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A COMPONENTIAL AND ELECTROPHYSIOLOGICAL ANALYSIS OF SKILLED READING

by

William M. Dince

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1988

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

1/26/88
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Abstract

A COMPONENTIAL AND ELECTROPHYSIOLOGICAL ANALYSIS OF SKILLED READING

by

William M. Dince

Advisor: Professor Jeffrey Rosen

Reading is a complex cognitive skill which involves learning to use the visual symbols, or orthography, of words to guide the access of phonetic, semantic, and syntactic information. The present study investigated the relationships between the behavioral and electrophysiological responses elicited while subjects performed tasks that represented some of the processing requirements of skilled reading. A group of highly skilled readers (mean education = 18 years) performed a task requiring comparison of word pairs based upon orthographic, phonetic, semantic, or syntactic characteristics. The stimuli were presented sequentially, in quasi-random order, with a pre-trial cue identifying the required processing. Subjects performed the tasks over three sessions, providing the time-on-task to reach a steadier state of behavior for the analysis of reaction time and evoked potential measures. Reaction time and accuracy measures were collected for all sessions, evoked

potential measures were collected to the pretrial cue in session three. A fourth session was constructed to investigate the effects of uncertainty on responses.

The results supported a proposed organization of the visual language system. Further analysis demonstrated a continuum of responses could be identified, based upon individual subjects' patterns of performance. Subjects who demonstrated a pattern where performance of the task requiring phonetic processing was rapid relative to the the tasks requiring orthographic and semantic processing (G-P-C), were the most rapid and accurate on the four tasks. Subjects who demonstrated a pattern where performance of the task requiring semantic processing was rapid relative to the tasks requiring orthographic and phonetic processing (G-C-P) were the least rapid and accurate on the tasks. Errors on the Phonetic task predicted performance on all of the tasks while errors on the Category task did not. The results support the importance of efficient phonological processing in the development of skilled reading. The introduction of uncertainty slowed overall performance but did not differentially impact upon any group of subjects identified by the pattern analysis.

Evoked potential measures indicated that the latency of P2 was less for the Graphic-Phonetic-Category group than the Graphic-Category-Phonetic group. This finding

suggests the G-P-C group forms an earlier integration of visual information. No differences were found at P3 or the late negativity present in the waveforms.

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Ultimately, this work must be dedicated to Dana, my wife, my best friend, and my love. Dana has been the joy in my life that has enabled me to survive the challenges of these past years. I will never forget all that you have given me. Thank you for being there, through sickness and dissertation...

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I. INTRODUCTION

A. Statement of the Problem

An individual who acquires the skill of reading learns to use the visual symbols, or orthography, of words to guide the access of information from memory. This information can take a number of forms and will include the sounds that the word can represent, its meaning, and the ways in which the word can be grammatically related to other words.

The readers of this thesis are likely to be individuals who have become highly efficient at this complex task, for in our society, the ability to read has become indicative of being educated. But many, many individuals cannot read well, or at all. It is estimated that 33 percent of the worlds population is illiterate (Huss, 1970) and that 30 percent of high school graduates in America may be functionally illiterate (National Commission on Excellence in Education, 1983). Investigation of this skill of reading poses both an intellectual challenge, due to the complexity of the process, and the potential to better understand the normal development of the skill and the problems that many experience in its acquisition.

As I embarked on this investigation, my interest was in studying the relationships between the behavioral and electrophysiological responses elicited while subjects performed tasks that represented some of the processing requirements of skilled reading. Posner, Pea, and Volpe (1982) have stated that a cognitive system, such as that required for reading, can be described by "the brain functions that support it...the subjective experiences or processing operations to which it gives rise, or in terms of the pathologies created by breakdowns of components of cognitive systems." The use of evoked potential and behavioral measures allows for an analysis of the first two of these descriptors. Rather than study the reading process as it "breaks down", information which will be used in this study to guide the identification of the components of the cognitive system which supports reading, I have chosen to investigate this ability in skilled readers for whom it can be assumed that the cognitive system has developed to a high degree and is characterized as both proficient and efficient.

The measurement of behavioral responses to a task, while also collecting measures of the electrical activity of the brain, is based in an assumption that the brain and behavior are inexorably linked. The investigation of this linkage constitutes a new domain for researchers and, as such, early investigations need to identify cognitive systems in which behavioral measures could be

appropriately compared to related neurophysiology. There is a striking similarity here to the systems that neuroscientists develop to determine the brain mechanisms involved in behavior in animals. These investigations require the development of a model of sufficient simplicity that the relationships between behavior and physiology can be deduced. In cognitive systems, it seems appropriate to study the mental operations that are the basis for more complex behaviors (Posner et. al., 1982). In this study, the investigation focused on some of the mental operations which are necessary in identifying and understanding the written word.

B. Background

In order for an individual to become a skilled reader he must develop a reliable set of relationships between a visual form and existing knowledge about the phonology, semantics, and syntax it can represent. For these relationships to develop, the beginning reader must be able to consistently perceive a visual form and have knowledge of the phonological, semantic, and syntactic information in language. In an individual where the systems that support this knowledge are intact, repeated practice will result in the development of a set of invariant relationships which will be accessed in the course of reading.

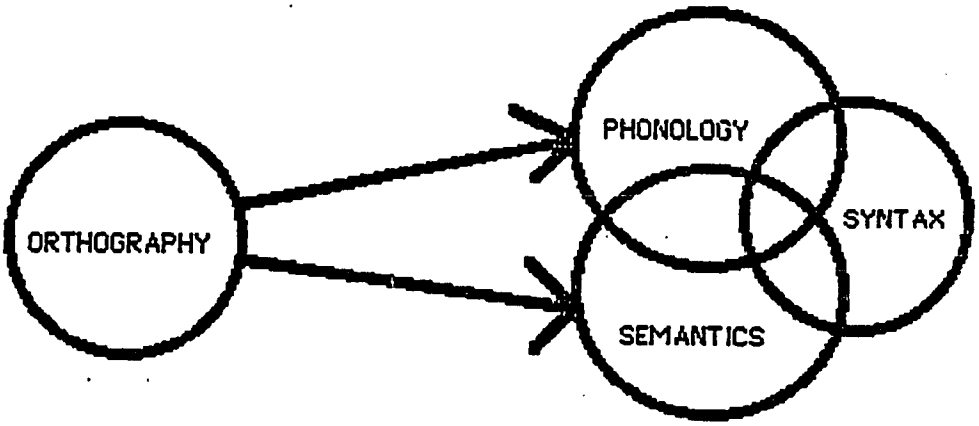
The acquisition of these relationships, or of any

cognitive skill, will require an interaction between the individual developing the ability and the environment (Gardner, 1986) For example, the individual who is learning to understand and generate spoken language requires the experience of interacting with other individuals who have acquired the skill. Practice provides the necessary time on task which, in conjunction with a set of prerequisite abilities, can promote learning and proficiency. For example, in developing spoken language, the child must have normal hearing for a variety of speech sounds, be able to visually observe the gestures of the speaker, and be able to sense the emotional tone of the verbalization (Gaddes, 1985). With repeated exposure, the child will develop a set of relationships between the sound of the words, their meaning, and their relationships to other words (see Figure 1).

Yet, the fact that so many individuals do not learn to read suggests that there are differences between the acquisition of this skill and the the ability to generate and understand spoken language. Learning to speak and understand spoken language can be considered a natural aspect of the human species. Despite extremely variable experience, both within and across languages, the child will learn to develop relationships between the phonology, semantics, and syntax of words. Reading is different in that it involves learning to relate an arbitrary set of symbols, an orthography, to the phonology, semantics, and

Figure 1

Proposed Organization of the Language Processing System in Reading



syntax of language. As such, it constitutes an invention which must be incorporated into the existing language processing system.

The child who is learning to read must first have developed an organized set of cognitive abilities (Byrd & Gholson, 1984). He must be able to distinguish and blend the speech sounds that represent words and have developed relationships to their meaning and grammatical function. The task of reading requires that an arbitrary set of symbols, an orthography, be consistently related to the information in an existing, if still developing, language system (see Figure 1). This orthography can be related to phonetic, semantic, and syntactic information. With sufficient practice relating the visual image of letters and words to the phonetic, semantic, and syntactic information they can represent, a reliable set of relationships will develop. Unlike the development of spoken language, the cognitive prerequisites for the development of reading occur later and the needed opportunities for learning are not provided by the immediate environment. As a result, the experiences necessary for reading to be acquired have been structured within our system of formal education.

When a reader views text he can be aware of these different types of interrelated information. He can be aware of the visual form (orthography), the sounds the word can represent (phonology), and/or its meaning

(semantics). In addition, the reader can be aware of the way in which the word can be grammatically related to other words in the lexicon (syntax). In different circumstances, some or all of these types of information can be used in the recognition of a word. For example, when viewing a very familiar word, the reader will be aware of its meaning. The repeated experience will enable the reader to immediately access meaning from orthography. However, upon encountering an unfamiliar word, the reader may identify the sounds it can represent and, in this way, attempt to discern its meaning. While the orthography of the word may be unfamiliar, the relationship between the sound of the word and its meaning may be available to the reader. Sufficient experience will enable the development of an association between the orthography and the meaning of the once unfamiliar word. The sophistication of the reader, therefore, plays an important role in the way in which words are recognized.

The beginning reader must learn to relate the visual form of the letter to the sounds it can represent and a relatively sophisticated knowledge of semantics and syntax (Brown, 1970; Nelson & Kosslyn, 1975). There is evidence that the beginning reader will only sample information from one source at a time. It is only with practice that information will be integrated from several sources (Byrd & Gholson, 1984). It was for this reason, in part, that the present study involved training over a number of

sessions. There is value in providing practice when using reaction time measures, as this significantly decreases the variability of responses. But the opportunity to have repeated exposure to a novel task, which requires using either orthographic, phonetic, semantic, or syntactic information, could provide an analog of the learning experience in which an individual must integrate these sources of information in successful reading.

The well-practiced, sophisticated reader has developed a set of strong associations between the orthography and meaning of words. It is possible to look at a familiar word and know what it means without conscious effort and even while performing another task. For example, it is possible to drive an automobile while reading the signs along the road. Further, it is possible to be aware of a road sign while absorbed in conversation. Once the skill of reading has been acquired sufficiently that many words can be understood efficiently and without conscious effort or intention, it can be considered to be "automatic" (LaBerge, 1980).

The fact that the access of a words meaning can be automatically derived from its orthography does not mean that one cannot consciously affect this set of relationships. While the direct access of meaning from orthography provides the most efficient means of identifying a word, the use of phonetic and syntactic information may be required. As previously discussed, a

word will sometimes be identified by relating the sounds it can represent, when there is an existing relationship between those sounds and a meaning for the word. Further, individuals can use the relationships between words comprising a sentence or phrase to aid in the identification of a word. Reading, and learning to read, can require using these different sources of information.

The efficiency which is available to the reader who can access meaning directly from orthography can be understood in the context of what Posner (1978) has called "limited capacity." Limited capacity describes the reduced performance which will occur when certain tasks are performed simultaneously. For example, he demonstrated that when a subject is instructed to focus on the phonetic properties of a letter or a word, the physical properties of the letter or word become less available. When a group of items which required similar processing were presented successively, subjects used one source of information as if the others were not available. Thus, the shifting from using one source of information in words to another, while a necessary aspect of reading, is not as efficient as the sustained direct access of meaning from orthography.

