CHAPTER I

INTRODUCTION

This thesis reports an experimental study of one specific mechanism of encoding process in the perception of speech. There are three major inter-related reasons derived from basic discoveries in the fields of human memory and phycholinguistics for the interest in experimentation and investigation of such mechanism. The first reason concerns the importance of vocal language in human communication systems in the modernized world. Speech is constantly used as a tool essential to our daily lives, and has become an efficient system for the exchange of ideas. Almost all of the telecommunication systems in the industrialized societies are progressively developed to transmit speech signal in order to send message which can be instantaneously and correctly comprehended. However, it is not always easy to communicate some complex ideas through the use we make of speech and many arguments arise through misunderstandings.

The second reason concerns the naturalistic approach. Owing to the fact that speech is naturally learned and commonly used by natives, those experimental designs which consist of non-sense syllables in the avoidance of accounting for cultural, nativistic and semantic factors may induce many arguments when their findings are inclusively concluded as a principle of natural speech perception or memory for meaningful materials. Bartlett (1932) criticized the Ebbinghaus tradition on the grounds that the use of non-sense material confined itself to a highly artificial situation.[1] This criticism should be cautiously considered in those experimental designs concerning the complexities of human information processing and memory.

The third reason concerns the dualistic point of view which was derived from the classical work of the early French philosopher, René Descartes (1596-1650). In brief, man has a mind but a mechanically operated body.[2] For this reason, a dual set of principles has to be considered in accounting for human nature of perception of speech, the physical and psychological nature. Since a substantial body of research in the past century has been directed to the physical nature of human auditory system which arose as a science of otology early before the Renaissance and became widespread studied throughout the anatomical, physiological and neurological aspects of the auditory system, and since the psychological part has been only recently brought into serious study, as a consequence, the imbalanced knowledge of speech perception has been undiscovered the mystery of internal mechanism for information processing which communicates him to the outside world and to others. Presently, it is assumed that there are a number of encoding processes, systems of storage or memory and some decoding processes. All of them are hypothetical structures in the study of verbal behavior. These interlocking hypothetical structures and processes play an important role in most of the theories of speech perception and human memory developed by

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[1]Alan D. Baddeley, The Psychology of Memory (New York: Basic Books, 1976), p. 9.

[2]David L. Horton and Thomas W. Turnage, Human Learning (New Jersey: Prentice-Hall, 1976), p. 3.

contemporary psychologists and psycholinguists. Perhaps the understanding of mechanism of encoding process, to know in what form and how the speech signal is encoded and stored, may be the key to the far reaching psychological breakthrough which provides a system of the most efficient speech communication.

Perception of Speech

Human utterances, the sound waves with a frequency spectrum in a range of 85-1,100 hertz[1] produced by human vocal tract, are perceived in a different manner from other audible sounds. Speech is a special kind of auditory stimulus which has a multidimensional nature varying in a complex way as a function of frequency, amplitude and time. Moreover, speech signal passes on many levels of internal processing which is an active process concerning not only biological activity but also activity related to semantic and syntactic aspects. A word or part of a word which is highly probable in the context of a sentence will be heard when the acoustic cues for the word are minimal or even completely absent (Warren, 1970).[2] This phenomenon of context-dependent perception of speech signal strongly suggest that speech is not processed by utilization of one-by-one acoustic cues or string of phonemes entering

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[1] S.S. Stevens, Fred Warshofsky, Sound and Hearing (Amsterdam: Time-Life International, 1973), p. 194.

[2] R.M. Warren, "Perceptual Restoration of Missing Speech Sounds," Science 167 (1970): 392-393.

through the auditory system. Kussat (1974)[1] investigated the relationship between rate of presentation of meaningful verbal materials and amount of information retained. He concluded that there were some subjects who showed no appreciable loss of information up to the rate of presentation between 200-250 words per minute compared to the 150 words per minute presentation rate which represent approximately normal speaking rate. The research in psychophysics showed that processing discrete sounds at that rate would overreach the temporal resolving power of the ear. It appeared that human ability to process speech was not dependent upon the assumption of an alphabetic sequence of sounds. Furthermore, Liberman et al. (1967, 1970, 1972) conducted a number of experiments, concerning parallel transmission of phonemes, by using synthetic spectrogram. The general conclusion is that the phonemes of the syllable are transmitted in parallel, and there is no simple stringing together of acoustic elements similar to what we find in handwriting. There is no simple correspondence between the phoneme and any particular segment of the syllable because several phonemes have been encoded into the same segment of the signal. It is argued that speech signal is a complex code and the perceptual encoding occurs almost simultaneously at several different levels of the nervous system from the peripheral sensory receptors to the highest levels of conceptual thought.[2]

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[1]Reinhart G. Kussat, "Information Retained as a Function of Time-Compressed Speech," Dissertation Abstracts International 35 (December 1974): 3526 A.

