working memory is involved in supporting a large range of everyday cognitive tasks, such as reasoning, language comprehension, long-term learning, and mental arithmetic.

Baddeley and Hitch (1974) identified three separate components of working memory: the central executive, the phonological loop, and the visuo-spacial sketchpad. They considered the central executive to be the most important component since its roles were viewed as including regulating information from other memory systems as well as information about information processing and storage. Baddeley and Hitch maintain that, if resources available to the central executive are limited in capacity, then efficiency is determined by the demands which are placed on it at a specific point in time. The remaining two components, the phonological loop and the visuo-spacial sketchpad, supplement the central executive component of working memory; each system is specialized to process and temporarily maintain material within a specific modality. Thus the phonological loop maintains verbally coded information and is considered to consist of both "a phonological short-term store and a subvocal control process used for both rehearsal and recoding information into phonological form" (Gathercole and Baddeley, 1993); Baddeley and Hitch (1974) suggest that the visuo-spacial sketchpad is involved in producing images and in maintaining representations with visual or spacial dimensions.

Gathercole and Baddeley (1993) summarize a variety of research concerned with working memory and its relationship to vocabulary, speech production, reading, and comprehension. On the basis of their summary, they conclude that comprehension of language in normal adults relies heavily on the phonological loop only when complex syntactic structures are used. In other words, the phonological loop may only be necessary for secondary or off-line processing. This hypothesis is supported by Carpenter, Miyake, and Just (1995) who also argue that the phonological loop seems to be only secondary in higher-level comprehension processes. Another important finding is that severe impairments in the phonological loop system due to brain damage do not necessarily result in severe impairments in sentence comprehension (Martin, 1993). This is evidence which supports a view that the central executive component of working memory makes a more "general contribution" (Gathercole & Baddeley, 1993) to the processing of language for comprehension. We can only speculate on specific identified links from the central executive component of working memory to language comprehension since the experimental evidence is only correlational; in addition, there is no accepted measure of central executive function.

Daneman and Carpenter (1980) have made substantial contributions to our understanding of working memory. Three principles guide their work on working memory and language comprehension:

1) comprehension of language involves both processing and storage;

2) one reservoir of resources exists for processing and storage. A trade-off, therefore, is necessary when a language processing task requires more than the available resources;

3) individual differences in functional working memory exist, either as a result of variation in the total capacity available, or as a result of variation in the efficiency of the

cognitive processes requiring the resources.

Much research linking general working memory capacity with language comprehension has been inconclusive (Gathercole & Baddeley, 1993). However, Waters, Caplan, and Hildebrandt (1987) developed a procedure which burdened the central executive component of working memory in normal young subjects. This procedure required that a subject maintain a random sequence of six digits while carrying out a working memory task. This process impaired subjects' comprehension of syntactically complex sentences. Further progress on identifying the connection between the central executive component of working memory and language comprehension is likely to occur with the development of techniques which directly manipulate the central executive's involvement in the comprehension of sentences of varying complexity (Gathercole & Baddeley, 1993).

Pichora-Fuller et al. (1995) suggest that a "toll" is placed on working memory when listening conditions are unfavorably noisy. They argue that in a poor listening environment, more limited-capacity resources will be required for listening. They suggest that more of the resources of working memory will be required to discriminate ambiguous messages and to recover information lost as a result of an inability to accurately perceive a message due to poor S:N conditions. It was hypothesized that with more resources allocated to perceiving what is heard, fewer resources remain for storage. It follows that the efficiency and speed required for other tasks could also be negatively affected. Therefore, it might be expected that being able to comprehend sentences of increasing complexity would be made even more difficult by decreasing S:N conditions.

The suggestion that individual differences in syntactic processing are governed by the amount of working memory capacity available for the processes involved in comprehending language has been investigated in two experiments by King and Just (1991). They focused on a classic example of a syntactic structure that makes a large demand on working memory capacity, the subject object relative, for example:

1. [The reporter [that the senator attacked]] [admitted the error].

The authors report that normal young subjects, who read a sentence such as (1), make errors in matching verbs with their agents approximately 15% of the time. They claim that demands on working memory during the processing of such sentences arise from three types of 'stress' on processing:

1) an embedded clause disrupts a main clause. To correctly comprehend a sentence, a clause that is read *prior* to the interruption must either be held in working memory or reactivated after the embedded clause has been read;

2) a listener experiences difficulty in assigning correct thematic roles to the two noun phrases. Comprehension of a relative clause is less accurate than that of a main clause in subject-object relatives since a listener must decide if the head of the relative clause is the agent or the patient of the relative verb clause (see Holmes and Regan, 1981); and

3) a listener experiences difficulty in assigning two separate and distinct roles to a single syntactic constituent. In (1), *'reporter'* is the agent in one clause and the recipient of the action in the second clause. A listener could experience two difficulties because of this relationship; he or she might:

a) simultaneously associate one concept with two different roles; and

b) switch perspectives in devising a concept.

This study represents a rare example in which investigators have studied the relationship between working memory capacity and language comprehension at the syntactic level of processing.

SYNTACTIC COMPLEXITY

Linguistic complexity is the result of many factors and is a property of individual sentences. Smith (1988) distinguishes between the following types of linguistic complexity:

(1) systematic complexity;

(2) surface syntactic complexity;

(3) interpretive complexity; and

(4) phonological complexity.

The present discussion focuses on the syntactic complexity which characterizes a sentence at its surface structure. Smith (1988) describes the determinants of sentence complexity as amount, density, and ambiguity. *Amount* refers to the specific number of linguistic units, i.e. words or morphemes. A sentence is considered more complex if it is longer and contains more complex morphology.

2. The dog barks.
3. The scraggly dog barks.

Sentence 3 is more complex than sentence 2 because it has more morphemes.

Density involves the way the linguistic material is distributed in a sentence.

Relatively many units are compressed into a dense unit (e.g. NP with embedded PP). Conversely, morphemic material may be distributed homogeneously among the units of a sentence.

4. [Bob wrote [a letter] [to his wife]]

5. [Bob wrote [a letter [about the course]]]

Sentence 4 has a simple object NP followed by a PP; sentence 5 has a complex object NP, consisting of an NP and a PP. The object of sentence 5 is denser than that of sentence 4 because:

1) it has more morphemes; and

2) it has more nonterminal node structures within a phrase (Smith, 1988).

Ambiguity describes the interpretation of the surface structure of a sentence. Sentences which contain categories with more than one interpretation or possible bracketing options are considered ambiguous; the greater the number of bracketings and interpretations that exist for a sentence, the more complex it is.

6. I read [a paper [on vowels [in Spanish]]].

7. I read [a paper [on vowels] [in Spanish]].

This sentence has two bracketings, depending on whether 'Spanish' refers to the paper (7) or the vowels (6) and is classified, therefore, as ambiguous.

An alternative to Smith's (1988) scheme for describing syntactic complexity is the approach taken by Caplan and Evans (1990) who list several features of syntactic structure which may contribute to the complexity of a sentence type. These include: noncanonical word order, number of arguments per verb, and number of verbs per sentence. Caplan, Baker, and Dehaut (1985) maintain that such features are additive, and that the relative difficulty of a sentence can be predicted from the number of features that occur in it. See Table 1.

Sentence Complexity Hierarchy		
Sentences with one verb		
Two-place verb sentences -		
Active	(A):	The mouse pulled the owl.
Passive	(P):	The duck was scratched by the mouse.
Cleft Subject	(CS):	It was the duck that kicked the owl.
Cleft Object	(CO):	It was the pig that the fox grabbed.
Three-place verb sentences -		
Dative	(D):	The mouse hauled the fox to the duck.
Dative Passive	(DP):	The owl was pushed to the mouse by the duck.
Sentences with two verbs		
Co-ordinated	(C):	The owl touched the mouse and hugged the pig.
Subject Object Relative	(SO):	The fox that the owl kissed tripped the duck.
Object Subject Relative	(OS):	The fox chased the owl that tapped the mouse.

(Caplan, et al., 1985)

Table 1. Hierarchy of syntactic complexity.

In a comparison between Smith's (1988) determinants of sentence complexity and the hierarchy of Caplan et al. (1985), a general pattern of ordering from less complex to more complex sentences is common. With respect to amount, there are typically more morphemes in sentences with two-place verbs as compared to sentences with three-place verbs except that three-place D sentences are similar to two-place CS and CO sentences. Furthermore, more morphemes occur in most of the one-verb sentences than in the two-verb sentences except that one-verb DP sentences have more morphemes than any other sentence type. Density also increases in accordance with Caplan's hierarchy, with two-place one-verb sentences being less dense and sentences with two verbs being more dense. The category of ambiguous sentences does not apply to the ordering of sentences in Caplan's hierarchy because none of the sentence types considered by Caplan possess multiple bracketings and therefore none are ambiguous.

There is a complex interaction between the syntactic structure of a sentence and the words in that sentence which determine what that sentence means. Thematic nouns that take different roles (see Caplan and Hildebrandt, 1988) differ as a result of the syntactic structures into which they are inserted. For example:

8. The dog chased the cat.

9. The dog was chased by the cat.

In (8), *'dog'* is the subject of an active sentence and, also, the agent of that sentence. In (9), *'dog'* is still the subject of the sentence, but since it is a passive sentence, *'dog'* is the theme (i.e. recipient of the action verb) of the sentence.

Syntactic structures consist of hierarchically organized constituents which, in turn, are drawn from words belonging to different syntactic categories (e.g. nouns, verbs). It is the hierarchical organization of the constituents of a sentence, not their linear presentation, that determines the grammatical and thematic roles of each constituent (Caplan, 1987).

It is unrealistic to think that we would mentally represent our knowledge of syntactic structures in the form of a list of words since syntactic structures are infinite in number. It is possible, however, that syntactic structures are represented in the form of rules, which in turn, can produce an infinite number of structures. Chomsky (1957) was one of the first linguists to propose such a rule-governed system and in his subsequent writings he has developed a method of representing an infinite number of structures with a finite set of rules.

Caplan and Evans (1990) state that "normal sentence comprehension involves a syntactic analysis of incoming words". Psycholinguists have developed models of comprehension in which this syntactic analysis is accomplished by a device known as a "parser". A parser uses an assigned syntactic structure to determine aspects of sentence meaning, e.g. thematic roles, coreference, etc. Many studies that have explored the essence of this syntactic route to sentence meaning point to the existence of a parsing device and reveal it by demonstrating that a change in syntactic structure affects both a subject's abilities to comprehend a sentence (Caplan et al., 1985; Caplan and Hildebrandt, 1988) and the time required for comprehension to take place (Frazier, Clifton, and Randall, 1983). For example, in the study of Frazier et al. (1983), normal young subjects read sentences on a computer-controlled video screen and judged, as quickly as possible after the end of the sentence, whether or not they understood the sentence. Their decision time was measured. The experimental sentences had multiple filler-gap dependencies and were either 'recent' or 'distant' filler sentences. Recent filler sentences take less time to comprehend than do distant filler sentences. The authors argue that the human sentence processor utilizes a strategy by which the most recent potential filler is assigned to a gap (for a review, see Frazier et al., 1983).

The case for the existence of a parser that is automatically engaged during the process of sentence comprehension is argued by Caplan and Evans (1990). It is not clear, however, that parsing is either sufficient or necessary for sentence comprehension to occur. In addition to or instead of using a parsing device, a listener might make inferences about the meaning of a sentence based on individual lexical items and by assigning an interpretation using nonsyntactic heuristics (Caplan and Evans, 1990). Examples of the nonsyntactical heuristics used by aphasic patients, include:

1) understanding "irreversible" sentences with syntactic structures that they cannot decode in reversible sentences (Caramazza and Zurif, 1976); patients would attempt to comprehend a sentence based on the meanings of lexical items and real-world knowledge about the possible relations between items. Thus, the patient would infer that in a sentence such as *"The cake was eaten by the boy"*, *the boy* is the agent and *the cake* is the theme since boys are animate and can eat and cakes are inanimate and can be eaten.

2) basing their understanding of a sentence on heuristics applied to the linear sequence of nouns and verbs in a sentence (Caplan and Futter, 1986); the use of such a strategy would lead to consistent misinterpretations of certain syntactic structures such as passives when the patient always takes the first noun as the agent of the sentence. This would be incorrect since the second noun is the agent of a passive sentence.

3) guessing correctly at the meanings of sentences when syntactic comprehension processes fail (Hildebrandt, 1988).

CAPLAN'S WORK

The work and ideas of Caplan and his colleagues have been very influential in developing an explanation for how sentences of varying complexities are comprehended. Caplan has focused on studies of aphasic patients and how they interpret different syntactic structures.

The Token Test (DeRenzi and Vignolo, 1962) has been widely used in the past as part of a sentence comprehension battery. In the most popular version of this test, commands are given and subjects must manipulate colored geometric forms to show that the commands were comprended. Caplan (1987) claims that it has been well established that scores on the Token Test distinguish patients considered aphasic from non-aphasic left-hemispheric-damaged patients and from right-hemispheric-damaged patients. He points out, however, that this test has at least three limitations:

1) several modifiers may be assigned to one or more nouns;

2) the final, most difficult section is made up of heterogenous sentence structures; and

3) the final section involves the interpretation of the lexical semantics of subordinate temporal conjunctions (see Caplan, 1987).

Overall, even though the Token Test can be used to differentiate aphasic from non-aphasic patients, it does not give specific information about which syntactic structures are correctly interpreted by aphasics.

A sentence-picture matching test of language comprehension is described by Caplan and Hildebrandt (1988). In the test they describe, an experimenter reads a sentence and a subject, who views two or three pictures (one representing the correct meaning, one representing a syntactic misrepresentation, and a third (in some cases) representing a lexical misrepresentation), chooses a picture which corresponds to the meaning of the sentence heard. This test also has limitations, the main one being that the incorrect foil pictures must be chosen by the experimenter thus preventing a subject from making spontaneous errors. This experimental paradigm may also result in the production of test sentences which a subject simply cannot 'believe' since they are so patently incorrect.

Comprehension of a variety of syntactic structures was studied by Caplan, et al. (1985) using a third test. In this test, nine sentence types were used. Subjects were required to indicate the thematic roles of the nouns in the sentences by manipulating toy animals whose names were provided in the sentences that were heard. Three studies of aphasics in which the properties of the object manipulation test (OMT) were investigated, are reported by Caplan et al. (1985). The mean number of correct responses for different sentence types was calculated. Consistent results were found across the three studies and in several later studies (Caplan, 1986; Caplan, 1987):

1) the same sentence types produced the highest mean correct scores in each study, except for variation in the relative rank-ordering of scores for C sentences with respect to CO, DP, SO, and OS sentences;

2) sentences with canonical word order were easier than sentences with noncanonical word order: (respectively, A vs. P, CS vs. CO, D vs. DP, and C and OS vs. SO);

3) verb argument structure affected correct interpretations; specifically, when matched for word order, D sentences were harder than A sentences, and DP sentences were harder than P sentences; and

4) sentences with two verbs were more difficult than those with one verb.

The authors argue that the results of the investigations imply that syntactic complexity influences sentence interpretation in aphasia.