The goal of this investigation was to further understand the general organization, the structure, of the system that enables the act of successful reading. One effective approach in the investigation of such questions is through the study of mental chronometry. Mental

chronometry involves the time course of information processing. The most common method in the study of mental chronometry involves reaction time; the measurement of the time between two events. These events involve a stimulus (input) and a response (output). By measuring the time subjects require to make decisions based upon the orthography, phonology, semantics, or syntax of words it is possible to plot functions which are a representation of the performances on the tasks. It is then possible to identify and relate patterns of performance to proposed processing systems.

In cognitive tasks, such as the reading of letters and words, it has been demonstrated that different amounts of time are required to process visual, phonetic, semantic, and syntactic information in words. Even for overlearned and very familiar words, the processing requires time. If an individual is presented with a word, different tasks can require that an answer be generated based upon its form, the sounds it can represent, its meaning, or its relation to other words. It can be demonstrated that these tasks can consistently require different amounts of time to complete.

The patterns of behavior which result can be related to the processing system which has been proposed (see Figure 1). The model logically predicts certain temporal relationships between the component skills. For example, individuals should be able to complete the task

which requires only comparisons based upon orthography with the greatest speed. Further, the access to phonological and semantic information should require similar amounts of time to complete, while the syntactic task should be performed at the slowest rate.

C. Components of Visual Language Processing

The different ways in which the information in a word can be processed can plausibly be conceived of as components of the reading system. But can these components be isolated from one another and, therefore, be considered distinct subsystems? If so, what is the organization of these different components in the recognition of words.

In the investigation of the linkage between orthography and phonology, it is useful to choose stimuli that will not engage semantic processing. By requiring comparisons between letters, it is possible to create tasks which will involve graphic and phonological information. Semantic information will only be used when the task involves the membership of the letter in a class.

In a study which demonstrates that decisions about letter pairs can require different amounts of time to complete, Posner and Mitchell (1967) asked subjects to respond if two letters were the "same" or "different" to stimuli which could be both vowels, both consonants, or a combination of the two. Reaction time measures demonstrated fastest responses when stimuli were the same

according to one of these dimensions and were also identical physically (e.g. "A A"). Somewhat slower reaction times resulted when the two letters were both vowels or consonants but were not physically identical (e. g. "A a"). When the two letters only shared the same class (e. g. "A e") the reaction time was even slower. While demonstrating that different tasks can require different amounts of time to complete, this type of data does not show that the processing of the different tasks involves different subsystems which can be isolated from one another.

Support for isolable subsystems can be derived from evidence that it is possible to differentially affect the responses to tasks which require the processing of visual, phonetic, and semantic information. The evidence supports the notion that the processing of these different types of information in words occurs along parallel pathways. If the processing of phonetic information, for example, was dependent upon the complete processing of orthographic information, it would not be possible to disrupt orthographic processing without affecting the phonetic processing. In the identification of a word, while it is obvious that the visual form of the word must be perceived for processing to continue, it becomes plausible to conceive of further processing as involving separate, parallel routes.

In order to demonstrate that comparisons based on

visual and phonetic information in letters do engage subsystems which can be isolated from one another, and are not merely different stages of elaboration along a common pathway, it is necessary to show that factors which disrupt one type of comparison will not affect the others. For example, it has been demonstrated that visual comparisons are affected by the visual similarity of the letters to be matched (Cohen, 1969; Posner & Taylor, 1969) and by the rotation of the letters (Cooper and Shepard, 1973). Corcoran and Besner (1975) manipulated the size and contrast of letters and found that these visual factors affected the time required to make physical matches while having no effect on name matches. On the other hand, matches based on letter names are affected by factors such as the letter names held in short term memory (Posner & Taylor, 1969).

Cooper and Shepard (1973) rotated single letters and asked subjects to determine whether the form was a mirror image or was in its correct orientation. Results demonstrated significant effects on reaction time which were correlated to the degree of rotation. While they did not design their investigation to specifically address the effects of rotation on naming, their results demonstrate that these effects are slight. In their study, the time required to make a physical manipulation could exceed the time required to identify the letter name. The fact that it is possible to identify the name of the letter in less

time than is needed to determine its orientation provides evidence that processing of these two types of information must be occurring at the same time. It is important to consider that changes in the conditions of the task, in these cases the physical characteristics of the stimuli, can affect the way in which the individual will respond to the graphic symbol.

In order to investigate the proposed linkage between orthography and semantics, it is useful to minimize the potential for phonological processing. When words are presented in a degraded or impoverished manner, the result of low illumination and contrast, rapid presentation, or the use of a masking stimulus, studies have demonstrated an effect in which it is easier to process a word, as a unit, than identify its constituent parts. This effect was elicited by the use of a forced choice task developed by Reicher (1969) and Wheeler (1970). In this task, a subject was asked to report as many letters as he could in a briefly presented stimulus display. Immediately following presentation of the display, which consisted of one to eight letters, a masking stimulus, consisting of a pattern mask and two additional letters, was presented. A masking stimulus consists of a pattern or a flash which briefly follows the target stimulus. The mask has the effect of eliminating the iconic image of the visual stimulus (Loftus, 1982). The resulting word superiority effect, the ability to more accurately report a four letter word than

a single letter or four letters which do not comprise a word, has been reported by a number of investigators (Wheeler, 1970; Johnston & McClelland, 1973; Baron & Thurston, 1973). Johnston and McClelland (1980) and McClelland and Rumelhart (1981) have discussed the vulnerability of lower level, orthographic representations, when using pattern-masking techniques. The word superiority effect demonstrates that there are a number of levels at which the information in words can be represented.

The principal communicative function of reading involves the recognition of meaning. Evidence from the study of normal readers and of individuals who experience a dysfunction of the reading process has consistently demonstrated that there are two routes by which meaning can be derived from printed words. In the "direct access" view, meaning is derived directly from the orthography of the word (Bower, 1970; Kolers, 1970; Becker, 1980). Another view is that meaning is derived through phonological mediation. In this view, often termed "indirect access," the word is transformed into the sounds that it can represent and then proceeds to meaning (Rubenstein, Lewis, & Rubenstein, 1971; Spoehr & Smith, 1973). Finally, there have been a number of investigators who have discussed the possibility of a "dual access" system in which both phonological mediation and direct access are involved in the processing of printed words

(Meyer, Schvaneveldt, & Ruddy, 1974; Coltheart, Patterson, & Marshall, 1980; Rumelhart & McClelland, 1982; Humphreys & Evett, 1985).

There is evidence from adult individuals who have lost the ability to read, following a neurological insult, that there can be selective impairment of the reading system. These deficits can occur in the processing of visual, phonetic, semantic, and syntactic information in words (Mitchell, 1982). The reported clinical case studies divide the observed dysfunctions into subtypes of alexia and dyslexia.

Alexia was first described by Dejerine in 1891 and 1892. Since that time there have been numbers of clinical case studies which document an acquired inability to read (Benson, Brown, & Tomlinson, 1971; Hecaen & Kremin, 1977). The alexias are commonly divided into three major classifications. These include: a) literal alexia, the inability to read letters with a relatively preserved ability to read words, b) verbal alexia, the inability to read words with a relatively preserved ability to read letters and, c) global alexia, the inability to read letters or words (Albert, 1979). In other words, the observation of these individuals has resulted in classifications which are based upon a relative disruption of the ability to extract phonological or semantic information from a visual representation of a word. These inabilities to access phonetic or semantic information

from printed words have also been termed "deep dyslexia" and "surface dyslexia."

The deep dyslexic accesses meaning without showing an awareness of the phonological information in words. This syndrome was first described by Beauvois & Derouesne (1979) and later by Shallice & Warrington (1980). The deep dyslexic is unable to read aloud nonsense syllables, cannot tell if words that have different orthographies rhyme (rope-soap), and cannot determine meaning from homophonic spellings (e.g. cote for coat). The deep dyslexic can name and understand a large number of words and these words can be of complex orthography and be of low frequency. The errors which are made by these individuals will often involve the identification of a semantically related response (cat for dog). The most preserved items in the deep dyslexic are concrete and specific nouns. More abstract nouns and verbs are identified with less accuracy. The most impaired items in the lexicon are those that have grammatical function; those that are involved with syntax. These words include conjunctions, articles, demonstratives, and pronouns.

In surface dyslexia, access to meaning is based predominantly on the phonology of the word (Marshall and Newcombe, 1973; Prior and McCorriston, 1985). The success of correctly identifying a word is independent of whether it is a concrete or abstract noun, a verb, or a grammatical function word. In addition, surface dyslexics

have shown a sensitivity to word length, with long words requiring more time to identify than short words (Patterson, 1981, Henderson, 1982).

The neuropsychological data, therefore, suggests that there are functional subsystems which are involved in word recognition. The existence of surface dyslexia and deep dyslexia support the view that there are different systems which support indirect and direct word recognition. Further, this evidence supports the notion of systems which operate in parallel and not as a series of interdependent stages. Regardless of the order chosen in such a serial model, it would not be possible to interrupt an earlier stage without disruption of later stages of processing.

The different levels at which the information required for successful reading can be represented can be identified in the development of the skill. In kindergarten, the child who is learning to read will begin by generating hypotheses which have little to do with the cues which are provided by the orthography of the word (Case, 1978; Gholson, 1980). Then, by the middle of the first grade, they begin to rely more on the information which can be derived from the symbols they are attempting to decode (Rieber, 1969). The knowledge of the kindergarten child is conceptual while the first grader becomes more attuned to data-driven sources of information. These sources of information, often called

top-down and bottom-up processes, become integrated as reading develops (Frederiksen, 1979). In the reading process, bottom-up information comes from data-driven intraword sources. This information includes the individual letters, the word shape, and the word length. Complex intraword information can include orthographic regularities and letter sound generalizations (Byrd & Gholson, 1984). Top-down processing is based on information extracted from the conceptual sources of semantics and syntax. Efficient reading involves the integration of these two sources of information. The individual who is reading will generate a set of hypotheses about the information which is available from the orthography of the word. The context and knowledge driven top-down processes must be confirmed or not confirmed by information from the environment.

While all recent attempts at understanding the means by which words are recognized posit the existence of top-down and bottom-up influences, a number of them do not account for the way in which the system will stop itself from further processing. It is in response to this requirement that more recent models of word recognition have included the verification set. In verification, a set of likely entries in memory are compared against the input. If there is a match the process terminates. If no match is found in the verification set, a new set of entries can be tested. The skilled reader will use the

many sources of information in words to efficiently generate top-down, conceptually driven hypotheses which will match the perceived bottom-up information.

This investigation was designed in an effort to identify the relative contribution of the different component skills that provide the information used in the recognition of words. As graphic, phonetic, semantic, and syntactic information can be available to the reader one must consider whether or not there is a configuration of these subskills that determines who will be able to rapidly and accurately identify words. A possible answer to this question can be identified through, once again, considering the developmental course of the acquisition of reading.

The development of reading skills is based upon the integration of intraword information (orthography and phonology) with conceptual information (semantics and syntax). Research on children who have had difficulty learning to read has demonstrated that poor readers rely primarily on contextual information (Biemiller, 1970), and encode semantic features but not phonetic features (Byrne & Shea, 1979). Farnham-Diggory and Gregg (1975) demonstrated that reading performance related to differences in the ability to rehearse and retrieve phonetic information. Poorer readers, therefore, are less able to use intraword sources of information in word recognition. It is possible that this results in a limit

to the integration of intraword and contextual information (Byrd & Gholson, 1984). The ability to process the phonetic information in words would therefore be a major factor in the development of rapid and accurate word recognition.