[2]David L. Horton and Thomas W. Turnage, Human Learning (New Jersey: Prentice-Hall, 1976), pp. 292-293.

Coding

The concept of coding generally refers to a process by which individuals transform stimulus inputs and store the results of the transformation in memory. In the case of speech coding, Cole and Scott(1974)[1] reviewed experimental research and theories of speech perception and suggested that there were at least three qualitatively different types of cues involved in the simultaneously identification of stimulus inputs; they are invariant cues, the acoustic cues which accompany a particular phoneme in any vowel environment, context-dependent cues e.g. frequency transition, and the cues provided by the waveform envelope. This suggestion leads to the conclusion that speech wave is highly redundant, i.e. multidimentional cues of the speech wave convey message and if some of the cues are destroyed, the remaining cues are sufficient to convey the message. The next problem is how these cues are encoded and stored.

Evidences that suggested the concept of coding were initially observed in the discovery of the span of immediate memory. Wundt(1905)[2] observed that the span was about six "simple impressions", whether they were digits, letters, words or unrelated lines. When items were grouped, however, the span increased greatly. Shannon (1948)[3] introduced

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[1] R.A. Cole and E. Scott, "Towards a Theory of Speech Perception," Psychological Review 81 (1974): 348-374.

[2] Alan D. Baddeley, The Psychology of Memory (New York: Basic Books, 1976), p. 110.

[3] John Beishon and Peter Zorkoczy, The Human Component Speech Communication and Coding (Buckinghamshire: The Open University Press, 1971), p. 34.

mathematical concept of information measurement in the unit of "bit" (binary digit) which was defined by the expression; $I = \log_2 n$, where $\underline{I}$ was the number of bits of information and $\underline{n}$ was the reciprocal of the probability of correctly received message. Hayes (1952)[1] and Pollack (1953)[2] tried such concept in memory span and concluded that it was not constant for bits. Miller (1956)[3] reported in an influential paper that memory span was "The magical number seven, plus or minus two" and he proposed the unit of "chunk" to refer to coding unit in memory. The concept of chunk was extensively supported by a test performed by Simon (1974)[4] He used a ratio test hypothesis and the results showed a constancy in the capacity of memory span in the formula; $R_1/R_2 = F_1/F_2$ where R_1 and R_2 were the number of recalled items in type I and type II materials, F_1 and F_2 were the number of items that could be learned in a given time.

According to the notion of chunking, meaningful materials can be recognized and held together by fewer relationships than the less meaningful materials, thus it is the efficient use of the fewer coding units that underlies the differences in recall meaningful materials rather than the nonsense materials or unrelated items.

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[1] J.R.M. Hayes, "Memory Span for Several Vocabularies as a Function of Vocabulary Size," in Quarterly Progressive Report (Cambridge, Mass.:Acoustics Laboratory, Massachusetts Institute of Technology, 1952).

[2] I. Pollack, The Assimilation of Sequentially Encoded Information," American Journal of Psychology 66 (1953): 421-435.

[3] G.A. Miller, "The Magical Number Seven, Plus or Minus Two : Some Limits on our Capacity for Processing Information," Psychological Review 63 (1956): 81-97.

[4] H.A. Simon, "How Big is a Chunk?," Science 183 (1974):482-488.

Acoustic-Semantic Encoding and Coding Process in Speech Perception

Conrad (1964)[1] reported an experiment which assigned the subject to write down immediately after the presentation of six letter strings and the data was analyzed for the consideration of the intrusion errors. The results suggested that short-term memory employed an acoustic-phonetic rather than semantic code. The results and conclusion were confirmed by the work of Wickelgren (1966). In a series of experiments, Baddeley (1966)[2] showed that acoustic similarity of items is more likely to produce interference in short-term tasks, where as semantic similarity leads to marked interference in long-term tasks. Such results was also reported by Kintsch and Buschke (1969)[3]. It seemed that the suggestion of selective auditory coding in short-term memory and selective semantic coding in long-term memory would settle down the issue of coding unless there was further evidence showed that semantic coding was demonstrated in short-term memory when the task required the subjects to process semantic characteristics of the material. Shulman (1972)[4] presented the subject a list of words which were to be remembered and then a test word

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[1] R. Conrad, "Acoustic Confusions in Immediate Memory," British Journal of Psychology 55 (1964): 75-84.