Caplan and Evans (1990) used a similar procedure to the one described above to study groups of aphasic patients and age-matched normal control subjects. The authors concluded that aphasic patients showed an effect of syntactic structure on sentence comprehension but that the effect was not demonstrated by normal subjects. Recently, a number of investigators have attempted to induce aphasia-like language deficiencies in normal young adults by presenting language stimuli which were time-compressed (Miyake, Carpenter, and Just, 1994) or by stressing the system with the addition of a competing noise signal (Kilbourn, 1991; Martin, Wogalter, and Forlano, 1988).

GOALS

The first goal of the present study was to determine whether or not changing S:N conditions affects the way in which sentences are comprehended by young, normal-hearing listeners performing an OMT.

The second goal was to determine whether or not sentence complexity would affect the way in which sentences are comprehended by young normal-hearing listeners performing an OMT in adverse S:N conditions.

The third goal was to determine whether or not S:N condition and the sentence complexity would interact in affecting comprehension.

The fourth goal was to determine whether or not subjects with larger working memory spans would perform better on an OMT than would subjects with smaller working memory spans.

The fifth goal was to determine whether or not sentence complexity and/or different S:N conditions would affect the types of errors in comprehension that were observed.

HYPOTHESES

Syntactic Complexity Hypothesis:

H_o1a: When a listener performs an OMT to demonstrate sentence comprehension, the percent correct scores that are measured will not differ significantly as a function of sentence complexity.

If the H_o is rejected, post-hoc tests will be conducted to determine the syntactic types which differ in terms of the number of sentences correctly comprehended as evidenced in the OMT.

H_o1b: When a listener performs an OMT to demonstrate sentence comprehension, the time taken to complete the OMT will not differ significantly as a function of sentence complexity.

If the H_o is rejected, post-hoc tests will be conducted to determine the syntactic types which differ in terms of the time taken to complete the OMT.

Noise Hypothesis:

H_o2: When a listener performs an OMT to demonstrate sentence comprehension, there will be no significant difference in the percent correct scores that are measured as a function of changing signal-to-noise (S:N) conditions.

If the H_o is rejected, post-hoc tests will be conducted to determine the difference in the percent correct scores as S:N changes from 0 dB to -3 dB to -6 dB.

H_o2b: When a listener performs an OMT to demonstrate sentence comprehension, there will be no significant difference in the time taken to complete the OMT as a function of changing S:N conditions.

If the H_o is rejected, post-hoc tests will be conducted to determine the difference in the time taken to complete the OMT as S:N changes from 0 dB to -3 dB to -6 dB.

Interaction Hypothesis:

H_o3a: When a listener performs an OMT to demonstrate sentence comprehension, there will be no significant difference in the percent correct score as a function of the interaction of sentence complexity and S:N conditions.

If the H_o is rejected, post-hoc tests will be conducted to determine the difference in the percent correct score that occurs as sentence complexity increases and S:N conditions decrease; for example, are there more errors for complex sentences as S:N conditions get worse compared to the rate of decrease in percent correct for less complex sentences.

H_o3b: When a listener performs an OMT to demonstrate sentence comprehension, there will be no significant difference in the time taken to complete the OMT as a function of the interaction of sentence complexity and S:N conditions.

If the H_o is rejected, post-hoc tests will be conducted to determine the difference in the time taken to complete the OMT that is measured as sentence complexity increases and S:N conditions decrease; for example, does it take more time to complete the OMT for complex sentences as S:N conditions get worse compared to the rate of increase in time to complete the task for less complex sentences.

Individual Differences Hypothesis:

H_o4a: There will be no significant correlation between the percent correct comprehension score and working memory span (WMS).

H_o4b: There will be no significant correlation between the time taken to complete the OMT when sentences are correctly comprehended and WMS.

Error Type Hypothesis:

H_o5a: The types of errors in the present study do not differ from those described by Caplan et al. (1985).

H_o5b: The types of errors do not differ across sentence complexity types.

H_o5c: The types of errors for each sentence complexity type do not differ across S:N conditions.

METHODS

PARTICIPANTS

Twelve subjects, 8 women and 4 men, were recruited for this study. Subjects had pure-tone air-conduction thresholds within normal limits bilaterally, where normal is defined as lower than 20 dB HL from 500 to 8000 Hz. Subjects were between the ages of 21 and 33 and spoke English as a first language (See Appendix A).

DEVELOPMENT OF MATERIALS

Three lists of 45 sentences each were utilized in the sentence comprehension test. The sentence materials utilized were similar to those used by Caplan et al. (1985). Each sentence list consisted of five exemplars of nine sentence complexity types: active (A), passive (P), cleft subject (CS), cleft object (CO), dative active (D), dative passive (DP), co-ordinated (C), subject-object relative (SO), and object-subject relative (OS). Examples of each sentence type are:

1) Active   The mouse pulled the owl.

[NP [VP NP]]

2) Passive   The duck was scratched by the mouse.

[NP [V PP]]

3) Cleft Subject It was the duck that kicked the owl.

[NP V NP] COMP [V NP]

4) Cleft Object It was the pig that the fox grabbed.

[NP V NP] COMP [NP V]

5) Dative Active The mouse hauled the fox to the duck.

[NP [V NP PP]]

6) Dative Passive The owl was pushed to the mouse by the duck.

[NP [V PP PP]]

7) Co-Ordinated The owl touched the mouse and hugged the pig.

[NP [V NP] CONJ [V NP]

8) Subject-Object The fox that the owl kissed tripped the duck.

[NP [NP V]] [V NP]

9) Object-Subject The fox chased the owl that tapped the mouse.

[NP] [V NP [V NP]]

To implement Caplan's OMT (see below), the nouns were required to be animate nouns which could be represented by small stuffed animals and the verbs were required to be action verbs which could be acted out using the stuffed animals. The materials used in the present study differed from those used by Caplan in terms of the syllabic structure of the nouns and verbs. The nouns in Caplan's sentences varied in number of syllables (i.e. goat, turtle, elephant). Because the purpose of the present experiment was to investigate the role of perception in comprehension, it was imperative that the sentences not allow for the discrimination of the various nouns merely on the basis of the identification of syllabic patterns. Therefore, the nouns chosen for use in the present study were all monosyllables. To ensure that the nouns chosen for the present study were equivalent to those used by Caplan in terms of word frequency, the word frequency of the words used by Caplan were determined using The American Heritage Word Frequency Book (Carroll, Davies, and Richman, 1971) and then the newly selected monosyllabic words were chosen from words in the same word frequency range as the original multisyllabic words that were replaced. Likewise, multisyllabic verbs were replaced with monosyllablic verbs. Specifically, the nouns chosen were: duck, fox, mouse, owl, and pig. The verbs chosen were: bumped, chased, grabbed, hauled, hugged, kicked, kissed, passed, pulled, pushed, scratched, tapped, tossed, touched, and tripped.

The five objects and 15 verbs were each given a letter from A to E (for objects) and a number from 1 to 15 (for verbs). A skeleton sentence frame was constructed for each of three 45-item sentence lists (see Appendix B). Several constraints were enforced in the construction of each of the three lists:

1) the same verb could not occur in consecutive sentences;

2) each complexity type was to occur five times for a total of 45 sentences per list.

In conjunction with these constraints, random number lists were utilized:

1) to determine which noun would occur in each noun slot;

2) to determine which verb would occur in each verb slot;

3) to determine the order in which the nine complexities would appear in the final lists. The selected items were entered into the skeleton sentence lists. This process was used to construct three separate lists of 45 sentences each, for a total of 135 sentences. Scoring forms were then developed to aid the experimenter in accurately recording the subjects' actions during the OMT (see Appendix C) .

Each of the three lists of 45 sentences were digitally recorded by a female speaker of English at a normal speaking rate with normal and appropriate intonation. Recording of the speech signal was conducted in a sound-attenuating booth using a Seinnheiser K3 microphone and a Proport 656 DSP Port Interface. The NeXT Soundworks 3.0 (v.2) software program was utilized to digitally record each list of sentences as an individual mono-soundfile, at a sampling rate of 16 KHz. Eight-talker babble was recorded from audio cassette tape as a separate mono-soundfile. Each sentence list and the babble were calibrated separately. Three soundfiles were created, each with a sentence list on one channel and babble on the other channel. Each of the mixed lists was then parsed into sentence-length soundfiles so that each sentence mixed with noise was contained within its own soundfile (see Appendix D).

The experimental protocol was assisted by a custom software application which allowed the replaying of the soundfiles in a sequential and specified order (see Appendix E). The output from the computer program recorded a history of the stimuli presented and the associated latencies of the subjects' actions. The beginning of the latency measure was triggered by a key press by the experimenter such that timing was initiated immediately after the presentation of a sentence was completed and it continued until the experimenter pressed the return key on a keyboard to indicate that the subject had completed the action for that sentence.

A brief instructional video was developed to ensure the subjects understood the instructions for the OMT. On the video tape, the animals were identified and each of the 15 verb actions were demonstrated twice using a variety of animals. The instructional video tape was recorded using a Panasonic camcorder. Subjects viewed the video tape prior to the experiment.

PROCEDURES

Each subject attended two sessions: an initial screening session and a subsequent experimental session.

Screening and Preliminary Procedures

In the first session, each subject completed the following preliminary procedures: a hearing and language history, a hearing test, a vocabulary test, and a reading working memory span test.

Each subject completed a questionnaire regarding his or her hearing and language history (see Appendix F).

The following hearing test measures were obtained: pure-tone thresholds, speech reception thresholds (SRTs), NU-6 speech discrimination scores, an SRT in noise for the right ear (adapted from Cheesman, 1992), and a babble threshold for the right ear. Hearing sensitivity was considered normal if all pure-tone air-conduction thresholds (measurement procedure described by Newby and Popelka, 1992) were 20 dB HL or less from 500 to 8000 Hz (Yantis, 1994). (See Appendix G).

Vocabulary was tested using the Mill Hill (1938) vocabulary test in which the subject chooses from a set of six words the one which has the most similar meaning to a target word (See Appendix H).

Subjects also completed a working memory span task (Daneman and Carpenter, 1980); they were required to read sentences aloud as they were presented one at a time on a computer screen. Once a group of sentences was presented (groups of two, three, four, or five sentences), subjects were asked to recall the final word from each of the sentences within that group. (See Appendix A).

Experimental Procedures

In the second session, subjects completed the experimental OMT in each of three noise conditions. All subjects completed all conditions.

Each subject first viewed the five minute instructional video in which the experimenter identified the animals and demonstrated each of the 15 action verbs. After seeing the video, each subject completed 2 practice trials. The experimenter re-instructed each subject as necessary to ensure that he or she understood the procedure and that he or she was able to clearly demonstrate each of the verb actions in an unambiguous fashion.

Each subject listened to the introduction to the task and the instructions (see

Appendix I). Each subject listened to sentences and eight-talker babble noise presented to the right ear under TDH-39P earphones while seated in a double-walled sound-attenuating IAC booth. The signal was always presented 50 dB above the babble threshold for the right ear. During each session, the first list was presented at 0 dB S:N, the second at -3 dB S:N, and the third at -6 dB S:N. The presentation level of the noise changed relative to that of the signal so the three S:N conditions ranged from easy to difficult. These S:N values were chosen on the basis of pilot testing in which it was determined that subjects performed almost perfectly at 0 dB S:N, yet experienced great difficulty comprehending the sentences at -6 dB S:N. By fixing the order of the S:N conditions to progress from easy to difficult, each subject was given an opportunity to become familiar with the task in the least arduous listening condition prior to listening in the more difficult listening conditions. Each subject listened to all three lists of 45 sentences for a total of 135 sentences; each list was completed in approximately 15 minutes. A five-minute break was provided after the first and second lists. The three lists of sentences were counter-balanced in their order of presentation so that each list was presented for each S:N level an equal number of times, once all subjects were tested.

Three practice sentences were presented in each S:N condition prior to the experimental set, in order to help familiarize each subject with the listening condition. Pilot testing had indicated the necessity of this practice session to obtain a reliable sample; it was observed that subjects in pilot testing needed to hear approximately three sentences before they felt they had adjusted to the new S:N condition.

Each subject was asked to perform the OMT; they were required to move stuffed animals to demonstrate the meaning of the sentences they heard. All five small stuffed toys, whose names could occur in one of the sentences, were placed in front of the subject. Each subject was instructed to listen to each sentence in its entirety and then to demonstrate who did what to whom by moving the animals. Each subject was videotaped while performing the OMT; this provided a record that was available in the event that subsequent analyses were warranted.

Each subject was required to say "go" to indicate when they were ready for the first, and subsequent sentences to be presented. This cue prompted the experimenter to press a key on the computer keyboard which initiated the playing of the next sentence.

SCORING METHODS

The experimenter scored the subject's actions on-line for each sentence. Each noun and verb was scored separately as either correct or incorrect. If an incorrect stuffed animal or action was used, the experimenter noted not only that the response was an error but also recorded the noun or verb that was used in place of the target word. If each noun and each verb received one point to obtain a "component" score (C-Score), then the maximum C-Score for each list was 160. In addition to obtaining a C-Score, a "sentence" score (S-Score) was also obtained. For the S-Score, each totally correct sentence received one point for a maximum S-score of 45 for each list. A sentence was scored as totally correct if all noun and verb components were correct. A sentence was scored as incorrect if at least one component was incorrect.

Error response summaries similar to those of Caplan's were developed to categorize patterns of errors (Caplan et al., 1985). The error responses utilized differed from those of Caplan's in two ways:

1) verbs were scored as correct or incorrect in the present experiment (but not by Caplan);

2) animals were scored as correct or incorrect because animals other than those named in the sentence could be chosen by a subject, since the repertoire of animals for each sentence was not limited in the present experiment as it had been in Caplan's studies.

The explanation of the response patterns is as follows: The numerals (1,2,3) refer to the animals in the sentences and the letters (A,B) refer to the verbs in the sentences. Codes are identified from left to right. The thematic role of each animal is identified by the order of the symbols in the correct pattern forms: the first number refers to the animal used as agent, the second number refers to the animal used as theme, and the third number refers to the animal used as goal (for a discussion of these terms, see Caplan and Hildebrandt, 1988). For example, a "1 A 2" response indicates that the first animal was identified as agent, the second animal was identified as theme, and the correct action verb was utilized. Several codes were required to indicate errors in the subjects' responses:

- "Y" indicated an incorrect action verb which was not presented in the sentence; Y1 and Y2 were used as necessary to indicate either that the same incorrect verb was used twice in one sentence or that two incorrect verbs were used in one sentence.

- "X" indicated an incorrect animal which was not presented in the sentence; X1 and X2 were as used for similar reasons, similar to the reasons Y1 and Y2 were used.

- "#" indicated no response or omission of a specific component of the sentence.

The correct response pattern for each sentence type is given below:

Sentence Type	Correct Response Pattern	Example Sentence
A	1 A 2	1 A 2 The mouse pulled the owl.
P	2 A 1	1 A 2 The duck was scratched by the mouse.
CS	1 A 2	1 A 2 It was the duck that kicked the owl.
CO	2 A 1	1 2 A It was the pig that the fox grabbed.
D	1 A 2 3	1 A 2 3 The mouse hauled the fox to the duck.
DP	3 A 1 2	1 A 2 3 The owl was pushed to the mouse by the duck.
C	1 A 2;1 B 3	1 A 2 B 3 The owl touched the mouse and hugged the pig.
SO	2 A 1;1 B 3	1 2 A B 3 The fox that the owl kissed tripped the duck.