When an individual reads a word there is orthographic, phonological, semantic, and syntactic information available to be processed. Further, it can be demonstrated that the systems which support access to meaning by direct and indirect routes can be considered functionally separate. But what is the relative contribution of these different types of information when an individual is engaged in the task of reading? The answer to this question depends upon the sophistication of the reader and the requirements of the task he or she is confronting. Highly sophisticated readers will access meaning directly from the visual form of the word, only using other strategies with complex material. However, instructions which specifically require a particular type of processing, such as comparing words that are spelled differently but sound the same, can create a setting in which even highly sophisticated readers will resort to phonological processing in identifying words.

There exist numerous factors which can differentially affect the processing of the orthographic, phonological, semantic, and syntactic information in printed words. These influences will result in biasing the

system towards relying on particular sources of information in words. For example, it is possible to affect the processing of orthographic information in words by altering the illumination, orientation, contrast, and the rate or nature of the presentation of the stimuli. When stimuli were presented simultaneously on a screen, letter matching was faster than word matching (Marmurek, 1977). If the task can be completed by only accessing the orthographic information, the individual will do so. However, when individuals are required to distinguish between words and non-words, or to identify stimuli verbally, phonological information will be processed. Given the opportunity to read words with which the reader is highly familiar, the meaning of the word will be accessed directly from its visual form.

When an individual is learning to read, he can have access to the graphic, phonetic, semantic, and syntactic information in a word. If the word is familiar he will access its meaning directly. If it is unknown, he can use the sounds it can represent in an attempt to identify the word. Further experience with the word will enable him to directly access meaning from the visual form. Further, the relational properties between words, the syntax, can aid in the identification of the correct meaning of a word. But without the use of phonology, it would not be possible to decode most of those words which have not been seen before. Phonology, therefore, becomes an important

mechanism in learning to read.

Liberman (1983) develops an argument which speaks to the preeminence of phonology in the development of skilled reading. While it is possible to create a language in which the characters refer not to the phonological units of speech, but to the words themselves, the resulting system cannot support a complex language. Unknown words could not be identified. An understanding of the phonological units of speech and their relationship to the graphic representations of words becomes necessary to develop into an efficient reader. Liberman (1973) has shown that the ability to segment words in pre-readers can be used to predict their reading achievements a year later. Numerous investigators have supported the relationship between reading difficulties and various measures of phoneme analysis (Mitchell, 1982).

It is possible to conceive of individuals relying heavily on the phonological analysis of words while learning to read. This process requires effort and has been shown to interfere with access to other sources of information in words. With repeated exposure, individuals dispense of this controlled access of phonological information allowing meaning to be derived directly from the visual representation of the word. The efficiency of the ability to phonologically decode words would therefore play an important role in determining the efficiency of the individual who is learning, and has learned, to read.

D. Evoked Potential Measures

The evoked potential, a measure of the electrical activity of the brain which is time locked to an event, allows real time examination of some of the processes that underlie language and cognition (Kutas, in press). When the evoked potentials are collected to two different behavioral tasks, as with reaction times, they can be compared chronometrically (Posner 1978; Posner et. al., 1982), as well as by the presence or absence of significant waveforms. Reaction time measures, collected while subjects perform cognitive tasks, can reflect the outcome of information processing. The evoked potential, on the other hand, can provide a view of the processing as it is unfolding.

The evoked potential or event-related potential is a component of the electroencephalographic (EEG) responses to visual, auditory, or somatosensory stimuli. This study involves the collection of cortical, or near-field, evoked potentials. On presentation of a stimulus, an electrode, which is termed the "active electrode," records potential deflections and shifts relative to a reference, or "inactive electrode." The reference electrode, which in the present study is two linked electrodes placed behind the earlobes, is located so as to be neutral with regard to the potentials being collected. The evoked potential consists of the potential difference between the active and inactive electrodes, over a set time period,

and is initiated by the presentation of the stimulus.

To clearly identify that part of the EEG which is related to the stimulus being presented, it is necessary to use techniques which will extract the waveform or "signal" from the "noise" which is the result of ongoing brain activity. By averaging many trials, an evoked potential waveform can be clearly defined. As the waveforms elicited by individual trials are averaged together, background activity, which is random with respect to the time locked evoked potential, will average towards a straight line. On the other hand, the evoked potential, which is present in every trial, will become clearer and clearer.

The evoked potential waveform which results in response to visual stimuli consists of a number of peaks and valleys which can be compared according to their order, latency, amplitude, and polarity. These peaks and valleys are considered to be components of the evoked potential and can be divided into those that are only elicited in the presence of a sensory stimulus, exogenous components, and those that can be elicited in the absence of such a stimulus, known as endogenous components (Sutton, 1979).

Following the presentation of a visual stimulus, the evoked potential will include an early positive component (P1) which is followed, in turn, by a negative component (N1) and another positive component (P2). Ritter, Simson,

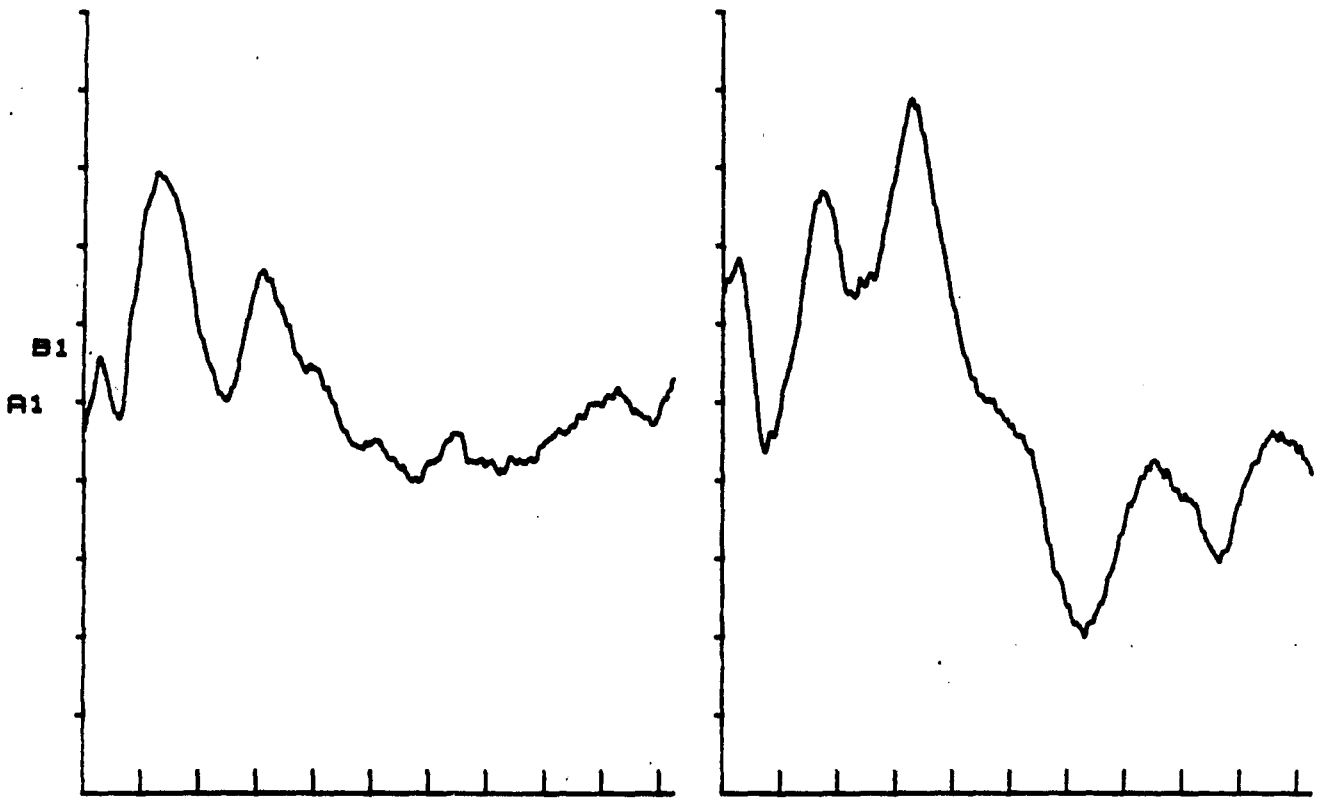
and Vaughan (1983) presented subjects with stimuli which consisted of brackets in different orientations ([]][<> ><) as part of a task which compared physical and semantic discriminations. In all of the waveforms elicited, as identified at the Pz electrode, there was a positive wave at approximately 110 milliseconds (P1), a negative wave at approximately 180 milliseconds (N1), and a positive wave which occurred from 240 to 300 milliseconds (P2). These constitute the exogenous components of the evoked potential.

In studies completed in this laboratory, subjects were presented with a blank card, for 100 milliseconds, in a tachistoscope. The visual evoked potential was collected in response to this stimulus and demonstrated a pronounced P1 component, an N1 component, and an identifiable, if lower amplitude, P2 component. Subjects were then presented a card that contained a fragmented letter with the fragments arrayed so as to fill the same area as an intact letter. The visual evoked potentials collected in response to these stimuli evidenced a diminished P1, an N1, and a P2 of greater amplitude (see Figure 2). The P1 represents the "switching on" of the visual system and is easily elicited by a flash of light. The P2 component, on the other hand, responded to the presence of the letter fragments.

The investigation of evoked potential components that are related to cognitive tasks has focused on the

Figure 2

Evoked Potential Waveforms to a Blank Card and Fragmented Letter Stimuli: Electrode Site Oz



later, endogenous, components. These components, which occur at latencies of 150 milliseconds and more, include the P3, or late positive component, and negativities identified as N2, N4, and the Contingent Negative Variation (CNV).

Molfese (1983) discussed the fact that while there have been three decades of evoked potential research on the correlates of language processing, suprisingly little has been determined. A significant portion of the research to date has focused on the lateralization of language (Neville, 1980). In evoked potential studies of language, phonology has received the most systematic investigation with limited attention to research in the areas of syntax, semantics, and sentence processing. Further, there are a limited number of studies of the evoked potential correlates of language which utilize visual evoked potentials as a measure.

Shelburne (1972, 1973) investigated differences between word and non-word stimuli in children, aged 8 to 12, and adults. Subjects viewed vowel-consonant-vowel trigrams which were presented successively and either resulted in the formation of a word or a non-word. Results demonstrated a significantly larger P3, or late positive component, to the final item of the trigram. In another experiment, when the first letter of the trigram acted as a cue signalling a word or non-word would follow, the amplitude difference was found in response to the first

letter. These differences were also seen earlier in the waveform between 165 and 245 milliseconds. This data was interpreted as reflecting a decision process.

A number of more recent studies have indicated that the P3 or late positive component can be viewed as a measure of stimulus evaluation and comparison processes which are independent of response selection and execution (Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1980; Chabot, York, and Waugh, 1984). Posner, Klein, Summers, and Buggie (1973) and Thatcher (1977) demonstrated differences of P3 associated with letter matches and mismatches, with Thatcher (1977) further demonstrating differences between synonyms, considered a match, and antonyms, a mismatch.