[2] A.D. Baddeley, "The Effect of Semantic Similarity on Retroactive Interference in Long and Short-Term Memory," Journal of Verbal Learning and Verbal Behavior 5 (1966): 417-420.

[3] W. Kintsch and H. Buschke, "Homophones and Synonyms in Short-Term Memory," Journal of Experimental Psychology 80 (1969): 403-407.

[4] H.G. Shulman, "Semantic Confusion Errors in Short-Term Memory" Journal of Verbal Learning and Verbal Behavior 1(1972): 221-227, quoted in Robert C. Calfee, Human Experimental Psychology (New York: Holt, Rinehart and Winston, 1975), p. 351.

was presented with either of the two questions: Was this word in the list? or Was a word with the same meaning in the list?, therefore the subject was persumably forced to code the list according to word meaning along any other codes. The results supported that there was semantic coding in short-term memory. The controversial issue about selective coding in memory system needs more clearcut explanation on the implicit coding mechanisms used in memory.

Besides Shulman (1972) 's demonstration of semantic content in short-term memory(STM) previously cited, evidences for semantic representation in STM has been found in other ways. Wicken et al. (1972) [1] used a release from proactive interference(PI)paradigm to demonstrate that shift in meaning led to the release from PI effect. They concluded that semantic aspects of the to-be-remembered items, and not just acoustic presentation, were stored in STM. Baddeley (1972) criticized those findings and conclusion of semantic STM that it was resulted from the subjects' use of retrieval strategies-techniques and rules that were stored in long-term memory (LTM). This criticism was supported by an empirical evidence on a retrieval-from-LTM explanation of PI release provided by Gardiner, Craik and Birtwistle (1972)[2].

The previously cited results and explanation seem to violate the simplicity of the duplex theory of memory in which many arguments arise through the variability and perhaps inadequacy of the derived hypotheses. To assume the storage portion of STM where material is stored in some rote manner, it seems unlikely that semantic content plays an important

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[1]Roberta L. Klatzky, Human Memory: Structures and Processes (New York: W.H. Freeman and Company, 1975), p. 126.

[2]Ibid.

part. On the other hand, if we consider that STM work space and particularly the role that LTM plays in performing such work as chunking, then we are considering an essentially semantic portion of STM. It is indicated that many tasks which require short term storage also require long term component. The idea of interaction between STM and LTM aids to accomodate the proposal that semantic information can be encoded in STM while the act of short-term encoding which involves LTM can be considered as a form of STM operation.

An encouraging technique developed in the Soviet Union to study semantic generalization came from the study of conditioned response. Luria and Vinogradova (1959)[1] 's work is specially interesting in that it seems to reveal levels of relatedness of meanings in semantic fields. Subjects were given electric shock upon the presentation of a given word in a series, and the generalization of vasomotor responses to other words was tested. It was found that subjects made an involuntary defense response (vasoconstriction of the blood vessels of both the finger and the forehead) to words close in meaning to the word on which they received shock, and that they made an involuntary orienting response (vasoconstriction in the finger and vasodilation in the forehead) to words more distantly related to the critical word. For example, if a subject was given a shock to the word violin, he made a similar defense reaction to such words as violinist, bow, string, mandolin, and others. He made an orienting response to names of stringless musical instruments, such as accordion and drum, and to other words connected with music, such as

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[1] Dan I. Slobin, Psycholinguistics (New York: Scott, Foresman and Company, 1971), p. 84.