		1 A 2 B 3
OS	1 A 2;2 B 3	The fox chased the owl that tapped the mouse.

Once error patterns were identified, they were then classified into one of three categories: syntactic violation, lexical substitution, or omission. A syntactic violation was defined as an error in which the correct animals and verbs were utilized but the agent, theme, or goal was erroneously identified. These patterns would be scored as incorrect responses according to the standard Caplan test procedure (Caplan et al., 1985). A lexical substitution was defined as an error in which an animal or verb used in the manipulation did not match the target sentence. Patterns where an incorrect animal was selected could not be observed in the standard Caplan procedure because the set of animals was constrained and only the target animals were displayed for each sentence. Patterns where an incorrect verb was acted out would be scored as correct in the standard Caplan procedure. An omission was defined as an error in which the subject chose not to respond at all or where the subject gave only a partial response in which an animal or verb was not selected. This pattern would be classified as a special no response error type in the standard Caplan procedure.

RESULTS

The purpose of the present investigation was to determine how the comprehension of sentences heard in noise varied as the structural complexity of the sentences increased and the amount of background noise increased. The effect of S:N and complexity on the accuracy and latency of comprehension was analyzed. Results will be described first for accuracy measures and second for latency measures. For each measure, the significance of the main effects of S:N and complexity and the interaction effect of S:N by complexity were tested.

Effect of S:N Condition on the Accuracy of Comprehension

The means and standard deviations of the number of correct sentence manipulations for each S:N condition (0, -3, -6 dB S:N) are shown in Table 2.

dB S:N	Mean	S.D.
0	38.25	5.03
-3	36.17	5.61
-6	28.25	9.04

Table 2. Mean correct score and standard deviation for each S:N condition.

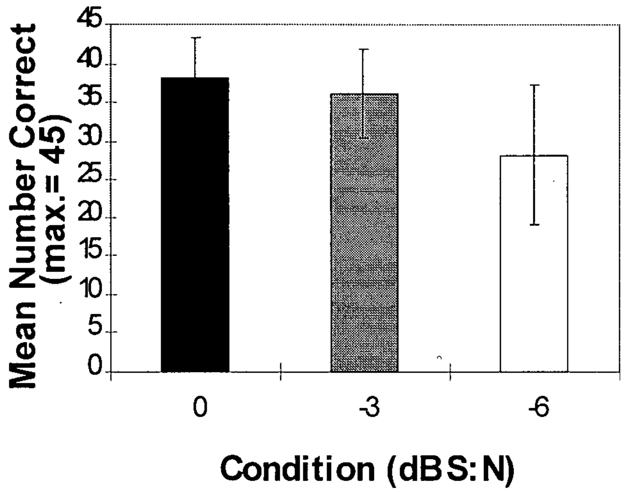

Figure 2. Mean correct score and standard deviation for each S:N condition.

Figure 2 demonstrates the effect of the different S:N conditions on the mean number of correct sentence manipulations. The number of correct sentences decreased as the S:N ratio decreased, with most sentences being correct at 0 dB S:N, fewer correct at -3 dB S:N, and the fewest correct at -6 dB S:N. An analysis of variance confirmed this description with a significant effect of S:N condition, $F(2,22)=22.46, p<.01$. A Student-Newman-Keuls test of multiple comparisons (see Table 3) indicated that there was a significant difference between the -6 S:N condition and the 0 and -3 dB S:N conditions ($p<.01$), but no significant difference was found between the 0 and -3 dB S:N conditions ($p>.05$).

0 dB S:N	-3 dB S:N	-6 dB S:N

Table 3. Results of the Student-Newman-Keuls tests of multiple comparisons performed at $p<.05$ and at $p<.01$. S:N conditions joined by a common line do not differ from one another; S:N conditions not joined by a common line do differ.

Effect of Sentence Complexity Type on the Accuracy of Comprehension

Recall that the sentence complexity types can be grouped according to Caplan et al.'s (1985) hierarchy into:

1. two-place one-verb sentences with one verb per sentence: A, P, CS, CO;
2. three-place one-verb sentences with one verb per sentence: D, DP; and
3. sentences with two verbs: C, SO, OS.

The means and standard deviations of the number of correct sentence manipulations for each sentence complexity type (A, P, CS, CO, D, DP, C, SO, OS) for each of the S:N conditions (0, -3, -6 dB) are shown in Table 4.

Sentence Type	0 dB S:N		-3 dB S:N		-6 dB S:N	
	Mean	S.D	Mean	S.D.	Mean	S.D
A	4.33	0.98	4.25	1.22	3.50	1.51
P	4.50	1.17	4.00	0.85	2.92	1.08
CS	4.75	0.45	4.67	0.89	3.92	1.16
CO	4.50	0.90	3.83	0.94	3.42	1.31
D	4.17	0.94	4.33	0.89	3.50	1.31
DP	4.58	0.67	4.58	0.51	3.58	1.24
C	4.25	0.87	3.75	1.06	2.75	1.29
SO	3.25	1.14	3.00	1.41	2.00	1.71
OS	3.83	1.19	3.75	1.14	2.67	1.50

Table 4. Mean correct score and standard deviation for each sentence complexity type for each S:N condition. (Maximum score= 5)

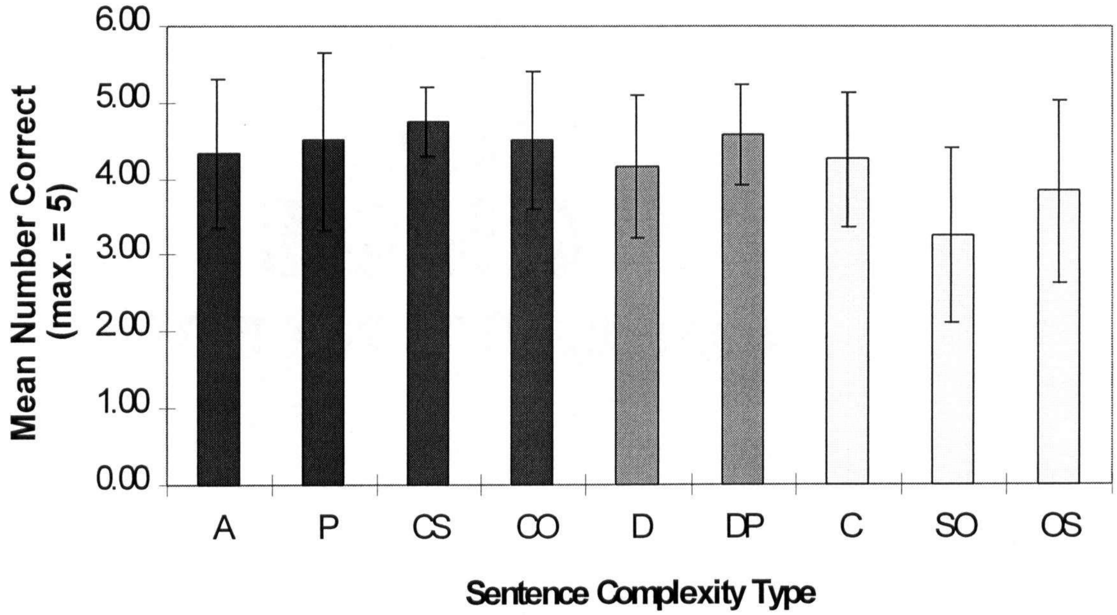

Figure 3. Mean correct score and standard deviation for each sentence complexity type for sentences heard at 0 dB S:N. Two-place one-verb sentences are shown by black bars; three-place one-verb sentences are shown by grey bars; two-verb sentences are shown by white bars.

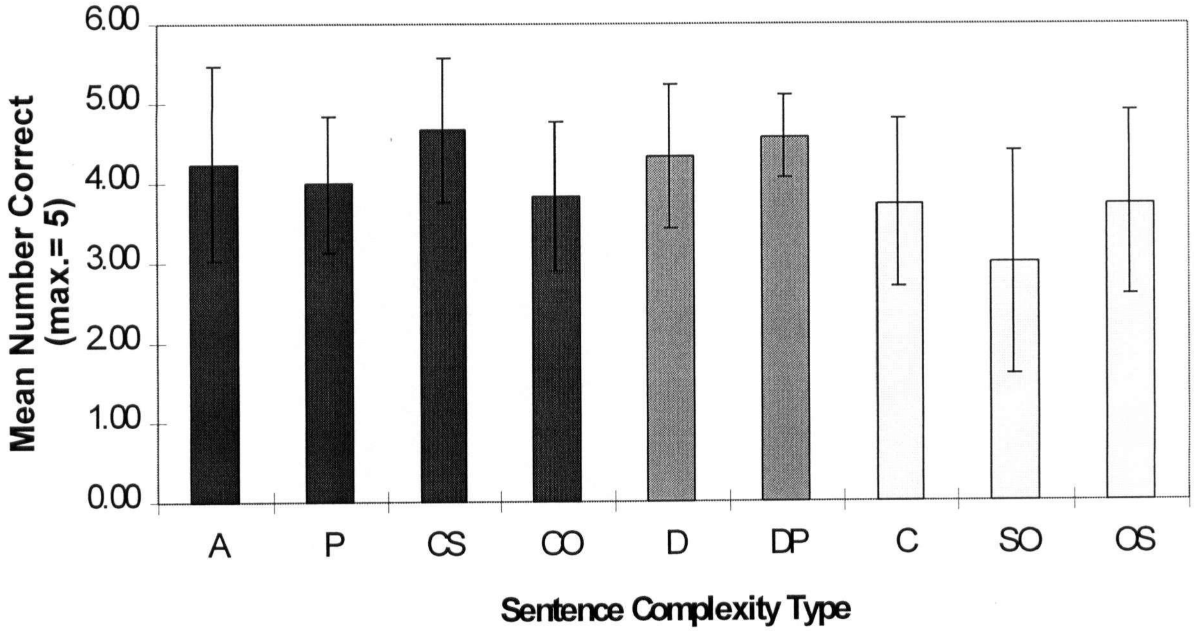

Figure 4. Mean correct score and standard deviation for each sentence complexity type for sentences heard at -3 dB S:N. Two-place one-verb sentences are shown by black bars; three-place one-verb sentences are shown by grey bars; two-verb sentences are shown by white bars.

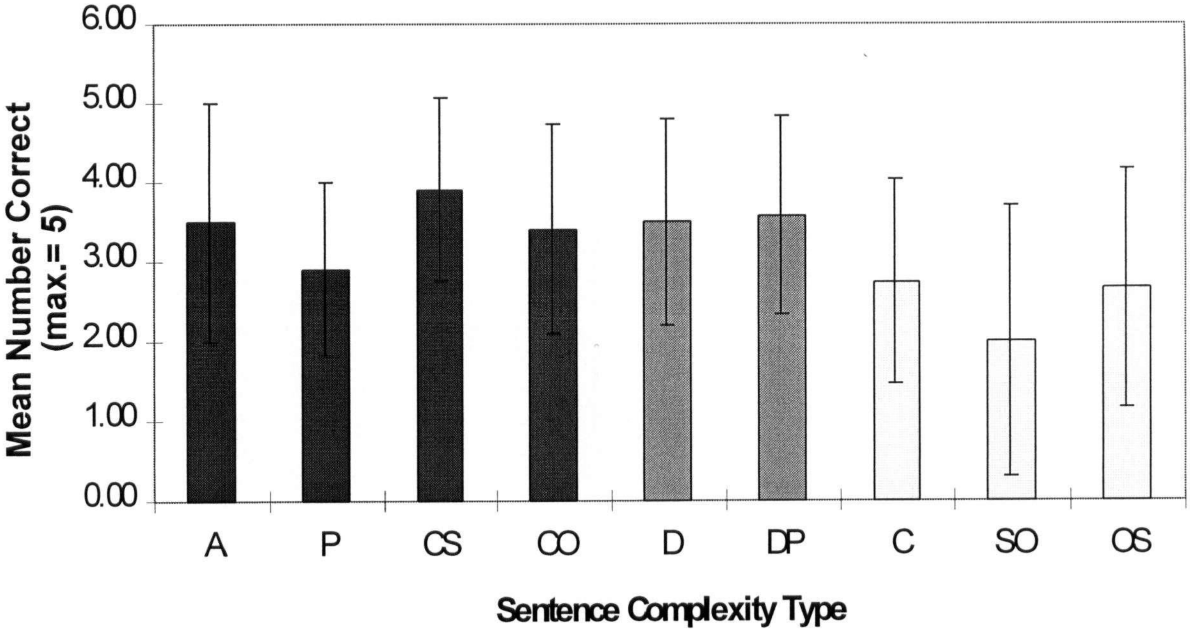

Figure 5. Mean correct score and standard deviation for each sentence complexity type for sentences heard at -6 dB S:N. Two-place one-verb sentences are shown by black bars; three-place one-verb sentences are shown by grey bars; two-verb sentences are shown by white bars.

Figures 3, 4, and 5 show the mean number of correct sentence manipulations for each sentence complexity type for the 0, -3, -6 dB S:N conditions respectively. The pattern of the relative number of correct sentences for the complexity types was similar for the three S:N conditions. Overall, fewer sentences of the types P, C, OS, and SO were performed correctly compared to the remaining sentence complexity types. An analysis of variance demonstrated a significant effect of complexity type on the number of correct sentence manipulations, $F(8,88)=13.37$, $p<.01$. The results of a Student-Newman-Keuls test of multiple comparisons (see Table 5) indicated that there were the following significant differences among the complexity types ($p<.05$).

1. complexity types CS, DP, A, D, and CO do not differ significantly from each other, but as a group, they differ from the more difficult types P, C, SO, and OS;
2. complexity types DP, A, D, CO, and P do not differ from each other, but as a group, they differ from type CS which is easier and types C, SO, and OS which are more difficult;
3. complexity types A, D, CO, P, and C do not differ from each other, but as a group, they differ from CS and DP which are easier and from SO and OS which are more difficult;
4. complexity types CO, P, C, and SO do not differ from each other, but as a group, they differ from CS, DP, A, and D which are easier and OS, which is more difficult.

Notice that sentence types with two verbs per sentence (C, OS, SO) are different from sentences with one verb whether they are two-place verbs (A, P, CS, CO) or three-place verbs (D, DP). However, no significant differences were found between the one- and two-place verbs. Also note that the ranking of types by the number of correctly manipulated sentences does not suggest more difficulties for two-place verb sentences than for three-place verb sentences.

CS	DP	A	D	CO	P	C	SO	OS
4.44	4.25	4.03	4.00	3.92	3.81	3.58	3.42	2.75

Table 5. Results of Student-Newman-Keuls test of multiple comparisons performed at $p < .05$. Numbers represent mean correct score for each sentence complexity type. Sentence types joined by a common line do not differ from one another; sentence types not joined by a common line do differ.

Effect of S:N Condition and Sentence Complexity Type on Accuracy of Comprehension

As stated above, the pattern of the number of correctly manipulated sentences for the different complexity types was similar for the three S:N conditions. This was confirmed by an analysis of variance which demonstrated no significant interaction between the S:N condition and sentence complexity type on the number of correctly manipulated sentences, $F(16,176)=0.53, p > .05$.