Sandquist, Rohrbaugh, Syndulko, and Lindsley (1980) demonstrated differences between waveforms to decisions based on the orthography of words and those based on phonetic or semantic decisions. They were not able to distinguish between waveforms collected on the phonetic and semantic tasks. Ledlow, Swanson, and Kinsbourne (1978) found no differences in the P300 between tasks based on orthographic features and those based upon phonetic features. Chabot et. al. (1984) demonstrated differences between three tasks which they identified as requiring decisions to be made based on feature (orthographic), lexical (phonetic), or semantic (category) comparisons of words. While the tasks used create question as to the

processing required to complete the lexical task, a significant P300 difference was demonstrated between the stimuli which were compared based upon their orthography and those which were compared based upon their semantic class.

Israel, Chesney, Wickens, and Donchin (1980) reported on the relationship between P300 and a limited capacity system. They reported that the P300 was decreased when the subject was required to perform dual tasks. The extent of the decrease appeared to be related to the degree to which the two tasks competed for an available pool of resources.

In studies which have required subjects to perform discriminations based on the physical characteristics of stimuli, investigators have demonstrated correlations between the latency of N2 and reaction time (Ritter, Simson, Vaughan, and Friedman, 1979) and latency changes as a result of difficulty in stimulus discrimination (Towey, Rist, Hakerem, Ruchkin, and Sutton, 1980). Ritter et. al. (1983), demonstrated that a component analagous to the N2 which resulted from physical discriminations was present during semantic discriminations. His group concluded that the N2 reflected the classification of the stimulus following pattern recognition.

In a study which relates to the syntactic processing of words, Kutas and Hillyard (1980) identified a negative component, the N400, which is sensitive to differences in

sentences between expected and unexpected endings. This waveform was elicited to the presentation of the last word in a sentence when the word did not constitute an appropriate alternative for completion of the sentence and, in so doing, abrogated the rules which guide the relational properties of words.

There exists a later, slow, negative shift in the evoked potential which has been termed the contingent negative variation (CNV). This shift develops when a cue, or signal, is presented which warns the subject that a stimulus requiring a response will appear. The negative shift begins approximately 400 milliseconds after the onset of the warning stimulus (Rockstroh, Elbert, Birmbaumer, and Lutzenberger, 1982). The CNV has been described as an "expectancy wave" as it can relate to the subjects' experience of the probability that a stimulus will occur or of a stimulus-response contingency. There have also been indications that the CNV reflects attentional processes as greater amplitudes have been reported preceding stimuli relevant to the required task and stimuli that are distinctly presented (Rockstroh et. al., 1982).

Two approaches have developed in the use of the evoked potential in studying cognition. One type of investigation involves identifying a set of conditions which will reliably elicit a component of the evoked potential. It is then possible to manipulate the stimuli

and observe the effect on the waveforms which are elicited. Another type of study involves the identification of a cognitive task of interest, a task which has been interpreted behaviorally, and to collect the evoked potentials which results (Kutas, in press).

In the present study, four tasks were constructed to represent the component processes that are involved in the recognition of words. Evoked potentials were to be collected during, and immediately following, the presentation of the cue/fixation stimulus. The subjects, therefore, would view four different words and evoked potentials would be collected as they prepared for the processing of the ensuing task.

The fact that the evoked potentials would be collected to a stimulus that does not require an overt response disentangles a methodological issue in the interpretation of these waveforms. In a reaction time task, premotor potentials overlap evoked potential components up to the response. In some cases, the postresponse wave could overlap the P300 and N400 waves. The timing of the stimulus presentation in the present task will provide ample time for such potentials to subside.

II. PILOT STUDY

A. Rationale

In order to investigate the relationships between the different types of processing that are involved in word recognition, an environment was developed to eliminate many of the factors which could create "noise" (variability) in the delivery and response to an experimental task. The experimental task was constructed to require either orthographic, phonetic, semantic, or syntactic processing of word pairs.

It was necessary to determine if the experimental task which was developed, and is described below, would reliably demonstrate significantly different mean reaction times for the orthographic, phonetic, semantic, and syntactic items and whether those differences would be maintained under conditions of repeated exposure to the task.

B. Subjects

Three subjects with normal (20/20) or corrected to normal vision served as volunteers. The subjects included a twenty-seven year old woman with a masters degree in Art History and 18 years of education, a twenty-six year old advertising executive with 16 years of education, and a twenty-seven year old doctoral student of Psychology with

19 years of education. All of these individuals were honors students and highly proficient readers.

C. Task Development

A task was developed for the pilot study which required subjects to make decisions about pairs of words. These successively presented words could be compared based upon their orthography, phonology, semantics, or syntax. The task involved the development of word lists in four categories: animals, body parts, clothing, and groceries. These lists consisted of twelve words per category and were balanced for word frequency (Thorndike & Lorge, 1963). In addition, the words were all four or five letters in length (see Appendix A).

The GRAPHIC task required comparisons based upon the visual features of words. In this task, a "yes" response consisted of a word from the four lists which was followed by exactly the same word (GOAT...GOAT). A "no" response consisted of a word from the lists, followed by the same word in which a letter had been removed and a non-letter symbol inserted (GOAT...G*AT). The non-letter symbol was randomly inserted to replace the first, second, or third letter of the word. This task was designed to enable the subject to compare the two words and respond with minimal processing of phonetic, semantic, or syntactic information.

The PHONETIC task required comparisons based upon

the sounds that letters and words can represent. A "yes" response to this task involves comparing a word from the lists and its homophone (GOAT...GOTE). A homophone is a word or a group of letters which will sound the same as another word but differ in spelling. A "no" response involves comparing a word from the lists and a word which has the same initial phoneme but is not a homophone (GOAT...GOLF). This task was constructed so as to require the use of the phonetic information that words can represent.

The semantic or CATEGORY task required subjects to determine whether or not two words belonged to the same nominal class. The categories used were the same as those which were used in the development of the stimulus set (animals, body parts, clothes, groceries). If the two words shared the same category (GOAT...TIGER) then the subject would respond "yes". If the words belonged to two different categories (GOAT...FLOUR) the subjects would respond "no".

The final task, SYNTACTIC, involved comparing words based upon their grammatical function. For example, a "yes" response would involve matching two nouns (GOAT...TENT) while a "no" response would involve matching a noun and a verb (GOAT...ROAM).[1]

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[1]This relationship was switched in the main experiment, with a yes response involving a match between a noun and a verb and a no response involving a match between two nouns.

The word pairs were ordered in a quasi-random fashion so that subjects would not be able to predict whether an orthographic, phonetic, semantic, or syntactic comparison would be required. A pre-trial cue was presented prior to each word pair which alerted the subject to the type of comparison which would follow.

D. Procedure

The subjects sat in a comfortable chair one meter away from a Hitachi Shibaden VM-904U black and white video monitor. The left eye was covered with a patch to make it easier to fixate on the center of the screen. The video monitor was controlled by an APPLE II/E computer which presented the stimuli and collected the reaction times through an input/output interfacing system (Cochran, 1982).

The three subjects participated in four sessions, each session consisting of 192 trials. Following dark adaptation, a series of instructions were presented on the video screen and read aloud by the experimenter (see Appendix B). Subjects then completed a set of twenty four practice trials, with an equal representation of the four tasks (graphic, phonetic, category, syntactic) and the two responses ("yes", "no"). At each session, one half of the total number of items in the stimulus set was presented with each half containing an equal number of graphic, phonetic, category, and syntactic trials. In

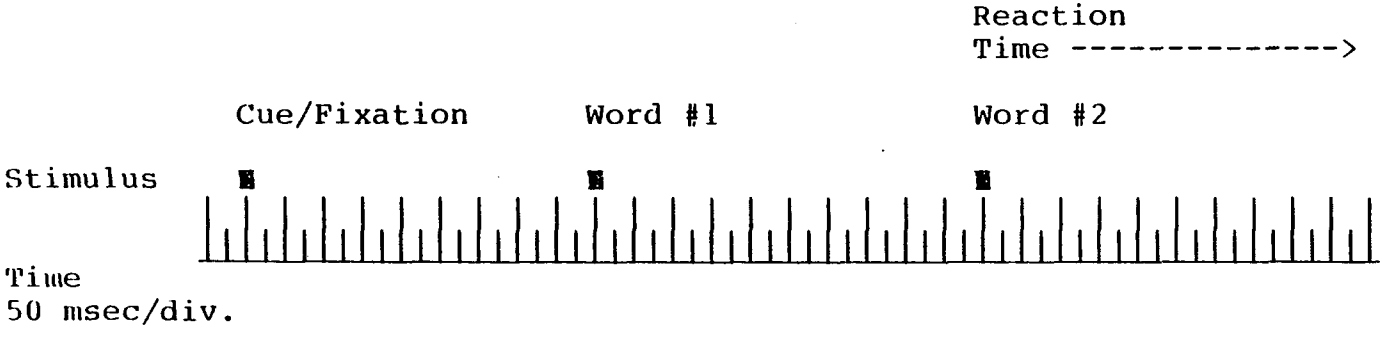
addition, there were an equal number of "yes" and "no" responses, per task, in each session.

Each trial consisted of the sequential presentation of three words. As each trial began, subjects viewed a word, arrayed vertically on the screen, which acted as cue and identified whether a graphic phonetic, semantic, or syntactic comparison was to follow. The cue also acted as a fixation site to orient subjects to the location of the word pair that was to follow. The cue signified the type of task, and therefore the type of processing, on that trial and consisted of the words LOOK (graphic task), SOUND (phonetic task), GROUP (semantic task), or SPEECH (syntactic task). Each cue was presented for 50 milliseconds.

The cue was followed by a delay of 1000 milliseconds, at which point the first word of a two word sequence appeared vertically on the screen at the fixation site. This word was presented for 50 milliseconds. Finally, following another 1000 millisecond delay, the second member of the word pair was presented for 50 milliseconds (see Figure 3). With the presentation of the third word, the subjects had to determine if a "yes" or a "no" response was warranted. For example, if the cue indicated that a word pair was to be compared in the GRAPHIC task, and the word GOAT was followed by G*AT, the subject would respond "no". Responses were registered through the use of a toggle switch which subjects held in

Figure 3

Time Course of Stimulus Presentation and Collection of Behavioral Measures



their dominant hand. This switch had two positions, one which registered a "yes" response and one which registered a "no" response. If the comparison of the stimuli required more than 1200 milliseconds, a message would appear on the screen indicating that their response was too slow.

E. Results

The reaction times were then analyzed to investigate the contribution of the four tasks (graphic, phonetic, semantic, syntactic), the four word categories (animals, body parts, clothing, groceries), and the four experimental sessions, to the speed with which subjects made linguistic decisions. A mixed model Analysis of Variance (Hays, 1981) demonstrated an effect for Task, $F(3,33)=25.76$, $p<.001$; and for Session, $F(3,22)=23.49$, $p<.001$. Word category was not found to have a significant effect on responses, $F(3,33)=0.55$, $p<.648$). In addition, a significant interaction was demonstrated between Session and Task, $F(6,66)=2.51$, $p<.05$) indicating that a subjects performance on a particular task was dependent on practice as reflected in the number of sessions.

The significant Task effect (see Table 1) indicated that the Graphic task was performed the fastest. The phonetic and semantic tasks were not significantly different from one another, while the syntactic task was slower than the other three.