sonata and concert. In addition, of course, there were neutral words to which the subject made no autonomic response. Shvartz (1964)[1] used a photochemical response, reduction in the sensitivity of peripheral vision, in response to a flash of light. With a word as conditioned stimulus, response will generalize to words of closely related meaning. But words of similar sound only at first produce the conditioned response, and then become differentiated and cease to do so. Thus a response conditioned to the Russian word doktor (doctor) will be evoked by a word like vrach (physician), but not by a word of similar sound but unrelated meaning, like diktor (announcer). Shvartz considered synonyms, such as doctor and physician, as identical stimuli, since each of them, though with different sounds, call into play the same cortical connections established in previous experience in medical contexts. In the study of language encoding mechanism, Motley (1970)[2] used an experimental paradigm based upon "semantic conditioning". As a conditioned stimulus, the subjects were presented with a word accompanied by a unconditioned stimulus, such as a loud blast noise, capable of eliciting some unconditioned response, such as a change in heart rate. With the removal of the unconditioned stimulus, it was generally found that the conditioned response is elicited not only by conditioned stimulus word but also words similar in meaning. Most importantly, the test words were not presented to the subjects by the experimenter, but rather were encoded by the subjects themselves. Encoding was induced by asking the

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[1]Dan I. Slobin, Psycholinguistics (New York : Scott, Foresman and Company, 1971), p. 84.

[2]M.T. Motley, "Semantic, Phonological and Syntactic Conditioning in Language Encoding," Dissertation Abstracts International 32 (July 1971): 413 a.

subjects to read sentences with blanks at the end, and fill in those blanks. The cloze sentences were designed to elicite the desired conditioned stimulus and generalized words. The results led to the conclusion of a lexicon organized around semantic-phonological-syntactic hierachy. For general conclusion on semantic conditioning, it is suggested that semantic encoding occurs immediately after the stimulus perception and subjects were unconcious to such process while they responded consistantly on an involuntary response basis.

Posner and Warren (1972)[1] reviewed various studies concerned with coding and suggested three different types of code; a physical code which contains acoustic structure that characterized stimulus presentation, a name code which consists of the name of the stimulus words and related words which refer to the same representation though different in acoustic structures, a code resulting from concious processing during the period of operation. This suggestion implies three levels of coding which resulted from the same stimulus input and the operations for physical code and name code are passive and automatic while the operation for the third type code is active and concious. Bower (1972)[2] reviewed coding operation and suggested four main types of coding operations; coding by stimulus selection, coding by rewriting, coding by componential description and coding by elaboration. According to types of code suggested by Posner and Warren and types of coding operation suggested by Bower, speech wave which contains multidimentional cues in a stimulus

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[1]David L. Horton and Thomas W. Turnage, Human Learning (New Jersey: Prentice-Hall, 1976), p. 250.

[2]Ibid., p. 252.

input is transformed into three levels of coding by some of the four types of coding operations. Thus the size of a chunk is related to the economy of coding operation and the level of coding type is affected by timing and vice versa.

Memory Span and Implication on Psycholinguistic Study

Chomsky (1957)'s revolutionary views on language had an influence on both linguistics and psychology of language. He argued that simple S-R associative model and information processing model were inadequate to account for the fact that language is essentially "creative", in that we are continually understanding and producing sentences which we have never before encountered. He proposed a model called "Tranformational Grammar" which could generate any grammartically permissible sentences in the language. But such model represents a formal description of the language rather than the description of the way in which people actually use the language, or in Chomsky's terminology, linguistic competence rather than performance. However, his contribution provided some interesting hypotheses on psycholinguistic interpretation which extended the investigation on psychology of language. A good review on Chomsky's work is available in Lyons (1970).[1]

Tulving and Patkau (1962)[2] generated lists of twenty-four words,

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[1]J. Lyons, New Horizons in Linguistic (New York: Penguin Books, 1970).

[2]E. Tulving and J.E. Patkau, "Concurrent Effects of Contextual Constraint and Word Frequency on Immediate Recall and Learning of Verbal Material," Canadian Journal of Psychology 16 (1962): 83-95, quoted in R.L. Klatzky, Human Memory: Structures and Processes (New York: W.H. Freeman and Company, 1975), p. 78.

varying in approximation to English and presented to subjects for immediate recall. They defined a unit called "adopted chunk" which was a grouping of items in output that matched a sequence of input. For example if an input list included "saw the football game will end at midnight on January" and subject recalled " the football game saw at midnight will end " he would be judged to be using the adopted chunks: (1) "the football game" (2) "saw" (3) "at midnight" (4) "will end". Such units were labeled chunks because the fact that each was grouped at recall in the same order as it had been presented suggested that the words within the adopted chunk were grouped together (chunked) by the subject at the time of presentation. The results provided some interesting evidence for the use of chunking in remembering the word lists. Though subjects always recalled about the same number of chunks, their ability to form larger chunks led to better recall performance. It was concluded that something about the structure of English leads to chunk formation.