Effect of S:N Condition on Latency of Response

Recall that latency was measured for each sentence; timing began when the sentence had finished playing and it terminated as soon as the subject finished acting out the sentence.

The mean and standard deviations of the median latencies of the sentence manipulations for each S:N condition (0, -3, -6 dB) are shown in Table 6. Since latency measures are not always normally distributed, rather than using the mean which would be inflated by unusually long latencies, the median latency value for each sentence type for each S:N condition for each subject was used. Furthermore, latencies were measured in the expectation that changes in latencies might reveal changes in the difficulty of comprehending the sentences even though the sentences were successfully comprehended. Therefore, only correctly comprehended sentences were included in the analyses of latency. There were three cases in which a subject did not correctly manipulate the animals for any of the five exemplars within a sentence complexity type. For these cases, the latencies used in the analyses were the means of the median latencies for the remaining subjects for that condition and sentence complexity type.

dB S:N	Mean (seconds)	S.D.
0	6.79	2.38
-3	7.03	2.29
-6	7.15	2.22

Table 6. Means and standard deviations of median latencies for each S:N condition. Although latencies appeared to increase as S:N conditions became more difficult, an analysis of variance demonstrated no significant effect of S:N condition on latency.

<u>Effect of Sentence Complexity Type on Latency of Response</u>

The means and standard deviations of the median latencies for each sentence complexity type (A, P, CS, CO, D, DP, C, SO, OS) for each of the S:N conditions (0, -3, -6 dB) are shown in Table 7. Median latencies were calculated as mentioned above.

Sentence Type	0 dB S:N		-3 dB S:N		-6 dB S:N	
	Mean	S.D	Mean	S.D	Mean	S.D
A	4.13	1.15	4.30	0.90	4.96	1.23
P	5.62	2.76	5.77	1.52	5.63	1.77
CS	4.76	1.72	5.07	1.56	5.32	1.28
CO	5.41	1.68	5.43	1.95	5.50	1.34
D	6.23	2.03	6.93	2.26	7.08	1.75
DP	6.86	2.04	7.28	2.45	7.53	2.91
C	8.41	2.77	8.81	3.27	8.48	2.37
SO	9.73	3.07	9.56	2.99	10.00	4.72
OS	9.97	3.37	10.10	3.21	9.83	3.71

Table 7. Means and standard deviations of median latencies (seconds) for each sentence complexity type and S:N condition.

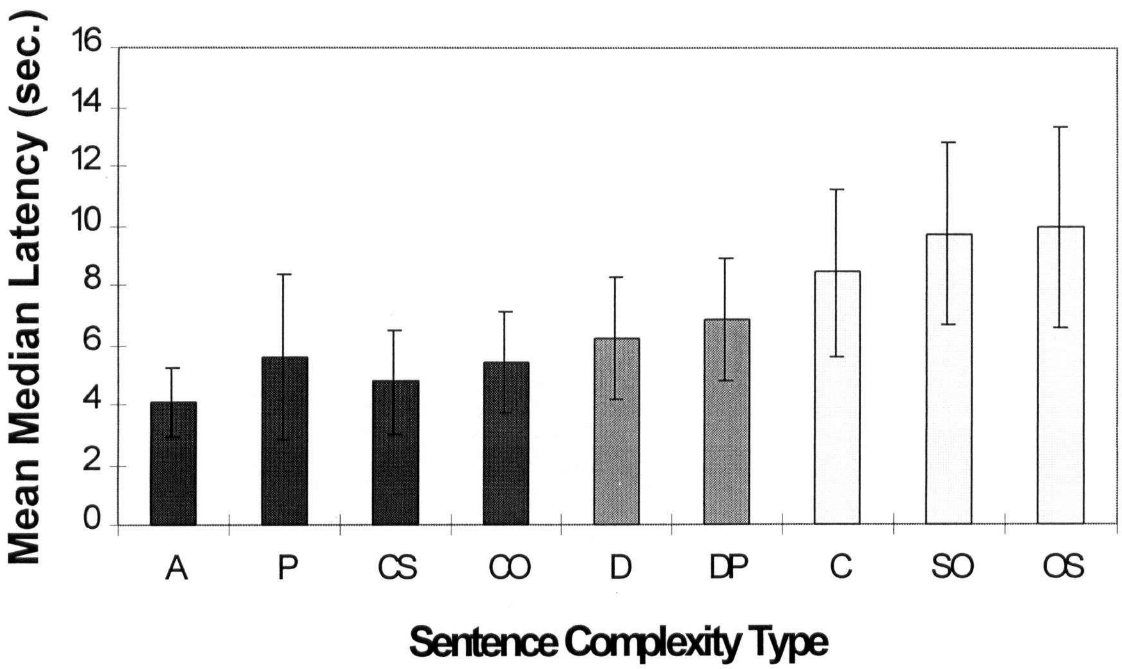

Figure 6. Mean median latency and standard deviation for each sentence complexity type for 0 dB S:N. Two-place one-verb sentences are shown by black bars; three-place one-verb sentences are shown by grey bars; two-verb sentences are shown by white bars.

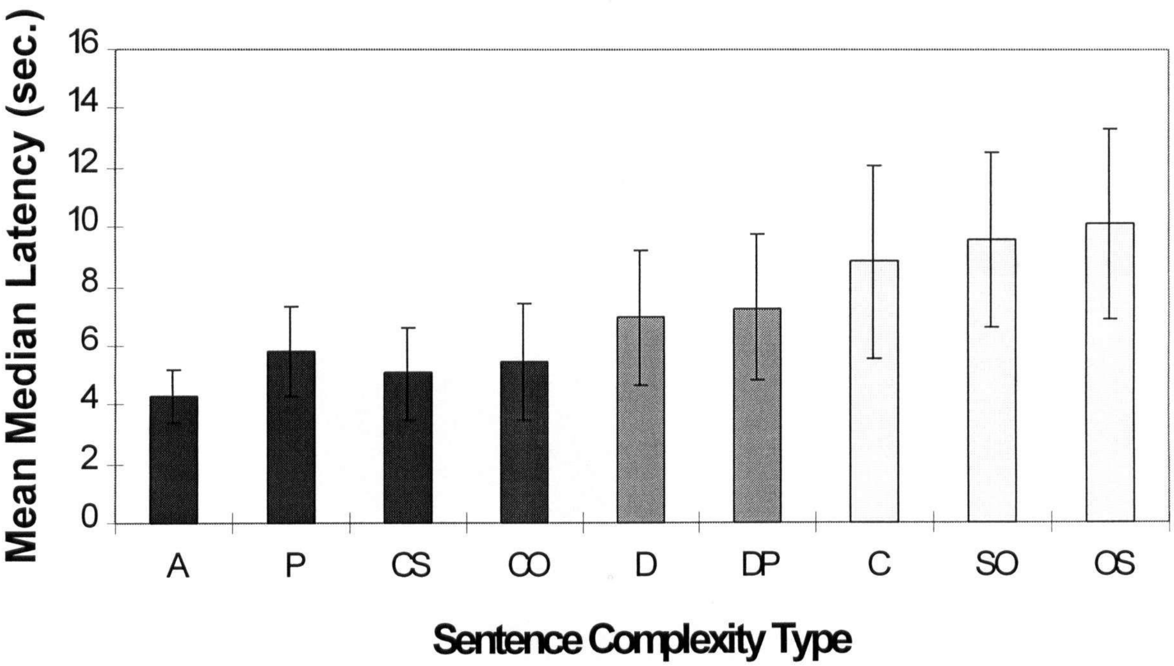

Figure 7. Mean median reaction time and standard deviation for each sentence complexity type for -3 dB S:N. Two-place one-verb sentences are shown by black bars; three-place one-verb sentences are shown by grey bars; two-verb sentences are shown by white bars.

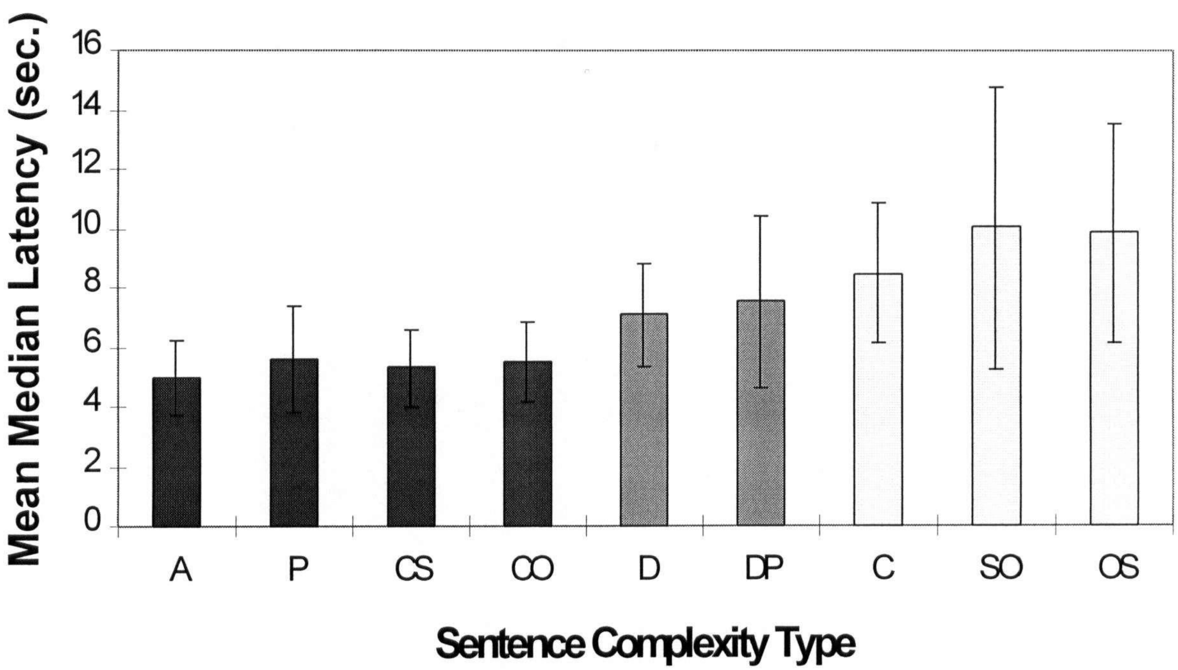

Figure 8. Mean median reaction time and standard deviation for each sentence complexity type for -6 dB S:N. Two-place one-verb sentences are shown by black bars; three-place one-verb sentences are shown by grey bars; two-verb sentences are shown by white bars.

Figures 6, 7, and 8 show the mean of the median latencies for the correctly performed sentences for each sentence complexity type for the S:N conditions 0, -3, -6 dB, respectively.

The pattern for the latencies across the complexity types is very similar for each of the S:N conditions. The latencies follow a general trend of increasing as sentence complexity increased. An analysis of variance demonstrated a significant effect of sentence complexity type on the median latency of the correctly manipulated sentences, $F(8,88)=38.73$, $p<.01$. The results of a Student-Newman-Keuls test of multiple comparisons (see Table 8) indicated that there were significant differences among the complexity types for the means of the median latencies ($p<.05$). The following complexity types did not differ significantly from each other:

1. OS and SO;
2. DP and D;
3. P, CO, CS, and A.

Each group was significantly different from the others, as well as being significantly different from type C. Note that sentences with two verbs (OS, SO, C) are different from sentences with one two-place verb (P, CO, CS, A) and from those with one three-place verb (D, DP). In addition, note that the mean median latencies for two- and three-place verbs are different from each other. The mean median latencies for the sentence types suggest that more time is required to act out two-verb sentences than one-verb sentences, but also that more time is required to act out three-place verb sentences than two-place verb sentences.

OS	SO	C	DP	D	P	CO	CS	A
9.97	9.77	8.57	7.22	6.75	5.67	5.44	5.05	4.46

Table 8. Results of Student-Newman-Keuls test of multiple comparisons performed at $p<.05$. Numbers represent the mean of the median latency scores for each sentence complexity type. Sentence types joined by a common line do not differ from one another; sentence types not joined by a common line do differ.

Effect of S:N Condition and Sentence Complexity Type on Latency of Response

As stated above, the pattern of mean median latencies for the correctly manipulated sentences for the different complexity types was similar for the three S:N conditions; this was confirmed by an analysis of variance which demonstrated no significant effect of the interaction between S:N condition and sentence complexity type on the latency of correctly manipulated sentences, ($p>.05$).

Working Memory and Sentence Comprehension

To determine whether or not the accuracy or latency measures were related to individual differences in working memory, correlations between WMS and the number of correctly manipulated sentences, and between WMS and the median latency for acting out the sentences were tested. Correlation coefficients were computed between WMS and the accuracy and latency measures obtained in each S:N condition and for each complexity type, and also for the accuracy and latency measures obtained when S:N conditions were collapsed.

Of 72 correlations, there was only one significant correlation between WMS and accuracy and only five significant correlations between WMS and median latency. However, all these significant correlations were positive, i.e. individuals with large WMS were slower and made more errors. These analyses failed to provide support for the notion that listeners with larger WMS were better comprehenders in the OMT.

Analysis of Errors Made in Object Manipulation

Recall that following Caplan and Hildebrandt (1988), a scheme for coding patterns of correct and incorrect responses was developed (see Chapter 2).

Classification of Coding System

In an attempt to understand the nature of the errors made by subjects when they manipulated the animals, each manipulation response was coded to describe the pattern of the response. The coded patterns were then classified as correct or incorrect. Each incorrect pattern was then further classified as a syntactic violation, a lexical substitution, or an omission (see Appendix J).

Correct Manipulation Patterns

To restate the findings described above, the number of correct patterns for each sentence complexity type in the three S:N conditions are presented in Table 9. Significantly more correct patterns are identified in the 0 dB S:N and -3 dB S:N conditions than in the -6 dB S:N condition. There is a general decrease in the number of correct patterns as sentence complexity type increases.

Sentence Type	S:N Condition		
	0 dB S:N	-3 dB S:N	-6 dB S:N
A	53	51	43
P	54	48	35
CS	57	56	47
CO	55	46	42
D	50	52	42
DP	54	55	43
C	51	44	32
SO	39	37	24
OS	47	45	32

Table 9. Sum of correct patterns for all subjects for each complexity type (Max.= 60).

Incorrect Manipulation Patterns

Tables 10-18 show the number of each of the types of errors (Syntactic, Lexical, or Omission) for each S:N condition for A, P, CS, CO, D, DP, C, SO, and OS, respectively.

Error type: Syntactic Violations

Syntactic violations showed the following general patterns:

1) more types of syntactic violations are seen for the sentence types: C, SO, and OS;

2) a large increase (>5) in the number of types of syntactic errors as S:N becomes more difficult occurs for C and OS;

3) a moderate increase (>2) in the number of types of syntactic violations as S:N becomes more difficult occurs for: A, CS, CO, D, DP, and SO;

4) no change (<2) in the number of types of syntactic violations as S:N becomes more

difficult occurs for P.