Further analysis of the effect of Session

Table 1

Post Hoc Analysis of Reaction Time Data for Task and Session

Student-Newman-Keuls Test for Variable: RT
Alpha = .05 DF = 2064 MSE=171516

Task	N	Mean (msec.)
Graphic	576	597.91
Phonetic	576	758.62
Category	576	767.47
Syntactic	576	864.01

Student-Newman-Keuls Test for Variable: RT
Alpha=.05 DF=2064 MSE=171516

Session	N	Mean(Msec.)
1	576	885.32
2	576	767.01
3	576	685.88
4	576	649.79

demonstrated that responses on the third and fourth sessions, as measured by reaction time, were not significantly different from one another (see Table 1).

The data generated by individual subjects demonstrated that each individual was operating at his or her own rate. Further analysis of the reaction times by Subject are presented in Table 2.

Table 2

Post Hoc Analysis of Reaction Time Performances for Pilot Subjects

Student-Newman-Keuls For Variable:RT
Alpha=.05 DF=2064 MSE=171516

Subject	N	Mean(msec.)
ND	768	815.12
MD	768	742.45
DD	768	683.43

F. Implications

A pilot study was developed to see if it would be possible to create a task which, after practice, would demonstrate consistently different reaction time performances when graphic, phonetic, semantic, and syntactic comparisons of word pairs were required. The task which was developed involved word lists in four categories: animals, body parts, clothing, and groceries. These lists consisted of twelve words per category and were balanced for word frequency (Thorndike & Lorge, 1963). In addition, the words which were chosen were all four or five letters in length (see Appendix 1).

This investigation involved the developemnt of four tasks which were designed to require orthographic, phonological, semantic, and syntactic processing for their successful completion. These tasks were presented in a quasi-random order where the subject did not know, from trial to trial, which type of processing would be required. Most studies of orthographic, phonological, semantic, and syntactic processing have involved the presentation of blocks of stimuli which required responding to one type of task at a time. The task developed for this study requires the subject to constantly switch between four different types of information, much as the reader must constantly use different sources of information in successful reading.

The study also provided several sessions in which to learn the task. On being presented with a novel task, one in which there is no advantage to processing words graphically, phonetically, semantically, or syntactically, and being provided with the opportunity to practice that task, the setting mimics the developmental course of reading. As in learning to read, the individual has access to these sources of information in words and must effectively utilize them, as needed, to render the graphic symbols meaningful.

All of the tasks were constrained so that there would be only one way to process them. The graphic task, for example, was designed to permit the individual engaged in the task to decide if there was a match, or mismatch, based on physical information. Furthermore, the method of presentation, which used a cue that identified the task which was about to appear and was followed by the first word of the pair, greatly constrained the possible number of items that could constitute appropriate responses. The stimuli were all balanced for word length and frequency. Stimuli were presented for 50 milliseconds, long enough for most individuals to perceive the words with ease. The stimuli were not degraded in any way and no masking stimuli were used.

The results of this pilot investigation were used in the development of the methodology for the ensuing study. Reaction time data demonstrated that the four tasks, after

repeated practice, still required different amounts of time to complete. The four word categories were found to not affect performance and no individual word pairs were identified for exclusion. A decision was made to alter the Syntactic task. As it was constructed in the pilot study, the task demanded subjects to categorize the word pairs as both nouns ("yes") or a noun and a verb ("no"). As the goal of the task was to test performance based upon the relational properties between words, the task was altered to more successfully achieve this end. Finally, it was possible to identify the point at which subjects had reached a "steady state" in their reaction times to the tasks. After having seen the entire stimulus set twice, there was no significant difference in reaction time performances between sessions.

III. HYPOTHESES

1) If the stimuli developed for the experiment continue, after practice, to demonstrate consistently different reaction time performances when graphic, phonetic, semantic, and syntactic comparisons of word pairs are required then:

   a) a significant effect for TASK should be indicated
   b) post hoc analysis of the effect of TASK should indicate a pattern of performance in which the Graphic task mean reaction time should be the fastest, the Phonetic and Semantic task mean reaction times should be indistinguishable, and the Syntactic task mean reaction time should be the slowest
   c) a significant effect for SESSION should be indicated
   d) post hoc analysis of the effect of SESSION should indicate improvement in reaction time as the sessions progress. Further, a "steady state" in reaction time performance should be reached by the third experimental session.

2) If there are differential gains in reaction time over the three sessions then:

   a) there should be greater improvement for the Phonetic task which may be reflected in a TASK by SESSION interaction.

3) If the progressive improvement in performance over time provides a recapitulation of the developmental process and, if the efficiency of phonological processing is the determining factor in the development of skilled reading, then:

a) those subjects who are the most rapid on all of the tasks should demonstrate the most rapid performances on the Phonetic task

b) those subjects who are the most accurate on all of the tasks should be the most accurate on the Phonetic task.

4) If the task eliminates much of the "noise" in the cognitive task to which the evoked potentials are collected then:

a) the evoked potential waveforms should be analyzed for differences at N2, P3, N4, and the CNV which might not be evident in less controlled experimental environments.

IV. METHOD

A. Subjects

Having determined that the experimental task reliably elicited different rates of response, as measured by reaction time, and that these differences were maintained with repeated exposure to the task, a larger group of subjects was employed in the investigation. Twelve volunteers (8 male, 4 female), aged 20 - 37, served as participants in the research protocol. Subjects were deemed to be expert readers and had a mean education level of 18 years. All subjects had vision which was normal (20/20), or corrected to normal. Two other potential subjects were not included in the study because of insufficient acuity to identify the stimuli on the screen at the required distance.

B. Stimuli

The word pairs used in the study were drawn from the stimulus set created for the pilot study. The graphic, phonetic, and category tasks were included without change. The syntactic task was modified to more reliably require processing based on the relational properties of words. In this modified version of the syntactic task, subjects were instructed to respond "yes" when the words could be placed

in a subject/predicate relationship (GOAT...ROAM) and "no" when they could not (GOAT...TENT). Due to the difficulties in creating a syntactic task based upon comparisons of word pairs, stimuli were developed for the animal word category only (see Appendix A). These items appear one-half as often as the graphic, phonetic, and category stimuli.

A final session was added to the investigation which attempted to disrupt the value of the information in the cue as a predictor of the type of processing which would be required on the task. In this session, 10 percent of the trials, equally divided among yes and no responses, tasks, and word categories, were altered so that the cue no longer identified the type of processing which was to follow. For example, the cue for a phonetic task (SOUND) would be followed by an orthographically based comparison (GOWN...G*WN).

C. Procedure

The procedure for the investigation, in many ways, was similar to that utilized in the pilot study with the introduction of evoked potential measures. Subjects were seated in a reclining chair which, with the stimulus presentation and evoked potential averaging computers, were within a Faraday cage to eliminate extraneous electrical signals which could obscure the evoked potential measures. A black patch was placed over the left

eye and subjects were provided time in which to adapt to the darkness. As in the pilot study, subjects sat one meter away from the Hitachi Shibaden VM-904U black and white video monitor and held a "yes/no" respose key in their dominant hand. The stimuli were presented vertically across the midline and subtended an angle of one degree. The monitor was controlled by an Apple II/E equipped with an input/output interfacing system (Cochran, 1982). A master control program was constructed which presented the stimuli, sent out a pulse to trigger the collection of the evoked potential, and collected the reaction time and yes/no responses to the task (see Appendix B).

All sessions began with the presentation of a set of instructions (see Appendix B). The instructions were viewed by the subject on the video monitor and were read aloud by the experimenter. Following the instructions, a series of 24 practice trials were administered (see Appendix A). Subjects responded "yes" or "no" to the practice trials. The instruction set and the 24 practice trials were presented at the beginning of each experimental session.

During sessions 1 and 2, subjects viewed and responded to the entire set of 336 trials. Sessions were approximately one and one-half hours in length. Reaction time and accuracy data were collected for each presentation of a word pair and stored on floppy disks. The stimuli were presented in blocks of 24 trials with a

brief rest between blocks. Subjects were asked not to move or blink during trials, behavior which is problematic during the collection of evoked potentials, and the built in rest periods provided ample opportunity for subjects to shift position, rest their eyes, etc.

Session 3 involved the viewing and response to the same set of 336 trials. However, this session involved the collection of evoked potential measures during the performance of the task. Subjects had silver/ silver chloride electrodes placed at Pz and O1 of the international 10/20 system (Jasper, 1958), referenced to linked earlobes, and grounded to the forehead (see Appendix E). All electrode sites were abraded before application of an electrolyte-filled electrode and inter-electrode impedences were kept below 2 Kohms. The evoked potentials were collected on a Nicolet Pathfinder II computer averaging system. Amplification was accomplished with Nicolet SM 200 physiological amplifiers. The evoked potentials were collected as single trials for each stimulus presentation. The Nicolet Pathfinder II was controlled by a MECOL program which set all machine parameters (see Appendix E). Evoked potential waveforms were stored on floppy disks for later analysis.

The pattern and timing of stimulus presentation was the same as that utilized in the pilot study. The pilot study had been constructed with the collection of evoked potentials in mind. For example, the timing of the

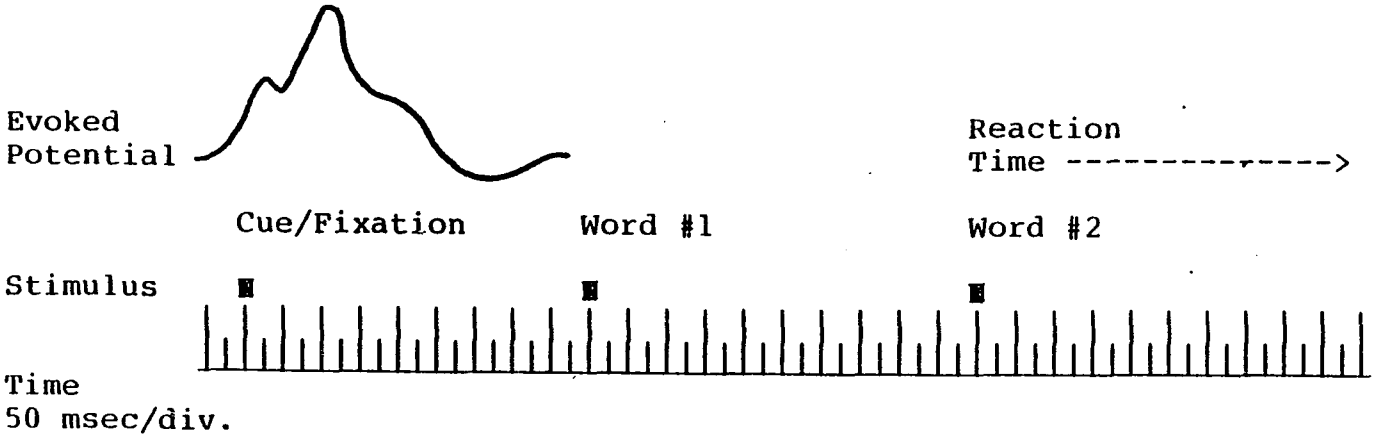
presentation of stimuli allowed for 1000 millisecond intervals during which an unimpeded evoked potential waveform could be collected. Further, the stimuli were presented at diminished contrast to minimize the illumination differential that could effect the evoked potential. The stimuli were arrayed vertically on the screen to minimize eye movements.

The pattern of stimulus presentation remained the same as that used in the pilot study with stimuli appearing for 50 milliseconds with 1000 millisecond interstimulus intervals. The trigger for the evoked potential appeared 100 milliseconds PRIOR to the appearance of the cue/fixation on the screen. This provided a period during which the subject was viewing a blank screen which was later used as a baseline for the interpretation of the evoked potential waveforms. The evoked potential was collected for a period of 900 milliseconds during and immediately following the presentation of the cue (see Figure 4).