Miller and Isard (1963)[1] carried out an experiment in which subjects were assigned to memorize sentences, all 22 words in length, but varying degree of self-embedding. They found that sentences with three or four self-embeded relative clauses were difficult for all subjects. They concluded that it was the burden that placed on immediate memory, i.e. the nouns which occured early in the sentence were related to the verbs which occured late in the sentence. Thus short-term memory span is an extremely important performance variable. A further step in applying memory span in psycholinguistic studies was demonstrated in the

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[1]G.A. Miller and S. Isard, "Some Perceptual Consequences of Linguistic Rules," Journal of Verbal Learning and Verbal Behavior 2 (1963): 217-228.

original experiment conducted by Savin and Perchonock (1965)[1] to test the displacement hypothesis in the memorization of sentences varying in syntactic structure which based on tranformational grammar. Their hypothesis and prediction were derived from the well-established facts in psychology; the capacity of short-term memory is limited to about seven chunks of information. If the list exceeds the capacity, there will not be enough space for the exceeding items.

Savin and Perchonock predicted that grammatical tags as passive, negative and question would take up more space in immediate memory than the active sentence. They assigned subjects to memorize sentences and each sentence followed by a list of words which was also to be memorized, the results are clear and dramatic as shown in the following table.

Sentence Type	Mean number of Words Recalled
Active declarative	5.27
Question	4.67
Passive	4.55
Negative	4.44
Negative question	4.39
Negative passive	3.48
Passive question	4.02
Negative passive question	3.85

The primary dependent measure was the number of words recalled. This measure allowed on estimated number of displacement for the various transformations by subtraction, for instance, the difference between word recall for ACTIVE and PASSIVE = 5.27-4.55 = 0.72 is the memory space in words for passive transformation. Savin and Perchonock concluded that various grammatical features of English sentences were encoded in immediate memory apart from one another and apart from the rest of the sentence. But their conclusion was argued on the ground that the semantic factor was neglected in the interpretation (Calfee, 1975).[1]

Johnson (1968)[2] demonstrated that syntactic rules led to chunking. He assumed that in learning the sentences, the subjects would re code, or chunk, the words into higher order units. Within any unit, the word should be more dependent upon one another than upon the words in any other unit. He predicted that recall of one word within unit should be more highly related to recall of other words within that same unit. The transitional-error-probability (TEP) was calculated and the results clearly supported the hypothesis that chunking can be based upon syntactic rules. However, chunking could be based upon semantic factor. Tejiran (1968)[3] generated new lists of words from approximations to English by substituing, for words in the original lists, new words of the same grammatical class (noun, verb, adverb, and so on). The substitution of a new word changed the semantic structure of the list but left the syntax

[1]Robert C. Calfee, Human Experimental Psychology (New York: Holt, Rinehart and Winston, 1975), p. 469.

[2]N.F. Johnson, "Sequential Verbal Behavior," in Verbal Behavior and General Behavior Theory ed, ed. D.L. Horton (New Jersey: Prentice-Hall, 1968), quoted in R.L. Klatzky, Human Memory: Structures and Processes (New York: W.H. Freeman and Company, 1975), p. 76.

[3]E. Tejiran, "Syntactic and Semantic Structure in the Recall of Orders of Approximation to English," Journal of Verbal Learning and Verbal Behavior 7 (1968): 1010-1015.

unchanged. His results indicated that such changes had no effect on the number of words recalled for orders of three and below. This indicates that semantic content of first-to-third order list is not an important factor in recall. However, above the third order, semantics were much more important, and word substitutions led to decrease in recall.

Kintsch, Crothers and Jorgenson (1971)[1] conducted an experiment on a version of Peterson-type-short-term memory with retention intervals of 3,6 and 24 sec. In one condition, subjects simply read the three stimulus nouns as they were presented. In other conditions, subjects had to respond to the meaning of each individual noun, irrespective of the meaning of the other words : subjects had to classify the words or to form a brief phrase by pairing each stimulus noun with an appropriate adjective or verb. Finally, a letter-counting condition was used. Secondary memory was unaffected by the experimental tasks. Strong interference with primary memory was obtained. In a fourth experiment, subjects formed a phrase linking the three stimulus words. Recall was excellent for all retention intervals. It was concluded that semantic processing of words does not facilitate retention, unless it leads to grouping or chunking of the learning material.