Error type: Lexical substitutions

Lexical substitutions showed the following general patterns:

1) no conditions occur in which there is a large increase (>5) in the number of types of lexical substitutions as S:N becomes more difficult;

2) a moderate increase (>2) in the number of types of lexical substitutions as S:N becomes more difficult is seen in: P, CS, D, DP, SO;

3) no change (<2) in the number of types of lexical substitutions as S:N becomes more difficult is seen in: A, CO, C, OS.

Error type: Omission

The omissions of items can be described according to the following general patterns:

1) more omissions occur for A sentences than any other type;

2) omissions tend to increase as S:N increases.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	0	1	4
Lexical	3	5	4
Omission	0	1	5

Table 10. Number of and types of errors across subjects for sentence complexity ACTIVE.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	2	1	2
Lexical	1	3	5
Omission	1	2	1

Table 11. Number of and types of errors across subjects for sentence complexity PASSIVE.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	0	1	2
Lexical	2	2	4
Omission	0	1	0

Table 12. Number of and types of errors across subjects for sentence complexity CLEFT SUBJECT.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	0	3	5
Lexical	1	1	2
Omission	1	1	1

Table 13. Number of and types of errors across subjects for sentence complexity CLEFT OBJECT.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	3	2	6
Lexical	3	2	5
Omission	0	0	0

Table 14. Number of and types of errors across subjects for sentence complexity DATIVE.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	2	2	5
Lexical	1	3	4
Omission	1	0	0

Table 15. Number of and types of errors across subjects for sentence complexity DATIVE PASSIVE.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	0	5	9
Lexical	7	5	5
Omission	0	1	1

Table 16. Number of and types of errors across subjects for sentence complexity CO-ORDINATED.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	9	9	11
Lexical	5	5	8
Omission	0	1	2

Table 17. Number of and types of errors across subjects for sentence complexity SUBJECT-OBJECT RELATIVE.

Error Type	0 dB S:N	-3 dB S:N	-6 dB S:N
Syntactic	2	6	15
Lexical	6	4	7
Omission	1	1	2

Table 18. Number of and types of errors across subjects for sentence complexity OBJECT-SUBJECT RELATIVE.

DISCUSSION

The purpose of the present study was to investigate the interplay between the perception and comprehension of heard sentences. S:N conditions were manipulated to stress the perceptual system. The syntactic complexity of sentences was simultaneously manipulated to stress comprehension. Subjects used toy animals to act out the meaning of sentences of varying syntactic complexity that they heard under a range of S:N conditions. The accuracy of their actions in representing the meaning of each sentence and the time taken to act out each sentence were measured. The pattern of results obtained as a function of the perceptual and comprehension manipulations was then used to evaluate the idea that working memory capacity may limit a listener's ability to comprehend.

It was found that more complex sentences were not comprehended as accurately as less complex sentences when people listened to the sentences in noise. Specifically, sentence types with two verbs per sentence were comprehended incorrectly more often than were sentences with one verb per sentence; within the one-verb-per-sentence category, however, there was no difference in accuracy scores depending on whether the verb was two-place or three-place. The pattern of the relative number of errors across sentence types was similar across S:N conditions, though fewer sentences were comprehended correctly in the -6 dB S:N condition as compared to the 0 dB and -3 dB S:N conditions. The error patterns for the incorrectly manipulated sentences were subdivided into three types: syntactic violations, lexical substitutions, and omissions. The patterns of syntactic-type errors did seem to change as S:N conditions became more adverse. Specifically, an increase was observed in the number of different types of syntactic errors from 0 dB S:N to -6 dB S:N for all sentence complexities except P. There were no such similar trends for the lexical substitution or omission error categories.

It was also found that it took more time for subjects to act out more complex than less complex sentences when the sentences were presented in noise. Specifically, sentence types with two verbs took longer to act out than sentences with one three-place verb which, in turn, took longer to act out than sentences with one two-place verb. This finding, however, might at least partially reflect the number of motor movements required to manipulate the animals for each of these sentence categories. Importantly, the time taken to act out the sentences did not change significantly as the listening condition changed.

The present study is unique in its focus on the combined effects of noise and syntactic complexity on young normal-hearing subjects' comprehension of heard sentences. One similar study, however, also investigated the effect of increasing perceptual difficulty for normal young subjects while simultaneously measuring performance on a sentence comprehension task (Miyake, Carpenter, and Just, 1994). Subjects (120 in two experiments) were required to read sentences of varying syntactic complexity while severe time constraints were imposed by presenting the sentences at two different rates using the rapid serial visual presentation (RSVP) technique. After reading each sentence, subjects were asked to answer a yes/no question to assess whether or not they had correctly understood the thematic role of the participants in the sentence. The reading memory span of each subject was also measured. Results indicate that the syntactic complexity of the sentences had a significant effect on the comprehension of the sentences as did the rate of sentence presentation and that reading span was correlated with comprehension.

Other investigations have been designed to manipulate only perception or comprehension. Perceptual studies have examined the effect of noise on grammatical processing (Kilborn, 1991), as well as the effect of unattended speech and music on reading comprehension (Martin, Wogalter, and Forlano, 1988). The effect of a low-level pink noise masker (i.e. random noise restricted to the speech band) on normal young subjects' ability to decide which of two nouns heard in a sentence was the grammatical subject was investigated by Kilborn (1991). Sentences varied according to three dimensions: word order, noun-verb agreement, and animacy. Speakers of English and German were tested. Kilborn found that English speakers, who regularly rely almost entirely on word order cues, were not affected by the noise manipulation. The German subjects made significantly less use of grammatical morphology under the noisy conditions and compensated with an uncharacteristic reliance on word order. In another study, the effect of unattended speech and music on reading comprehension in normal young subjects was investigated (Martin et al., 1988). Subjects were required to read passages while listening to backgrounds of various types, such as: continuous spoken speech, randomly arranged speech, instrumental music, random tones, white noise, and quiet. Subjects were asked multiple-choice and cued recall/short-answer type questions about the passages following a search task (subjects were asked to search for a specific number or letter on a sheet of symbols) which served as an interpolated task between the reading of each passage and the comprehension test. Results indicate that unattended speech but not music interfered with reading comprehension. Additional experiments lead the authors to believe that the detrimental effect of the speech backgrounds on reading was due to the semantic rather than the phonological properties of the backgrounds.

In studies of comprehension, the effect of varying syntactic complexity on sentence comprehension in pathological subjects has been examined (Caplan et al., 1985; see also Caplan and Hildebrandt, 1988). In the series of studies completed by Caplan et al. (1985), aphasic patients were tested on their comprehension of nine syntactic constructions using the OMT, in which patients indicated the thematic roles of the animals in the sentences by acting out the relationships with toy animals. Results indicate that there was a strong effect of syntactic complexity on comprehension, with there being a similar ranking of the difficulty of sentence complexity types in the three studies. The relative difficulty of the sentence types from easy to difficult were: A, CS, P, D, CO, OS, C, DP, and SO.

In normal young subjects, the effect of a divided attention task on written sentence comprehension while varying the syntactic complexity and the number of propositions in a sentence was investigated by Waters, Caplan, and Hildebrandt (1987). In the studies completed by Waters and her colleagues (1987), normal young subjects performed semantic acceptability judgements on sentences that differed on two dimensions: syntactic complexity and number of propositions. In the first experiment, subjects made these judgements without performing a concurrent task; on subsequent studies, subjects simultaneously performed additional experimental tasks (such as retaining a memory load, repeated articulation of digits, or finger tapping) which were assessed to stress different components of the working memory system.

Results from the first experiment suggest that processing time and the number of errors increase as a function of both syntactic complexity and propositional density. If subjects were required to retain a memory load while performing the task, there was an additional decrement in their performance scores when the complexity and number of propositions increased. Comparisons of the results of experiments in which the subjects had additional tasks (that presumably draw on the various components of the working memory) lead the authors to conclude that the articulatory loop is not involved in the syntactic analysis of a sentence but that it is involved in the post-syntactic interpretative processes involved in the judgement of the acceptability of a sentence.

In another study, the relationship of working memory capacity to the ability of normal young readers to maintain multiple interpretations of a lexically ambiguous word during reading comprehension was investigated by Miyake, Just, and Carpenter (1994). In the study by Miyake and his colleagues (1994), the distance between the ambiguous word and the disambiguating phrase was varied. The results indicate that readers with a large working memory capacity were able to maintain multiple interpretations of an unresolved lexical ambiguity longer than subjects with a small working memory capacity.

With respect to the role of perception in comprehension, the findings of the present study support the findings of some, but not all, of the previous research in this area. The results of the present study are consistent with the findings of Martin et al. (1988) in that a detrimental effect on comprehension resulted from the addition of background speech noise. Nevertheless, there are some important differences between the two studies. In the present study, the effect of competing speech babble on the comprehension of heard sentences was examined while Martin and colleagues investigated the effect of one speaker talking while the subject read. Note that the finding that background noise does significantly affect listening comprehension is not in full agreement with the findings of Kilborn (1991) who found that his English subjects were not affected by the noise manipulation; he did conclude, however, that a reduction in processing capacity can affect some aspects of language more than others, such as grammatical morphology in German. Since we do not have any information about the S:N condition that was employed by Kilborn, it may be that the S:N conditions employed in the present study were more adverse and therefore stressed perceptual processing to a greater degree thereby resulting in breakdowns that were not observed for the English speakers in the Kilborn study.

The results of the present study are consistent with previous studies which have attempted to determine the effect of syntactic complexity on comprehension. Previous studies have examined both the comprehension of heard sentences as well as the comprehension of read sentences and have used normal young adults as well as aphasic patients. Regardless of the modality of presentation of the sentences to be comprehended, subjects have provided strikingly similar results on tests of comprehension. When normal subjects are perceptually stressed with a visual presentation of the sentences at increased speed (Miyake et al., 1994) or with an auditory presentation of the sentences in a background of noise (present study), the patterns of difficulty are similar to those observed in aphasic patients (Caplan et al., 1985). Specific levels of difficulty have been determined by a complexity metric. The factors which might contribute to this ranking, as pointed out by Caplan et al. (1985), are:

1. the number of thematic roles associated with a single verb;

2. the number of verbs, or the number of pairs of thematic roles, within the sentence;

3. whether or not the order of thematic roles is canonical;

4. the necessity of retaining the first noun phrase while another set of thematic roles is computed; and

5. whether a noun plays two different thematic roles in two clauses.

Using this complexity metric, scores are computed for each sentence type on a scale from one to five, depending on the number of factors mentioned above that are inherent to that particular sentence type. Both the data of Caplan and Hildebrandt (1988) and of Miyake et al. (1994) are in full agreement with this metric; that is, the relative accuracy of comprehension for the syntactic complexity types is ranked according to the number of complexity factors inherent to the sentence types.

The only difference between the studies mentioned above (and the complexity metric) and the present study is that, in contrast to the ranking observed in the previous studies, in the present study the object manipulations for the sentence type DP were performed correctly relatively more often than the manipulations for the other sentence types. The DP sentences score a '2' on the metric since they have three thematic roles to a single verb and they have a noncanonical order of thematic roles. In the present study, however, subjects performed better overall on the DP sentence type than on the A, D, CO, and P sentence types which contain, at most, only one of the complexity factors mentioned above. A possible explanation for the relative ease of comprehending DP sentences is that DP sentences have a characteristic rhythmic pattern that remains perceptible even when segmental aspects of the signal are confused.

A comparison can be made between the syntactic errors obtained in the present study and those obtained in the studies of Caplan (1985) and Miyake (1994). This comparison will only consider the most dominant error pattern(s) of the three most difficult sentence types (C, SO, and OS) because these contained the largest number of errors in the studies. Recall that there are important differences between Caplan's scoring system and the one employed in the present study. Specifically, Caplan's scoring system did not consider lexical substitutions because his subjects were only given the target animals for each sentence and subjects were not penalized for acting out an incorrect verb. Neither the incorrectly acted out verbs nor the lexical substitutions that were scored as errors in the present study will be considered here so that differences in the coding strategies employed in the three studies are minimized. It should also be noted that percentage scores will not be considered here as was done by Miyake (1994); instead, the rank ordering of the error patterns according to the number of errors observed for each type of error will be used for the comparison.

For C sentences, in all three studies the same primary syntactic error was found: 12;23 (correct pattern: 12;13). Note that Miyake et al. (1994) obtained three error patterns which ranked as first, the one above as well as 13;12 and 21;23. For the OS sentences, the same primary syntactic error was reported in all three studies: 12;13 (correct pattern: 12;23 or 23;12). For the SO sentences, the top three error patterns were the same in all three studies, although for each study a different error was ranked as most common: 21;23, 12;23, and 12,13 (correct pattern: 21;13 or 13;21). In addition to the evidence provided by the accuracy scores, the qualitative similarities of error types across studies provide further evidence that similar breakdowns in sentence comprehension abilities occur in aphasic patients and in normal young subjects whose perceptual processing capabilities are stressed by signal degradation. It is also interesting to note that some aphasic patients show improvements in their syntactic comprehension performance when speech rate is slowed (Blumstein, Katz, Goodglass, Shrier, and Dworetsky, 1985). This result appears to be consistent with the proposed hypothesis of an implementational deficit; when the perceptual task is simplified (slowed down), more resources are available for the computational (comprehension) functions. Conversely, when the perceptual task is made more difficult then fewer resources are available for comprehending the sentences.

As a result of the differences in the coding strategies employed in these studies, for the present study it is possible to make observations that were not made in the other studies. There are several examples in the present data set which indicate that Caplan's scoring method may overlook interesting and informative error patterns. Specifically, the present study scored the accuracy of naming verbs for each sentence manipulation as well as the accuracy of naming the animals in each sentence. Several error patterns were observed which were counted as lexical substitutions where the error involved a misidentified action but the misidentified action actually created a separate category of errors that could be considered to be syntactic. For example, the correct pattern for C sentences is:

1 A 2; 1 B 3. Several of the interesting error patterns are:

1. 1 B 2; 1 A 3

2. 1 Y 2; 1 A 3

3. 1 A 2; 1 A 3

These manipulations would not be scored as incorrect by Caplan because the thematic roles of the animals are correctly identified; it is the order in which the actions are carried out which is incorrect. In all the examples, the first target verb, 'A', is used incorrectly as the second action and not as the first action. Such an error of ordering suggests that the computation of the meaning of the sentences has gone wrong.

Several other factors pertaining directly to the present study should be mentioned. In addition to a frequency count of how often a particular error pattern was used, a count was also made for the number of different error patterns (types) that were used in each of the three error categories (syntactic violation, lexical substitution. and omission). Two interesting trends became apparent with the analysis of the number of types of syntactic errors as S:N decreased from 0 dB to -6 dB:

1. There was no measurable change in the number of types of syntactic errors as S:N decreased from 0 dB to -6 dB for P sentences; P sentences may be more robust in noise as a result of the unique rhythmic pattern of the sentence type which might have helped the listener to identify the sentence as having passive voice even in the most aversive S:N conditions where only suprasegmental aspects of the signal may be available.

2. There was a relatively large increase in the number of types of syntactic errors as S:N decreased from 0 dB to -6 dB for C and OS sentences; C and OS sentences may be more susceptible to the noise as a result of the words 'and' and 'that' which may relatively easily become confused in a background of speech babble.