The collection of the evoked potentials for two randomly selected subjects involved a channel to monitor their eye movements while performing the tasks. For these subjects, the electrode at O1 was replaced by an electrode placed below the right eye. In this way, any potentials due to electrical activity which was related to movement of the eyes would be represented, with opposite polarity, and could be compared to the evoked potential waveform

Figure 4

Time Course of Stimulus Presentation and Collection of Behavioral and Evoked Potential Measures



collected at the second electrode site. As with the rest of the subjects, the other electrode was placed at Pz.

The fourth, and final session, involved the presentation of the stimulus set of 336 trials, 10 percent of which were altered so that the cue did not identify the ensuing task. All presentation parameters were identical to those in the three previous trials. Reaction time measures were collected for each trial and stored on floppy disks for later analysis.

V. RESULTS

Performances on the graphic, phonetic, semantic, and syntactic tasks were examined for the effects of Task, Session, Word Category, Subject, and the interactions between these variables. While the present study was designed to eliminate many of the factors which create extraneous variability in responses to the experimental task, reaction time data is simply inherently noisy (Shoben, 1982). In order to provide as reliable a data base as possible, two types of reaction time scores were excluded from the analyses; a) reaction times for incorrect responses, and b) reaction times which were in excess of 2000 milliseconds. The reaction times for incorrect responses were excluded because it was impossible to determine the strategy, or type of processing, engaged in the performances on those trials. Pilot subjects reported in all instances where reaction time was in excess of 2000 milliseconds that they had not seen one of the stimuli and, as a result, could not complete the trial. Further, excessively long reaction times can alter the mean by skewing and distorting the distribution of scores. The exclusion of these reaction times resulted in each subject having a different number

of responses for each of the tasks, in each of the sessions.[2]

The syntactic task, which only uses words from the animal category, introduced an aspect of the study which resulted in an unbalanced design. The General Linear Models (GLM) procedure of the SAS computer software system for data analysis was utilized to perform the data analysis due to its ability to manage cells which contain an unequal number of values. This procedure uses the method of least squares to fit general linear models (SAS Users Guide, 1985).

The analysis of the data will be described in two parts. Initially, the data were analyzed as a strictly nested Analysis of Variance which was replicated on twelve subjects. Since it was not possible to know, a priori, the order of all of the task effects, a post hoc analysis method that would permit a .05 experimentwise error rate was chosen at the possible risk of a slight loss of power. These analyses were accomplished using the GLM procedure in SAS. The data were later analyzed to gain an understanding of the individual differences in subjects' performances.

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[2] While transformation of the data may be good statistical practice, Shoben (1982) describes the importance of viewing reaction time as a naturalistic measure. In this case,the reaction time is seen as reflecting the time required to perform a cognitive operation. Transformation is described as having little effect on the statistics performed, provided that extremely long reaction times have been excluded.

A. GLM Analysis of Reaction Time Data

A GLM Analysis of Variance for an Unbalanced Design resulted in a highly significant effect for Task, $F(3,33)=71.77$, $p<.001$, which demonstrated that the Graphic, Phonetic, Semantic, and Syntactic tasks were responded to at different rates. A Scheffe post hoc comparison of means indicated that the Graphic task was performed at a significantly faster rate than the other tasks ($p<.05$). All of the tasks were significantly different from one another with the Category task being faster than the Phonetic task. The Syntactic task was performed at the slowest rate (see Appendix C). Analysis of the reaction time performances on the third experimental session demonstrated the significant effect for Task; $F(3,33)=27.37$, $p<.001$. A Scheffe post hoc comparison of means for the session three data indicated that the Graphic task continued to be performed the fastest but, by this point in time, reaction times to the Category and Phonetic tasks were not significantly different (see Appendix C).

A significant effect for Session, $F(2,22)=20.46$, $p<.001$, indicated that the reaction time performances systematically changed over the course of the experiment. A Scheffe post hoc comparison of means indicated that the rates of performance were significantly different for the three sessions ($p<.05$), with the subjects reaction time

performances becoming more rapid as the sessions progressed (see Appendix C). Unlike the data resulting from the pilot study, in which with an N of 3 it was possible to identify a point at which the reaction time performances between sessions did not differ significantly, the data collected in the course of the experiment indicated that the reaction times continued to improve.

An effect for word category was identified; $F(3,33)=6.71$, $p<.001$. Further analysis with a Scheffe post hoc comparison of means indicated that rates of response to the Animal category were significantly slower ($p<.05$) than those to the categories of Groceries, Body Parts, and Clothing. This finding was at odds with the data from the pilot study, which did not identify an effect of word category. However, since the revised Syntactic task consisted of word pairs which were based exclusively on the Animal word category, and the comparison of means for Task indicated that the Syntactic task was performed at the slowest rate, this effect is understandable. Further, analysis of the reaction time performances at the third session indicated that, by this point in the course of the experiment, there was not a significant effect for Category; $F(3,33)=1.94$, $p<0.14$. This result suggests that a Task by Category interaction is likely when looking at the three sessions and, if so, that the interaction would be due to this interplay

between the Animal word category and the Syntactic task.

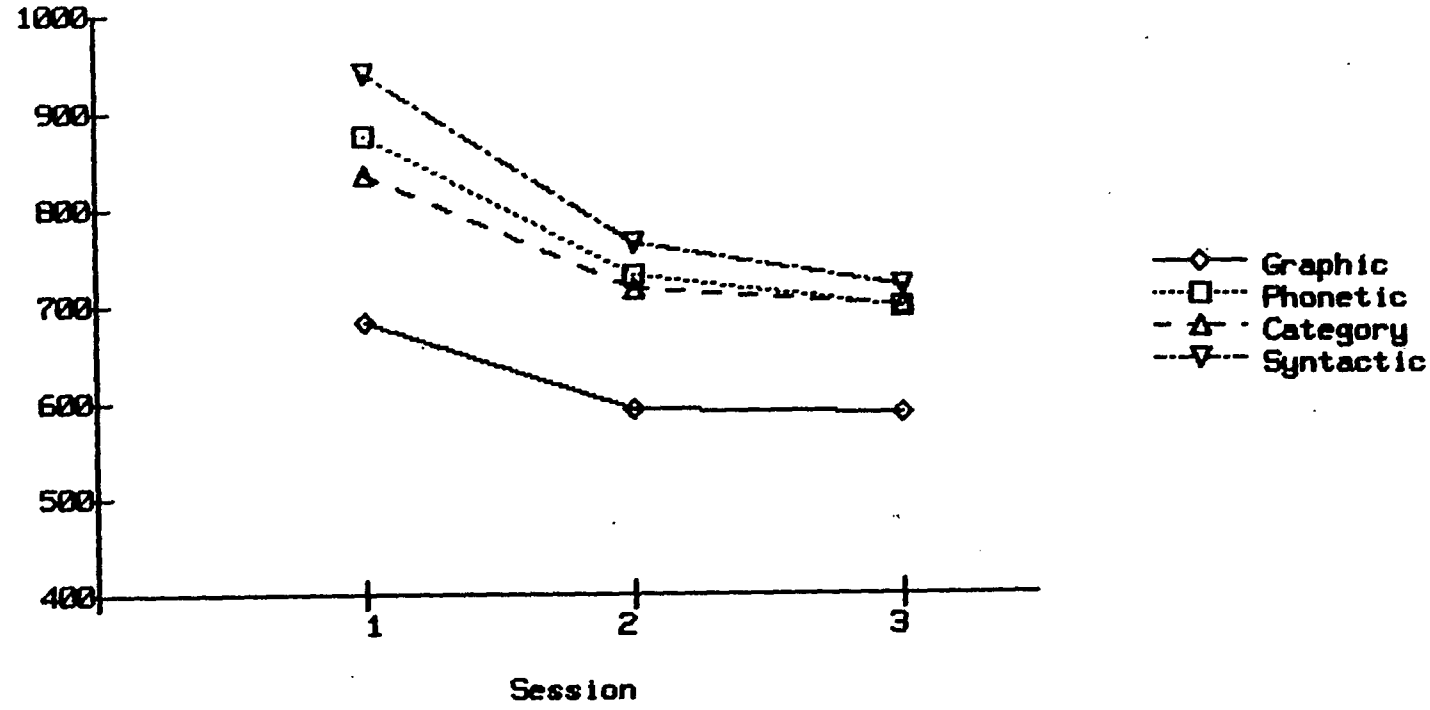
A significant Task by Session interaction was identified, $F(6,66)=7.58$, $p<.001$, indicating that the difference in reaction time performances among the four tasks differed depending upon which session the subject was engaged in. The mean reaction time performances for the four tasks and the three sessions, collapsed across the twelve subjects, are presented graphically in Figure 5.

The interaction between Task and Category was significant, $F(6,66)=4.15$, $p<.001$, a result which was not unexpected considering the exclusive representation of the Animal word category in the Syntactic task. The Session by Category interaction was found to be not significant, $F(6,66)=1.76$, $p<0.12$, indicating that the patterns of performance on the four word categories did not vary over the three sessions. In the pilot study, where the four word categories were equally represented in the four tasks, no effect of Category was noted. Further, the performances for the word categories did not change over the three sessions. The introduction of a Syntactic task which consisted exclusively of words from the Animal category appears to be responsible for the significant effect of Category and the interaction of Task by Category.

A significant three-way interaction was noted for Task by Session by Category; $F(36,467)=4.93$, $p<.001$.

Figure 5

Mean Reaction Time: All Subjects, All Tasks, Sessions 1, 2, 3



Considering the significant effects for Task, Session, and Category independently it is not surprising that this complex interaction is significant.

A significant interaction of Task by Session by Category by Subject, $F(467,11059)=17.01$, $p<.001$, indicated that different subjects were showing different performances on the tasks during the three sessions. This complex interaction can be seen by visual inspection of charts which present individual subjects performances (see Figures 6 - 17). While the graphic task was consistently the fastest, the rates of responding on the Phonetic, Category, and Syntactic tasks differed, as did the patterns of performance on these tasks from subject to subject, during the course of the three sessions.