It can be concluded from the previously cited evidences that chunking in STM uses information from LTM. Chunking process can occur under some conditions; first, the material to be chunked must come into STM at approximately the same time. Second, chunking should be

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[1]Walter Kintsch, E.J. Crothers and C.C. Jorgenson, "On the Role of Semantic Processing in Short-Term Memory," Journal of Experimental Psychology 90 (1971): 96-101.

facilitated to the degree that to-be-chunked items have some inherent relationship that permits them to form a unit. In particularly, if a group of stimuli has a structure that matches some code in LTM, it might be expected that stimuli form a chunk corresponds to that code. It can also be concluded that both semantic and syntactic factors play an important role in encoding process of speech perception.

The Present Experiment

The previous review of literature shows a substantial body of research upon perception of speech and verbal coding process in human memory system. It is the lacking of investigation upon mechanism of encoding process of multidimentional-cue-speech-signal inputs;whether it is serial or parallel and delayed or prompt in the chunking process, that conceals some underlying explanation on the controversial issue on semantic coding in STM and perhaps such understanding may verify some of the theories of psycholinguistics. In attempting to reveal some aspects of such mechanism, the following experiments were designed with a paradigm based upon displacement hypothesis and differential processing time hypothesis. The investigation was focused on "The Effect of Modifier Positions upon Perception and Short-Term Memory".

Assumption

There were three assumptions underlay the hypothesis and paradigm. The first assumption was derived from the information processing model and the duplex theory which divided nonsensory memory into two stores, STM and LTM. The second assumption was on the limited capacity of STM with average size of 7 ± 2 chunks. The third assumption was on the chunking process in which stimuli could be grouped and stored in a chunk unit.

Hypothesis

The modifier position in verbal language can effect semantic encoding process in STM in the way that chunking economy will be different due to the mechanism which is serial and delayed when the modifier comes before noun, but when the modifier follows noun the mechanism is instantaneous; thus the latter provides more efficient code in the perception of speech which results both in speed and accuracy.

Paradigm

In order to verify the proposed hypothesis, two inter-supporting experiments were specially and carefully designed to obtain data of verbal performance on varied-modifier-position tasks. In one experiment, based upon displacement hypothesis, the verbal presentation of items, consisted of a noun with three modifiers in various positions, were followed by a string of digits exceeding the STM span, and immediate-serial recall of both words and digits was the required task. Dependent variable was the displacement of the followed-digit recall, independent variable was the modifier position in the to-be-remembered item. Data would be statistically calculated for the comparison of amount of chunks displaced according to the mechanism of chunking process . In another experiment, based upon differential processing time hypothesis, reaction time of verbal-visual matching of the varied-modifier-position items would be considered for the differential processing time. Independent variable was the modifier position in the to-be-perceived item, the dependent variable was the perceptual speed. Performance error analysis in both of the two experiments would be inclusively undertaken in the consideration and interpretation of the obtained data.

<u>Prediction</u>

In the immediate-serial-recall paradigm, the quantitative results are predicted as in the following statements:

1. The increment of word-digit-recalled capacity varies as a reciprocal function of the number of modifiers prior to noun in the to-be-remembered-items (TBRI), or in a mathematical statement,

$$C_r \propto \frac{1}{n_m} \qquad \text{........(1)}$$

where C_r = recall capacity

n_m = number of modifiers prior to noun

2. The conditional error probability of each pattern is much more than a critical value of 0.5 (chance level), or in a mathematical statement,

$$P(\bar{M}|\bar{N}) \gg 0.5 \qquad \text{........(2)}$$

which implies that

$$P(\bar{M}|\bar{N}) \gg P(\bar{M}|N) \qquad \text{........(3)}$$

where $P(\bar{M}|\bar{N})$ = error probability of modifier given that noun is <u>not</u> recalled.

and $P(\bar{M}|N)$ = error probability of modifier given that noun is recalled.

3. The increment of conditional error probability varies as a reciprocal function of the number of modifiers prior to noun, or in a mathematical statement,

$$P(\bar{M}|\bar{N}) \propto \frac{1}{n_m} \qquad \text{.......(4)}$$

In the verbal-visual matching paradigm, the quantitative results are predicted as in the following statement;

The increment of reaction time of verbal-visual matching varies as a linear function of the number of modifiers prior to noun in the to-be-perceived-items (TBPI), or in a mathematical statement,

$$T_{vvm} \propto n_m$$

where T_{vvm} = verbal-visual matching reaction time

and n_m = numbers of modifiers prior to noun