These peculiarities should be noted as they may be specific to the speech-in-noise aspect of this study; they may or may not be directly relevant to the issue of how working memory resources may or may not be related to comprehension performance.

Miyake et al. (1994) discuss a working memory capacity theory of syntactic comprehension deficits. Based on the work of Just and Carpenter (1992), the theory specifies how reductions in working memory capacity can lead to sentence comprehension patterns like those seen in studies of aphasic patients. This theory is based on the premise that the aphasic disorder results from an effective reduction in the patient's working memory capacity for language. This theory proposes that working memory capacity consists of "a flexible deployable pool of limited cognitive resources that supports the two functions of working memory, namely computation and storage" (Miyake et al., 1994). These authors believe that storage and computational requirements are mediated by the same supply of resources; therefore, these requirements compete with each other for limited resources when the demand on the resources is high, as it is in the comprehension of complex sentences in degraded perceptual conditions. They claim that a reduction in the resources used for storage results in a kind of 'forgetting' of the components of a sentence while a reduction in the resources used for computation results in a slowing in the speed of processing of a sentence.

The three categories of errors assessed in the present study can be considered in light of the theory that there are shared resources for storage and computation. It is unsure the degree to which syntactical errors result from either a storage or a computational processing problem. Results indicate that, in general, syntactic type errors increase in most sentences types as S:N becomes unfavorable. This trend, however, could be a result of a reduction of resources for either storage or computation. It could be argued that the lexical substitutions and omissions may be considered to be either a direct result of deficiencies in the storage functions of the working memory system or a result of an auditory failure in which difficultly perceived information could indirectly lead to faulty storage. If lexical substitutions and omissions are considered as a single category, increases in the number of errors are seen only in sentence types A, P, and OS as S:N becomes unfavorable. While OS is one of the most complex sentence types, A and P are two of the least complex so it is difficult to credit that these errors would result from an increased computational load. It would follow from this argument that these errors resulted from a lack of resources to carry out only the storage functions during sentence processing. On occasion, a subject would pause upon hearing a sentence and try to piece together what he or she heard as compared to what would make sense; for example, a subject might hear a verb which ended with '-shed' or began with 'scr-'. The subject would then proceed to mentally work through the closed set of possible verbs and, often correctly, choose to act out 'pushed' or 'scratched'. There does not appear to be an obvious reason why these sentence types would be singled out in this instance. It is possible that the degree of audibility of these sentence types in noise makes them more difficult to process.

The present findings seem to be consistent with the theory presented by Miyake et al. (1994) which postulates that aphasic patients' comprehension deficits may originate, in part, from reductions in working memory capacity for language. The introduction of background noise to stress the perceptual system could be seen as resulting in a relatively larger depletion of resources from the working memory system, with this reduction, in turn, leaving fewer resources available for the computational functions of sentence comprehension, and a consequent reduction in performance on a sentence comprehension task. This hypothesis is also consistent with the argument presented by Pichora-Fuller et al. (1995) who interpret their results as supporting a model in which the reallocable resources are used to support auditory processing when the perceptual task becomes more difficult with the introduction of background noise, leaving fewer resources available for the more central cognitive processes such as storage and retrieval.

Comprehension patterns similar to those of aphasic patients' were obtained by stressing the perceptual system and possibly, in turn, the working memory system of young normal adults. The comprehension process breaks down in predictable ways when the necessary resources become unavailable. When the task is changed from listening in quiet to listening in a competing background of speech babble, an apparent shift occurs for the normal young adult from effortless listening to effortful listening; when this shift occurs, it seems that the resources required for the comprehension of the more complex sentences are reduced.

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APPENDIX A

Individual Subject Data for : Age, Sex, Babble Threshold, SRT in Noise, Vocabulary Test, and WMS

Subject #	Sex	Age	Babble Threshold	SRT in Noise	Vocabulary Score	WMS
1	F	26	0	-11	14	3.33
2	F	23	5	-10	15	2.33
3	M	21	0	-11	15	2.33
4	M	29	0	-12	15	3.33
5	F	28	0	-12	17	4.33
6	F	21	-5	- 9	16	3.67
7	F	33	0	-10	13	2.33
8	F	24	0	- 9	13	4.33
9	M	22	0	-10	14	2.33
10	F	24	0	-13	16	4.00
11	M	26	0	-10	15	1.67
12	F	23	0	-13	13	4.67

NOTE :
Babble threshold (BT) was measured for the right ear only and is expressed in dB HL. SRT in noise score was measured for the right ear only and is expressed in dB S:N. Vocabulary scores are on a scale of 0 to 20.

APPENDIX B

List #1: Skeleton Sentence List

1. The C 1 the B.
2. The A 8 the D.
3. The C 15 the E to the A.
4. The B 9 the C and 12 the D.
5. The A was 3 by the C.
6. The E that the B 7 10 the A.
7. It was the D that the E 13.
8. The B was 2 to the C by the A.
9. The E 14 the B that 5 the C.
10. It was the A that 11 the B.
11. The D 13 the A and 9 the B.
12. It was the C that the A 6.
13. The D 2 the A to the E.
14. The B was 4 by the C.
15. The D that the A 12 7 the C.
16. It was the A that 4 the C.
17. The B was 11 to the E by the A.
18. The D 1 the A that 14 the B.
19. The C was 8 by the B.
20. The C 10 the A and 5 the D.
21. The D 6 the B to the C.
22. The E that the C 4 13 the A.
23. The E 3 the B.
24. The D 7 the E that 2 the C.
25. It was the D that 5 the B 11.
26. The C was 8 to the A by the E.
27. It was the D that 5 the B.
28. The D 9 the E that 10 the A.
29. The C 15 the D to the E.
30. It was the A that 6 the D.
31. The E that the A 3 14 the B.
32. The D was 1 by the E.
33. The C was 15 to the A by the E.
34. It was the D that the B 12.
35. The C 6 the E and 7 the B.
36. It was the C that 4 the E.
37. The D 5 the B that 11 the E.
38. The C was 2 to the E by the D.
39. It was the E that the D 3.
40. The B that the E 13 12 the A.
41. The D was 14 by the B.

VERB KEY:
1= pulled
2= pushed
3= scratched
4= bumped
5= tapped
6= passed
7= kissed
8= tossed
9= touched
10= tripped
11= kicked
12= hugged
13= grabbed
14= chased
15= hauled

ANIMAL KEY:
A= duck
B= owl
C= mouse
D= pig
E= fox

42. The B 9 the D and 10 the E.
43. The C 15 the A to the E.
44. The A 8 the C.
45. The B 1 the D.

APPENDIX C

<u>Experimental Sentence Lists and Score Sheets</u>

LIST 1

( ) /3 1. The mouse pulled the owl.
mouse ( ) pulled < > owl ( ).

( ) /3 2. The duck tossed the pig.
duck ( ) tossed < > pig ( ).

( ) /4 3. The mouse hauled the fox to the duck.
mouse ( ) hauled < > fox ( ) to duck ( ).

( ) /6 4. The owl touched the mouse and hugged the pig.
owl ( ) touched < > mouse ( ).
owl ( ) hugged < > pig ( ).

( ) /3 5. The duck was scratched by the mouse.
mouse ( ) scratched < > duck ( ).

( ) /6 6. The fox that the owl kissed tripped the duck.
owl ( ) kissed < > fox ( ).
fox ( ) tripped < > duck ( ).

( ) /3 7. It was the pig that the fox grabbed.
fox ( ) grabbed < > pig ( ).

( ) /4 8. The owl was pushed to the mouse by the duck.
duck ( ) pushed < > owl ( ) to mouse ( ).

( ) /6 9. The fox chased the owl that tapped the mouse.
owl ( ) tapped < > mouse ( ).
fox ( ) chased < > owl ( ).

( ) /3 10. It was the duck that kicked the owl.
duck ( ) kicked < > owl ( ).

( ) /6 11. The pig grabbed the duck and touched the owl.
pig ( ) grabbed < > duck ( ).
pig ( ) touched < > owl ( ).

( ) /3 12. It was the mouse that the duck passed.
duck ( ) passed < > mouse ( ).

( ) /4 13. The pig pushed the duck to the fox.
pig ( ) pushed < > duck ( ) to fox ( ).

( ) /3 14. The owl was bumped by the mouse.
mouse ( ) bumped < > owl ( ).

( ) /6 15. The pig that the duck hugged kissed the mouse.
duck ( ) hugged < > pig ( ).
pig ( ) kissed < > mouse ( ).

( ) /3 16. It was the duck that bumped the mouse.
duck ( ) bumped < > mouse ( ).

( ) /4 17. The owl was kicked to the fox by the duck.
duck ( ) kicked < > owl ( ) to fox ( ).

( ) /6 18. The pig pulled the duck that chased the owl.
duck ( ) chased < > owl ( ).
pig ( ) pulled < > duck ( ).

( ) /3 19. The mouse was tossed by the owl.
owl ( ) tossed < > mouse ( ).

( ) /6 20. The mouse tripped the duck and tapped the pig.
mouse ( ) tripped < > duck ( ).
mouse ( ) tapped < > pig ( ).

( ) /4 21. The pig passed the owl to the mouse.
pig ( ) passed < > owl ( ) to mouse ( ).

( ) /6 22. The fox that the mouse bumped grabbed the duck.
mouse ( ) bumped < > fox ( ).
fox ( ) grabbed < > duck ( ).

( ) /3 23. The fox scratched the owl.
fox ( ) scratched < > owl ( ).

( ) /6 24. The pig kissed the fox that pushed the mouse.
fox ( ) pushed < > mouse ( ).
pig ( ) kissed < > fox ( ).

( ) /3 25. It was the pig that the owl kicked.
owl ( ) kicked < > pig ( ).

( ) /4 26. The mouse was tossed to the duck by the fox.
fox ( ) tossed < > mouse ( ) to duck ( ).

( ) /3 27. It was the pig that tapped the owl.
pig ( ) tapped < > owl ( ).

( ) /6 28. The pig touched the fox that tripped the duck.
fox ( ) tripped < > duck ( ).
pig ( ) touched < > fox ( ).

( ) /4 29. The mouse hauled the pig to the fox.
mouse ( ) hauled < > pig ( ) to fox ( ).

( ) /3 30. It was the duck that passed the pig.
duck ( ) passed < > pig ( ).

( ) /6 31. The fox that the duck scratched chased the owl.
duck ( ) scratched < > fox ( ).
fox ( ) chased < > owl ( ).

( ) /3 32. The pig was pulled by the fox.
fox ( ) pulled < > pig ( ).

( ) /4 33. The mouse was hauled to the duck by the fox.
fox ( ) hauled < > mouse ( ) to duck ( ).

( ) /3 34. It was the pig that the owl hugged.
owl ( ) hugged < > pig ( ).

( ) /6 35. The mouse passed the fox and kissed the owl.
mouse ( ) passed < > fox ( ).
mouse ( ) kissed < > owl ( ).

( ) /3 36. It was the mouse that bumped the fox.
mouse ( ) bumped < > fox ( ).

( ) /6 37. The pig tapped the owl that kicked the fox.
owl ( ) kicked < > fox ( ).
pig ( ) tapped < > owl ( ).

( ) /4 38. The mouse was pushed to the fox by the pig.
pig ( ) pushed < > mouse ( ) to fox ( ).

( ) /3 39. It was the fox that the pig scratched.
pig ( ) scratched < > fox ( ).

( ) /6 40. The owl that the fox grabbed hugged the duck.
fox ( ) grabbed < > owl ( ).
owl ( ) hugged < > duck ( ).

( ) /3 41. The pig was chased by the owl.
owl ( ) chased < > pig ( ).

( ) /6 42. The owl touched the pig and tripped the fox.
owl ( ) touched < > pig ( ).
owl ( ) tripped < > fox ( ).

( ) /4 43. The mouse hauled the duck to the fox.
mouse ( ) hauled < > duck ( ) to fox ( ).

( ) /3 44. The duck tossed the mouse.
duck ( ) tossed < > pig ( ).

( ) /3 45. The owl pulled the pig.
owl ( ) pulled < > pig ( ).

SUMMARY: LIST 1

ACTIVE	PASSIVE	CLEFT SUBJ.	CLEFT OBJ.	ACTIVE-3	PASSIVE-3
1.____	5.____	10.____	7.____	3.____	8.____
2.____	14.____	16.____	12.____	13.____	17.____
23.____	19.____	27.____	25.____	21.____	26.____
44.____	32.____	30.____	34.____	29.____	33.____
45.____	41.____	36.____	39.____	43.____	38.____

CO-ORDINATED	SUBJECT-OBJECT	OBJECT-SUBJECT
4.____	6.____	9.____
11.____	15.____	18.____
20.____	22.____	24.____
35.____	31.____	28.____
42.____	40.____	37.____

LIST 2

( ) /3 1. It was the pig that passed the duck.
pig ( ) passed < > duck ( ).

( ) /6 2. The owl that the mouse pulled tossed the duck.
mouse ( ) pulled < > owl ( ).
owl ( ) tossed < > duck ( ).

( ) /3 3. The fox was hauled by the mouse.
mouse ( ) hauled < > fox ( ).

( ) /3 4. The duck tripped the fox.
duck ( ) tripped < > fox ( ).

( ) /4 5. The pig was pushed to the owl by the duck.
duck ( ) pushed < > pig ( ) to owl ( ).

( ) /6 6. The pig touched the owl and chased the fox.
pig ( ) touched < > owl ( ).
pig ( ) chased < > fox ( ).

( ) /4 7. The owl kicked the pig to the fox.
owl ( ) kicked < > pig ( ) to fox ( ).

( ) /6 8. The pig that the fox hugged grabbed the mouse.
fox ( ) hugged < > pig ( ).
pig ( ) grabbed < > mouse ( ).

( ) /4 9. The fox was passed to the owl by the pig.
pig ( ) passed < > fox ( ) to owl ( ).

( ) /6 10. The owl scratched the fox that tapped the mouse.
fox ( ) tapped < > mouse ( ).
owl ( ) scratched < > fox ( ).

( ) /3 11. It was the duck that the fox bumped.
fox ( ) bumped < > duck ( ).

( ) /3 12. It was the owl that kissed the mouse.
owl ( ) kissed < > mouse ( ).

( ) /3 13. It was the pig that hauled the fox.
pig ( ) hauled < > fox ( ).

( ) /6 14. The duck that the mouse hugged pulled the pig.
mouse ( ) hugged < > duck ( ).
duck ( ) pulled < > pig ( ).

( ) /3 15. The fox chased the owl.
fox ( ) chased < > owl ( ).

( ) /3 16. The duck was scratched by the fox.
fox ( ) scratched < > duck ( ).

( ) /6 17. The duck touched the pig and tripped the mouse.
duck ( ) touched < > pig ( ).
duck ( ) tripped < > mouse ( ).

( ) /4 18. The fox pushed the pig to the duck.
fox ( ) pushed < > pig ( ) to duck ( ).

( ) /6 19. The fox touched the pig that tapped the owl.
pig ( ) tapped < > owl ( ).
fox ( ) touched < > pig ( ).

( ) /6 20. The pig passed the fox and tossed the mouse.
pig ( ) passed < > fox ( ).
pig ( ) tossed < > mouse ( ).

( ) /3 21. The owl kissed the pig.
owl ( ) kissed < > pig ( ).