Figure 6

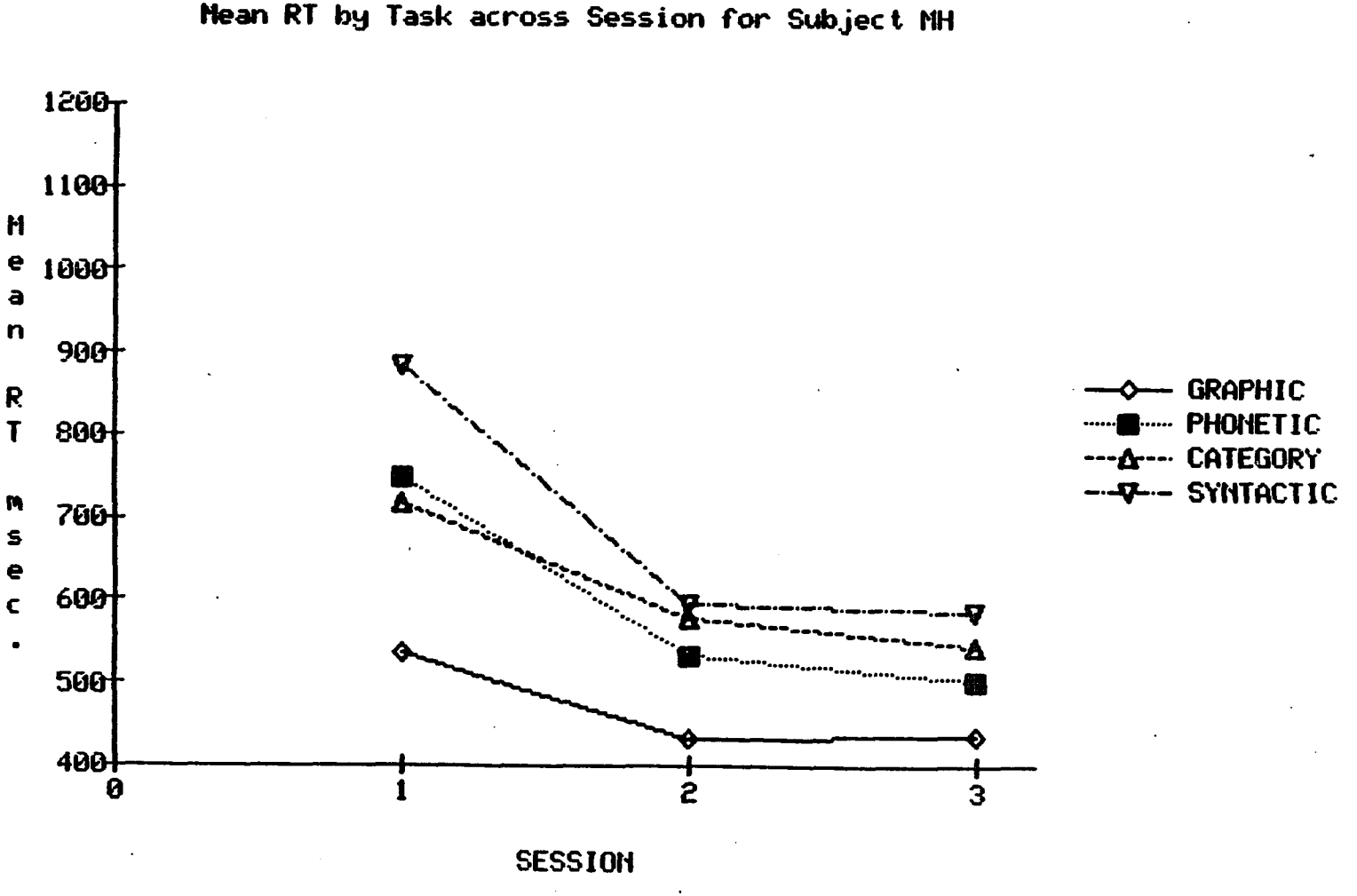

Mean RT by Task across Session for Subject MH
1200
1100
1000
900
800
700
600
500
400
Mean RT msec.
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 7

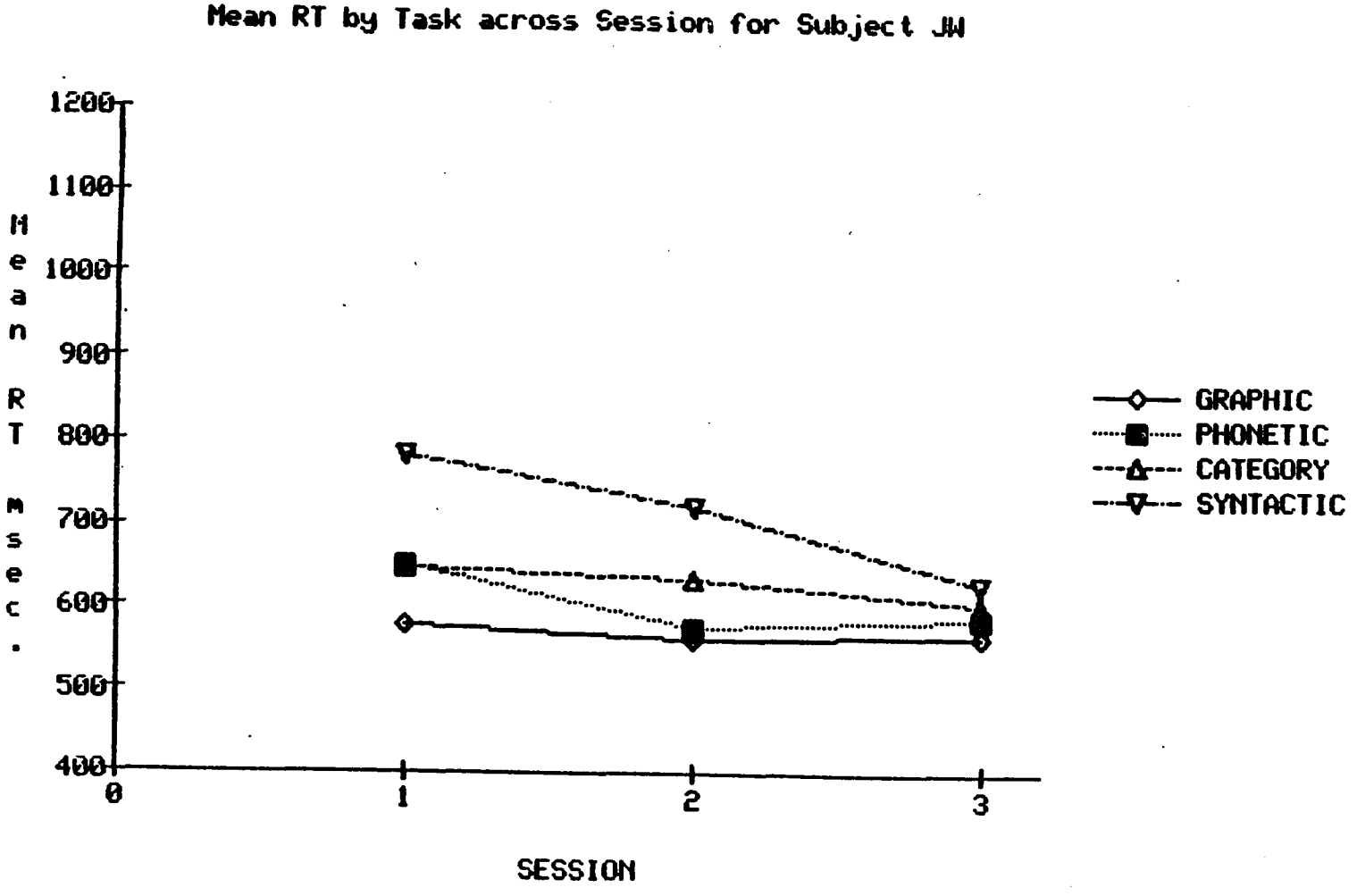

Mean RT by Task across Session for Subject JW
1200
1100
1000
900
800
700
600
500
400
Mean RT Msec.
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 8

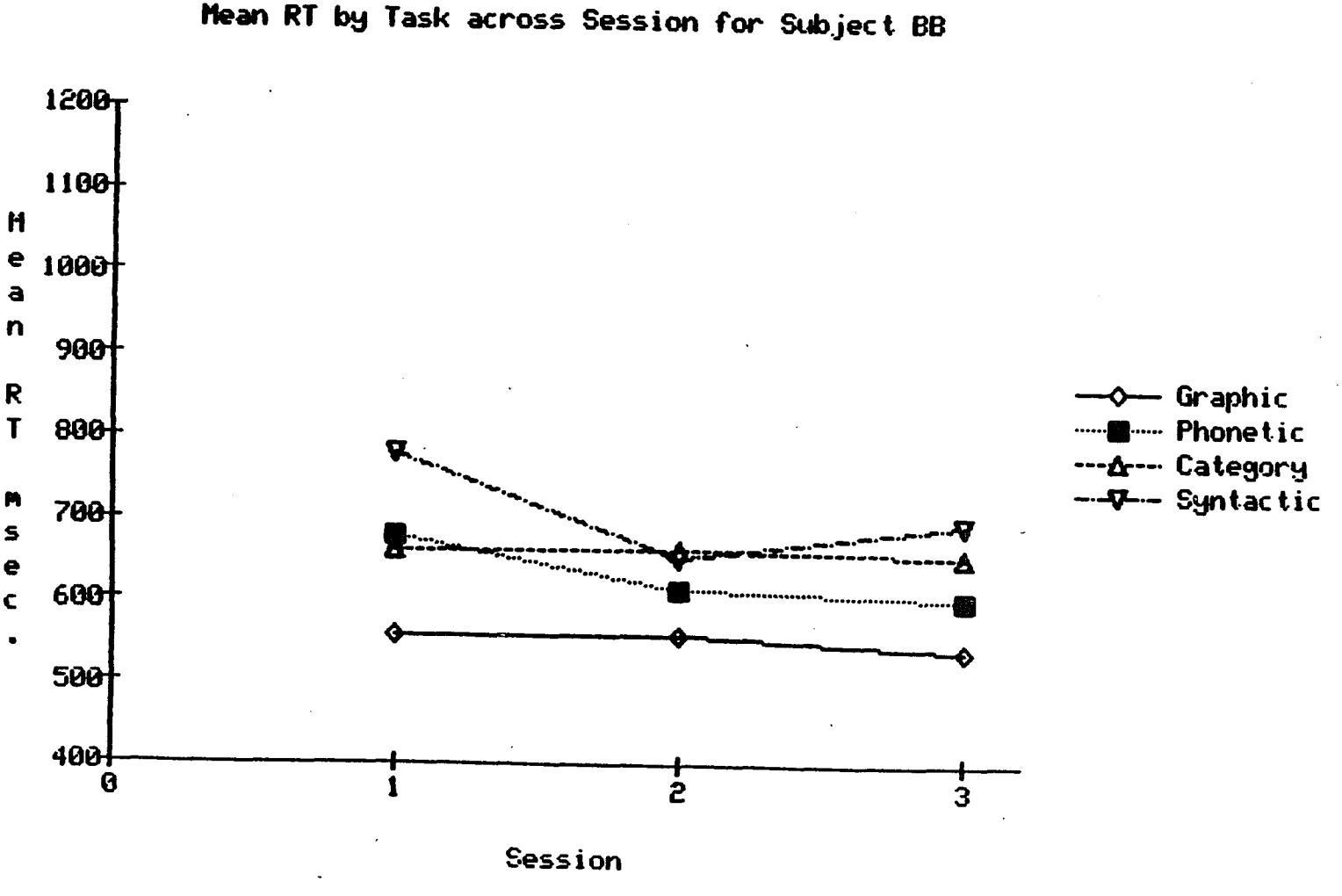

Mean RT by Task across Session for Subject BB
1200
1100
1000
900
800
700
600
500
400
Mean RT msec.
0
1
2
3
Session
Graphic
Phonetic
Category
Syntactic