( ) /3 22. The pig scratched the mouse.
pig ( ) scratched < > mouse ( ).

( ) /4 23. The fox was kicked to the pig by the owl.
owl ( ) kicked < > fox ( ) to pig ( ).

( ) /4 24. The duck tossed the fox to the mouse.
duck ( ) tossed < > fox ( ) to mouse ( ).

( ) /3 25. It was the fox that grabbed the mouse.
fox ( ) grabbed < > mouse ( ).

( ) /6 26. The owl bumped the pig that tapped the duck.
pig ( ) tapped < > duck ( ).
owl ( ) bumped < > pig ( ).

( ) /3 27. The mouse was tripped by the owl.
owl ( ) tripped < > mouse ( ).

( ) /3 28. It was the mouse that the owl chased.
owl ( ) chased < > mouse ( ).

( ) /3 29. It was the owl that the mouse pulled.
mouse ( ) pulled < > owl ( ).

( ) /4 30. The duck hauled the pig to the fox.
duck ( ) hauled < > pig ( ) to fox ( ).

( ) /6 31. The owl kicked the duck that bumped the mouse.
duck ( ) bumped < > mouse ( ).
owl ( ) kicked < > duck ( ).

( ) /6 32. The duck that the mouse kissed hugged the owl.
mouse ( ) kissed < > duck ( ).
duck ( ) hugged < > owl ( ).

( ) /6 33. The duck pushed the pig and bumped the mouse.
duck ( ) pushed < > pig ( ).
duck ( ) bumped < > mouse ( ).

( ) /4 34. The fox was passed to the mouse by the duck.
duck ( ) passed < > fox ( ) to mouse ( ).

( ) /3 35. The pig was touched by the duck.
duck ( ) touched < > pig ( ).

( ) /6 36. The owl that the pig grabbed kicked the duck.
pig ( ) grabbed < > owl ( ).
owl ( ) kicked < > duck ( ).

( ) /3 37. The owl pushed the duck.
owl ( ) pushed < > duck ( ).

( ) /3 38. It was the mouse that the owl hauled.
owl ( ) hauled < > mouse ( ).

( ) /3 39. It was the fox that tapped the duck.
fox ( ) tapped < > duck ( ).

( ) /3 40. It was the owl that the mouse chased.
mouse ( ) chased < > owl ( ).

( ) /4 41. The fox tossed the pig to the duck.
fox ( ) tossed < > pig ( ) to duck ( ).

( ) /6 42. The owl grabbed the fox and tripped the mouse.
owl ( ) grabbed < > fox ( ).
owl ( ) tripped < > mouse ( ).

( ) /3 43. The duck was kissed by the pig.
pig ( ) kissed < > duck ( ).

( ) /6 44. The mouse that scratched the owl hugged the duck
owl ( ) hugged < > duck ( ).
mouse ( ) scratched < > owl ( ).

( ) /4 45. The fox was pulled to the mouse by the pig.
pig ( ) pulled < > fox ( ) to mouse ( ).

SUMMARY: LIST 2

ACTIVE	PASSIVE	CLEFT SUBJ.	CLEFT OBJ.	ACTIVE-3	PASSIVE-3
4.____	3.____	1.____	11.____	7.____	5.____
15.____	16.____	12.____	28.____	18.____	9.____
21.____	27.____	13.____	29.____	24.____	23.____
22.____	35.____	25.____	38.____	30.____	34.____
37.____	43.____	39.____	40.____	41.____	45.____

CO-ORDINATED	SUBJECT-OBJECT	OBJECT-SUBJECT
6.____	2.____	10.____
17.____	8.____	19.____
20.____	14.____	26.____
33.____	32.____	31.____
42.____	36.____	44.____

LIST 3

( ) /6 1. The pig that the duck grabbed bumped the owl.
duck ( ) grabbed < > pig ( ).
pig ( ) bumped < > owl ( ).

( ) /3 2. The duck was tapped by the pig.
pig ( ) tapped < > duck ( ).

( ) /4 3. The owl passed the duck to the mouse.
owl ( ) passed < > duck ( ) to mouse ( ).

( ) /6 4. The owl tripped the fox and tossed the duck.
owl ( ) tripped < > fox ( ).
owl ( ) tossed < > duck ( ).

( ) /6 5. The mouse chased the owl and pulled the fox.
mouse ( ) chased < > owl ( ).
mouse ( ) pulled < > fox ( ).

( ) /4 6. The pig was kicked to the duck by the fox.
fox ( ) kicked < > pig ( ) to duck ( ).

( ) /3 7. It was the pig that the mouse bumped.
mouse ( ) bumped < > pig ( ).

( ) /3 8. The duck was kissed by the pig.
pig ( ) kissed < > duck ( ).

( ) /6 9. The mouse hugged the owl that pushed the duck.
owl ( ) pushed < > duck ( ).
mouse ( ) hugged < > owl ( ).

( ) /4 10. The fox passed the mouse to the pig.
fox ( ) passed < > mouse ( ) to pig ( ).

( ) /3 11. It was the duck that bumped the owl.
duck ( ) bumped < > owl ( ).

( ) /6 12. The mouse that the duck touched grabbed the fox.
duck ( ) touched < > mouse ( ).
mouse ( ) grabbed < > fox ( ).

( ) /3 13. The pig kicked the owl.
pig ( ) kicked < > owl ( ).

( ) /4 14. The mouse was pushed to the owl by the duck.
duck ( ) pushed < > mouse ( ) to owl ( ).

( ) /6 15. The mouse that the duck hauled tapped the owl.
duck ( ) hauled < > mouse ( ).
mouse ( ) tapped < > owl ( ).

( ) /3 16. The duck chased the mouse.
duck ( ) chased < > mouse ( ).

( ) /6 17. The fox grabbed the pig that tripped the duck.
pig ( ) tripped < > duck ( ).
fox ( ) grabbed < > pig ( ).

( ) /4 18. The owl was tossed to the mouse by the duck.
duck ( ) tossed < > owl ( ) to mouse ( ).

( ) /6 19. The mouse kissed the owl and scratched the pig.
mouse ( ) kissed < > owl ( ).
mouse ( ) scratched < > pig ( ).

( ) /3 20. It was the owl that the mouse hugged.
mouse ( ) hugged < > owl ( ).

( ) /3 21. It was the fox that touched the mouse.
fox ( ) touched < > mouse ( ).

( ) /4 22. The duck was pulled to the fox by the owl.
owl ( ) pulled < > duck ( ) to fox ( ).

( ) /3 23. The pig scratched the fox.
pig ( ) scratched < > fox ( ).

( ) /3 24. It was the owl that kissed the mouse.
owl ( ) kissed < > mouse ( ).

( ) /3 25. It was the fox that the mouse pulled.
mouse ( ) pulled < > fox ( ).

( ) /4 26. The owl tossed the pig to the fox.
owl ( ) tossed < > pig ( ) to fox ( ).

( ) /3 27. The duck was hauled by the mouse.
mouse ( ) hauled < > duck ( ).

( ) /6 28. The pig that the fox tripped touched the owl.
fox ( ) tripped < > pig ( ).
pig ( ) touched < > owl ( ).

( ) /3 29. The duck chased the fox.
duck ( ) chased < > fox ( ).

( ) /4 30. The owl pushed the fox to the pig.
owl ( ) pushed < > fox ( ) to pig ( ).

( ) /3 31. It was the mouse that hugged the duck.
mouse ( ) hugged < > duck ( ).

( ) /6 32. The fox grabbed the pig and scratched the duck.
fox ( ) grabbed < > pig ( ).
fox ( ) scratched < > duck ( ).

( ) /3 33. The pig was kicked by the fox.
fox ( ) kicked < > pig ( ).

( ) /4 34. The owl was passed to the pig by the fox.
fox ( ) passed < > owl ( ) to pig ( ).

( ) /3 35. It was the pig that tapped the mouse.
pig ( ) tapped < > mouse ( ).

( ) /6 36. The mouse bumped the owl that kissed the pig.
owl ( ) kissed < > pig ( ).
mouse ( ) bumped < > owl ( ).

( ) /6 37. The pig hauled the mouse that hugged the fox.
mouse ( ) hugged < > fox ( ).
pig ( ) hauled < > mouse ( ).

( ) /3 38. It was the owl that the fox pulled.
fox ( ) pulled < > owl ( ).

( ) /6 39. The pig chased the mouse and scratched the fox.
pig ( ) chased < > mouse ( ).
pig ( ) scratched < > fox ( ).

( ) /3 40. The duck passed the owl.
duck ( ) passed < > owl ( ).

( ) /3 41. The mouse was tripped by the duck.
duck ( ) tripped < > mouse ( ).

( ) /3 42. It was the fox that the duck tossed.
duck ( ) tossed < > fox ( ).

( ) /6 43. The mouse that the fox touched tapped the pig.
fox ( ) touched < > mouse ( ).
mouse ( ) tapped < > pig ( ).

( ) /6 44. The owl kicked the pig that pushed the duck.
pig ( ) pushed < > duck ( ).
owl ( ) kicked < > pig ( ).

( ) /4 45. The fox hauled the owl to the pig.
fox ( ) hauled < > owl ( ) to pig ( ).

SUMMARY:LIST 3

ACTIVE	PASSIVE	CLEFT SUBJ.	CLEFT OBJ.	ACTIVE-3	PASSIVE-3
13.____	2.____	11.____	7.____	3.____	6.____
16.____	8.____	21.____	20.____	10.____	14.____
23.____	27.____	24.____	25.____	26.____	18.____
29.____	33.____	31.____	38.____	30.____	22.____
40.____	41.____	35.____	42.____	45.____	34.____

CO-ORDINATED	SUBJECT-OBJECT	OBJECT-SUBJECT
4.____	1.____	9.____
5.____	12.____	17.____
19.____	15.____	36.____
32.____	28.____	37.____
39.____	43.____	44.____

APPENDIX D

Directory of soundfiles

calibrate.1.snd	- Calibration tone for set 1.
calibrate.2.snd	- Calibration tone for set 2.
calibrate.3.snd	- Calibration tone for set 3.
intro.snd	- Introduction to project.
sample.1.snd	- First sample sentence.
sample.2.snd	- Second sample sentence.
sample.3.snd	- Third sample sentence.
sample.cal.snd	- Calibration tone for sample sentences.
sample.conclude.snd	- Conclusion of samples. Introduction to experiment.
sample.intro.snd	- Introduction to the sample sentences.
[1-3].[1-45].snd	- Series of sound files for each sentence (1 to 45) for each of the sets (1 to 3).

Files match regular expression : [1-3].[1-45].snd

APPENDIX E

Hardcopy of source code for custom application: "play_samples"

```
/*****************************************************************

Program          : play_samples.c
Author           : Simon Edgett (sedgett@island.net)
Functions        : main(void)
Returns          : void
Uses             : stdio.h, sys/time.h
External         : play, A sound program by J. Laroche

Notes        : Sound file path is hardcoded as /Net/odin/thor/Sounds/lmd/
                 Timing path is hardcoded as /Net/wigner/Users/lmd/timing/
                 Play is assumed to be in the path.
Comments     : This program was designed for Lisa Dillon.
                 It's purpose is to expedite the testing of subjects
                 for the thesis "The Effect of Noise and
                 Syntactic Complexity on Listening Comprehension"

*****************************************************************/


#include<stdio.h>
#include<sys/time.h>

#define clrscr() system("clear")

void main()
{
     /* Vars used through out */
     char command[255]; int set, num, setloop;
       char subject[255];
       FILE *timing;
       struct timeval tp, my_tp;
       struct timezone tzp;
       long t1, t2;
       float elapsed;

     /* Start of program */
     printf ("Simon's Sound App\n");
```

```
  printf ("Using Sound path /Net/odin/thor/Sounds/lmd.\n\n");
  command[0] = '\0';

/* Get subject code to store latency in file */
while (command[0] == '\0')
  {
        printf ("Please enter subject code for timing :");
        gets(command);
  }

/* Open file to store latency info */
sprintf (subject, "/Net/wigner/Users/lmd/timing/%s.data", command);
  printf ("\n\n");
  printf ("Opening %s for timing data.\n", subject);
  timing = fopen(subject, "w");
  if (timing==NULL)
  {
        printf ("There has been an error opening the timing file.\n");
        printf ("This is not good - your best bet is to close this program (click on X
in top right corner)\n");
        printf ("If it happens a second time, you can continue w/o saving the
timing info.\n");
        printf("/n/nPress enter to override the saving of timing info.\n");
        getchar();
  }

  printf ("\nPress enter to continue..\n");
  getchar();
  clrscr();

/* Play intro */
printf ("Ready to Play Intro  (You will hear....)\n");
  printf ("Press enter to continue...\n");
  getchar();
  system("play /Net/odin/thor/Sounds/lmd/intro.snd");
  printf ("\n");

/* Prompt for set, then start play back */
  printf ("Start sets.\n");
  for (setloop=1;setloop<=3;setloop++)
  {
   printf ("Enter the set # to play : ");
   gets(command);
   printf("\n");
   set = atoi(command);
```

```
  if (set==999)
   {
    printf ("Exiting....\n");
        fclose (timing);
    return;
   }
  if (set < 1 || set > 3)
   {
    set=0;
    printf ("Invalid set # - Enter 1-3 or 999\n");
    setloop--;
    continue;
   }

/* play sample stuff */
clrscr();

  printf ("Ready to play Sample Intro. (Now we will do 3 practice ....)\n");
  printf ("Press enter to continue...\n");
  getchar();
  system ("play /Net/odin/thor/Sounds/lmd/sample.intro.snd");
  printf ("\n");

  printf ("Ready to play calibration for samples.\n");
  printf ("Press enter to continue..\n");
  getchar();
  system("play /Net/odin/thor/Sounds/lmd/sample.cal.snd");
  printf ("\n");


  printf ("Ready to play first sample sentence. (pig hugged fox)\n");
  printf ("Press enter to continue.\n");
  getchar();
  system("play /Net/odin/thor/Sounds/lmd/sample.1.snd");
  printf("\n");

  printf ("Ready to play second sentence. (owl touched by mouse)\n");
  printf ("Press enter to continue.\n");
  getchar();
  system("play /Net/odin/thor/Sounds/lmd/sample.2.snd");
  printf("\n");

  printf ("Ready to play third sentence. (duck kicked owl and chased pig)\n");
  printf ("Press enter to continue.\n");
  getchar();
```

```
  system("play /Net/odin/thor/Sounds/lmd/sample.3.snd");
  printf("\n");



  printf ("Ready to play sample conclusion. (Now we will do a set ...)\n");
  printf ("press enter to continue...\n");
  getchar();
  system ("play /Net/odin/thor/Sounds/lmd/sample.conclude.snd");
  printf ("\n");

  clrscr();



/* Play actual set info */
printf ("Ready to play set [%d] calibration tone.\n",set);
  printf ("Press enter to continue...\n");
  getchar();
  sprintf(command, "play /Net/odin/thor/Sounds/lmd/calibrate.%d.snd",set);
  system(command);
  printf ("\n");
  for (num=1;num<=45;num++)
  {
      printf ("Ready to play Set [%d] Sentence [%d].\n",set,num);
        printf ("Press enter to continue...\n");
        getchar();

        sprintf(command, "play /Net/odin/thor/Sounds/lmd/%d.%d.snd", set, num);
        printf ("Playing [%d].[%d]\n\n",set,num);
        system(command);
        printf ("\n");

    /* As soon as sentence is finished get timeofday */
        gettimeofday(&tp, &tzp);
        printf ("Press enter to record latency.\n");
    getchar();

    /* Enter is pressed so calculate latency */
        gettimeofday(&my_tp, &tzp);

    /* Convert timeofday to seconds elapsed */
    t1 = ((tp.tv_sec%10000)*1000000) + tp.tv_usec;
        t2 = ((my_tp.tv_sec%10000)*1000000) + my_tp.tv_usec;
```

```
            elapsed = (((float)(t2 - t1))/1000000);

            printf ("Latency : %2.2f\n\n", elapsed);
            fprintf (timing, "Set [%d]  Sentence [%2d]  Latency [%2.2f]\n", set, num,
elapsed);
        }
        clrscr();
      }

/* Close of the latency file */
/* Reminder to thank subject and of latency file name */
fclose (timing);
printf ("Subject testing complete.  (Thank-you)\n");
printf ("Timing info is stored in : %s\n", subject);

}
```

APPENDIX F

HEARING AND LANGUAGE HISTORY

Subject Code:_____ Date:_____

1. Birthday:_____ (d-m-y)
2. a. What is your first language?_______________
   b. Do you speak any other language fluently?_______________
   c. Are you right- or left-handed? Right Left
   d. How many years did you attend school?_____
   e. Geographic locations where you lived as a child:________
   f. Geographic locations where you lived as an adult:________
3. a. Do you know how to play a musical instrument? Yes No
   b. Have you had any training in music? Yes No
4. a. Do people ever complain about your hearing? Yes No
   b. Have you ever had a hearing test? Yes No
   c. Do you wear a hearing aid? Yes No
5. Did anyone in your family have a hearing loss before old age? Who?_______________ Yes No
6. a. Do you often get colds? Yes No
   b. Do you have one now? Yes No
7. a. Do you have allergies? Yes No
   b. Are you bothered by one now? Yes No
8. a. Do you often get ear infections? Yes No
   b. Do you have one now? Yes No
9. Have you ever had ear surgery? Yes No
   What kind?_______________
10. Do you have ringing in your ears? Yes No
    When? Always Sometimes
    Which ear(s)? Right Left
11. a. What is/was your occupation?_______________
    Was it extremely noisy at work? Yes No
    Did you use ear protection? Yes No
    b. Were you ever in the military? Yes No
    c. Do you have noisy hobbies? (e.g.loud music, carpentry, ski-doo) Yes No
    What kind?_______________
12. Do you regularly take any medication? Yes No
    What kind?_______________
13. Do you have any trouble with your vision? Yes No
    What kind?_______________
14. Will your participation in the study be affected by a health problem? Yes No
    What kind?_______________

APPENDIX G

Pure Tone Thresholds of Individual Subjects

	Frequency in kHz											
	Right Ear						Left Ear					
Subject	.25	.5	1	2	4	8	.25	.5	1	2	4	8
1	0	0	0	5	0	-5	5	0	0	-5	0	0
2	0	0	0	0	0	-5	5	-5	0	10	0	-5
3	10	5	10	0	5	5	5	5	0	0	10	-5
4	0	0	5	0	10	0	0	0	5	0	0	5
5	10	10	0	5	0	5	5	0	0	5	-5	0
6	5	0	-5	0	10	10	10	-5	0	-5	10	15
7	0	0	0	-5	-5	5	0	0	0	-5	0	-5
8	0	0	5	5	5	0	0	0	-5	10	5	-5
9	5	5	5	0	0	-5	5	5	5	5	5	5
10	0	0	0	-5	10	0	-5	0	-5	-5	5	0
11	-5	-5	-5	5	-5	-5	-5	0	-5	5	-5	-5
12	0	-5	-5	-5	-5	0	0	0	0	-5	-5	0

Note : All threshold values are expressed in dB HL.

APPENDIX H

Mill Hill Vocabulary Test

Name:______________________________

Date:______________Age:____________

Sex:_______________________________

Last grade in school:_______________

Occupation:_________________________

In each group of six words below, underline the word which means the same as the word in capital letters above the group, as has been done in the first example.

1. CONNECT

accident	join
lace	bean
flirt	field

2. PROVIDE

harmonize	commit
hurt	supply
annoy	divide

3. STUBBORN

obstinate	steady
hopeful	hollow
orderly	slack

4. SCHOONER

building	man
ship	singer
plant	scholar

5. LIBERTY

worry	freedom
rich	serviette
forest	cheerful

6. COURTEOUS

dreadful	proud
truthful	short
curtsey	polite

7. RESEMBLANCE

fondness	assemble
attendance	repose
likeness	memory

8. THRIVE

flourish	cry
thrash	leap
think	blame

9. PRECISE

natural	stupid
faulty	grand
small	exact

10. ELEVATE

revolve	move
raise	work
waver	disperse

11. LAVISH

selfish	unaccountable
romantic	lawful
praise	extravagant

12. SURMOUNT

mountain	descend
overcome	concede
appease	snub

13. BOMBASTIC

pompous	democratic
bickering	cautious
anxious	destructive

14. ENVISAGE

activate	contemplate
surround	estrange
enfeeble	regress

15. PERPETRATE

appropriate	commit
propitiate	deface
control	pierce

16. LIBERTINE

missionary	rescuer
profligate	canard
regicide	farrago

17. QUERULOUS

astringent	fearful
petulant	curious
inquiring	spurious

18. FECUND

esculent	optative
profound	prolific
sublime	salic

19. ABNEGATE

contradict	decry
renounce	execute
belie	assemble

20. TRADUCE

challenge	attenuate
suspend	establish
misrepresent	conclude

21. TEMERITY

impermanence	rashness
nervousness	stability
submissiveness	punctuality

APPENDIX I

Introduction to and Instructions for the Experimental Task

You will hear sentences in a background of noise. The sentences you hear will be similar to these:

1. The cat tackled the dog.
2. It was the goose that the frog followed.
3. The frog was tickled by the cat.

When combined with background noise, what you hear will be similar to this:

4. The goose punched the dog.
5. The cat was followed by the goose.
6. It was the frog that smacked the cat.

Sometimes there will be a little background noise and the sentences will be pretty easy to hear. Other times, there will be more background noise and you will have trouble hearing some of the sentences. That's how the test goes.

Throughout the test when you are ready to listen, say "go". Then I will play you the sentence in noise. After you hear the sentence, use the objects in front of you to act out the meaning of the sentence you heard. Even if you haven't heard all of the sentence, always act out your best guess. Then when you are ready to listen to the next sentence, say "go".

If you have any questions, feel free to ask now.

APPENDIX J

Coded Patterns for Correct and Incorrect Manipulations, With Total Counts for Each Sentence Type and Error Pattern.

S= syntactic violation error type
L= lexical substitution error type
O= omission error type

Sentence Type: Active

Correct Pattern	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
1,A,2	53	51	43

Error Pattern	**Type**	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
2,A,1	S		1	1
2,Y,X	S			1
X,Y,1	S			1
2,Y,1	S			1
1,Y,2	L	5	3	3
1,A,X	L	1	1	2
X1,A,X2	L	1		
X,A,2	L		1	1
X1,Y,X2	L		1	
1,Y,X	L		1	1
#	O		1	2
X,#,2	O			1
2,#,1	O			1
1,#,#	O			1
#,A,2	O			1

Sentence Type: Passive

Correct Pattern	0 dB S:N	-3 dB S:N	-6 dB S:N
2,A,1	54	48	35

Error Pattern	Type	0 dB S:N	-3 dB S:N	-6 dB S:N
1,Y,X	S	1		
1,A,2	S	1	1	6
1,Y,2	S			2
2,Y,1	L	2	4	10
2,A,X	L		3	2
X,A,1	L		1	2
X,Y,1	L			1
X1,Y,X2	L			1
2,#,1	O	2		
#	O		2	1
2,#,#	O		1	

Sentence Type: Cleft Subject

Correct Pattern	0 dB S:N	-3 dB S:N	-6 dB S:N
1,A,2	57	56	47

Error Pattern	Type	0 dB S:N	-3 dB S:N	-6 dB S:N
X,Y,1	S			1
2,A,1	S		1	1
1,Y,2	L	1	1	4
1,Y,X	L		1	1
X,A,2	L			1
1,A,X	L	2		5
1,#,2	O		1	

Sentence Type: Cleft Object

Correct Pattern	0 dB S:N	-3 dB S:N	-6 dB S:N
2,A,1	55	46	42

Error Pattern	Type	0 dB S:N	-3 dB S:N	-6 dB S:N
1,A,2	S		3	1
1,Y,2	S		1	1
1,Y,X	S		1	
1,A,X	S			1
2,A,1,X	S			1
1,Y1,X;1,Y1,2	S			1
2,Y,1	L	4	8	11
X1,Y,X2	L			1
X,#,1	O	1		
1,Y,#	O		1	
1,#,#	O			1

Sentence Type: Dative

Correct Pattern	0 dB S:N	-3 dB S:N	-6 dB S:N
1,A,2,3	50	52	42

Error Pattern	Type	0 dB S:N	-3 dB S:N	-6 dB S:N
X,Y,1,3	S	1		
2,Y,3	S	1		
1,Y,2	S	1		2
2,A,1,3	S		2	1
1,A,2	S		2	2
3,A,1,2	S			1
2,Y,X,3	S			1
2,Y,X	S			1
1,Y,2,3	L	3	3	5
1,A,X,3	L	3	1	2
1,Y,X,3	L	1		
1,A,2,X	L			1
X,A,2,3	L			1
X1,A,X2,3	L			1

Sentence Type: Dative Passive

Correct Pattern	0 dB S:N	-3 dB S:N	-6 dB S:N
3,A,1,2	54	55	43

Error Pattern	Type	0 dB S:N	-3 dB S:N	-6 dB S:N
1,A,2,3	S	3	1	1
1,A,3,2	S	1		
1,A,2	S		1	
3,A,2,1	S			2
3,A,1	S			1
3,Y,1	S			1
1,A,X1;X1,Y,3	S			1
3,Y,1,2	L	1	1	3
3,A,1,X	L		1	4
3,Y,X,2	L		1	
X,A,1,2	L			3
X,Y,1,2	L			1
3,#,#	O	1		

Sentence Type: Co-ordinated

Correct Pattern	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
1,A,2;1,B,3	51	44	32

Error Pattern	**Type**	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
2,B,3;1,A,2	S		2	1
1,A,2;3,B,1	S		1	1
1,A,2;2,B,3	S		1	3
1,A,X;1,Y,2	S		1	
2,B,1;2,A,3	S		1	
1,Y,2;2,B,3	S			4
2,A,1;1,B,3	S			1
X,Y,1;1,B,3	S			1
X1,Y,1;X1,B,2	S			1
1,A,2,X	S			1
1,A,2,3	S			2
1,A,X;1,B,3	L	2	1	1
1,Y,2;1,B,3	L	2	2	2
1,A,2;1,Y,3	L	1	4	5
1,B,2;1,A,3	L	1		
1,A,2;1,B,X	L	1		2
X1,A,2;X1,B,3	L	1		
1,Y1,2;1,Y2,3	L	1		
1,Y,2;1,A,3	L		1	
1,A,2;1,A,3	L		1	
1,A,2;1,Y,X	L			2
1,A,2;1,#,3	O			1
1,A,2;2,#,3	O		1	

Sentence Type: Subject-Object Relative

Correct Pattern	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
2,A,1;1,B,3	38	37	24
1,B,3;2,A,1	1		
TOTAL	39	37	24

Error Pattern	**Type**	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
2,A,1;2,B,1	S	2		
2,A,1;2,B,3	S	2	3	2
2,A,1	S	2		
1,Y,2;2,B,3	S	1	1	
2,A,1;3,B,1	S	1	1	
1,A,2;1,Y,3	S	1		
1,A,2;1,B,3	S	1	2	
1,B,3	S	1		1
3,A,2	S	1		
2,A,1;2,Y,3	S		1	
2,A,1;3,Y,2	S		1	
2,A,X;2,B,3	S		1	
2,A,1;2,Y,X	S		1	
1,Y1,2;2,Y2,3	S		1	
1,A,2;2,B,3	S			2
2,A,1;1,B,2	S			1
1,A,2;2,Y,3	S			1
2,A,1;2,B,X	S			1
2,A,1;X,Y,1	S			1
X,A,2;2,B,3	S			1
1,B,2;X,Y,2	S			1
1,Y,3	S			1

Sentence Type: Subject-Object Relative (cont.)

Error Pattern	Type	0 dB S:N	-3 dB S:N	-6 dB S:N
X, A, 1	S			1
2,Y,1;1,B,3	L	4	1	7
2,A,1;1,Y,3	L	2	6	5
2,B,1;1,A,3	L	1	1	1
2,A,1;1,B,X	L	1		3
2,B,1;1,B,3	L	1		
X,A,1;1,B,3	L		1	
X,Y1,1;1,Y2,3	L		1	
2,A,1;1,Y,X	L			1
2,Y,1;1,B,X	L			1
1,B,3;2,Y,1	L			1
X,Y,1;1,B,3	L			1
#	O		1	2
#,B,#	O			1

Sentence Type: Object-Subject Relative

Correct Pattern	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
1,A,2;2,B,3	19	18	11
2,B,3;1,A,2	28	27	21
TOTAL	47	45	32

Error Pattern	**Type**	**0 dB S:N**	**-3 dB S:N**	**-6 dB S:N**
1,A,2;1,B,3	S	3	3	2
1,B,3;1,A,2	S	1		
1,B,3;1,Y,2	S		2	
2,Y,1;1,B,3	S		1	
1,A,2;1,Y,3	S		1	
2,B,3;2,A,1	S		1	
1,A,2;3,Y,1	S		1	
1,Y,2;1,B,3	S			2
2,Y,3;3,A,2	S			1
1,A,2;2,B,1	S			1
1,A,3;3,Y,2	S			1
2,B,3;1,A,2	S			1
1,A,2;3,A,2	S			1
1,A,2;1,A,3	S			1
1,Y,2;1,B,3	S			1
1,Y,2;1,B,X	S			1
1,A,2,3	S			1
2,B,3	S			1
1,Y,2,3	S			1
1,A,2	S			1
3,A,1	S			1

Sentence Type: Object-Subject Relative (cont.)

Error Pattern	Type	0 dB S:N	-3 dB S:N	-6 dB S:N
2,B,3;1,Y,2	L	2		2
1,A,2;2,Y,3	L	2	2	2
2,Y,3;1,A,2	L	1	1	2
X1,B,3;1,A,X1	L	1		1
X1,B,3;1,Y,X1	L	1		
X1,Y1,3;1,Y1,X1	L	1		
2,B,X;1,A,2	L		1	
1,A,2;2,B,X	L		1	
1,Y1,2;2,Y2,3	L			1
1,A,X1;X1,B,3	L			1
1,A,X1;X1,Y,3	L			1
#	O		1	1
2,B,3;2,Y,#	O	1		
1,#,3	O			1