Figure 9

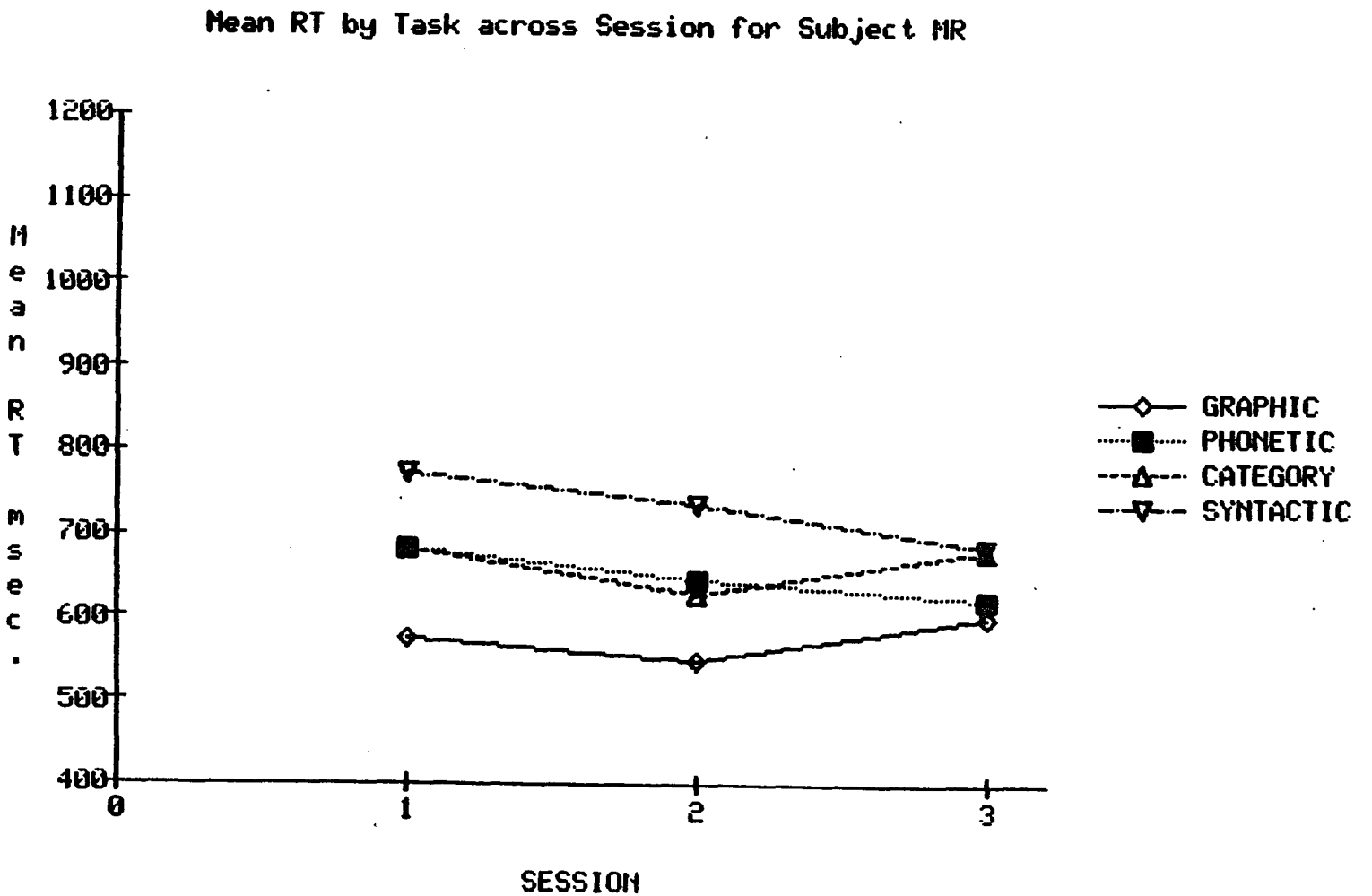

Mean RT by Task across Session for Subject MR
Mean RT msec.
1200
1100
1000
900
800
700
600
500
400
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 10

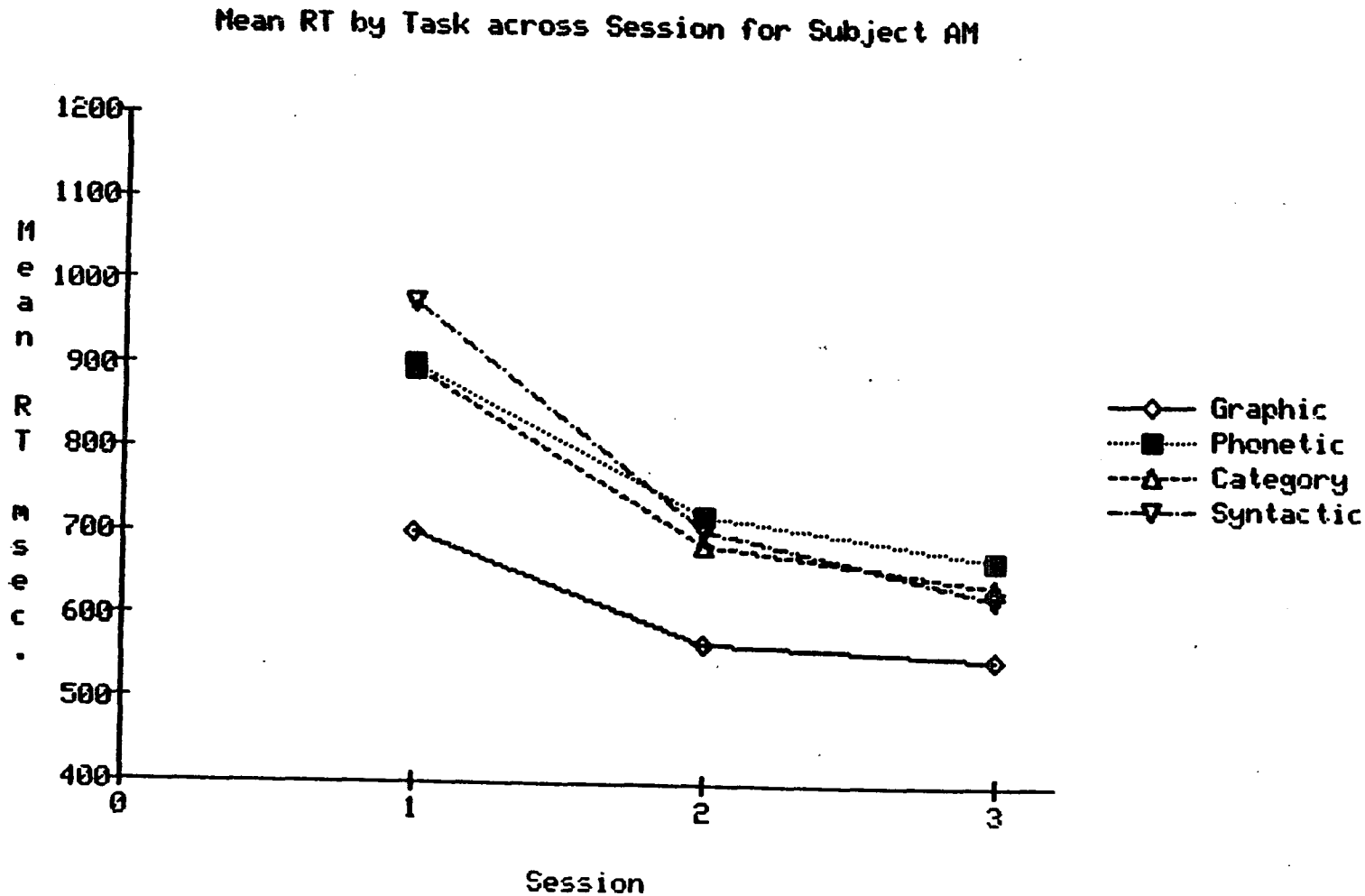

Mean RT by Task across Session for Subject AM
1200
1100
1000
900
800
700
600
500
400
Mean RT msec.
0
1
2
3
Session
Graphic
Phonetic
Category
Syntactic

Figure 11

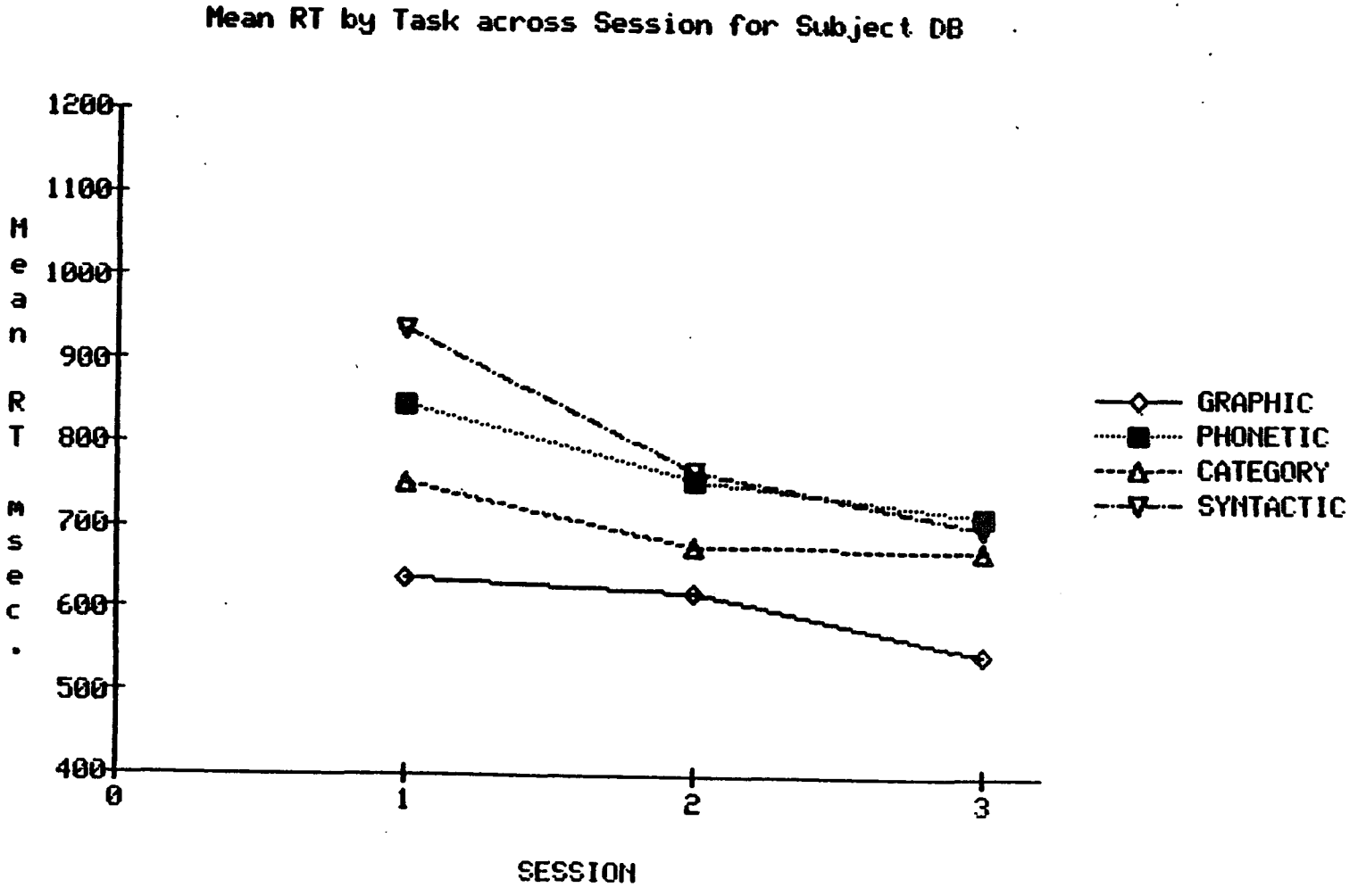

Mean RT by Task across Session for Subject DB
1200
1100
1000
900
800
700
600
500
400
Mean RT Msec.
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 12

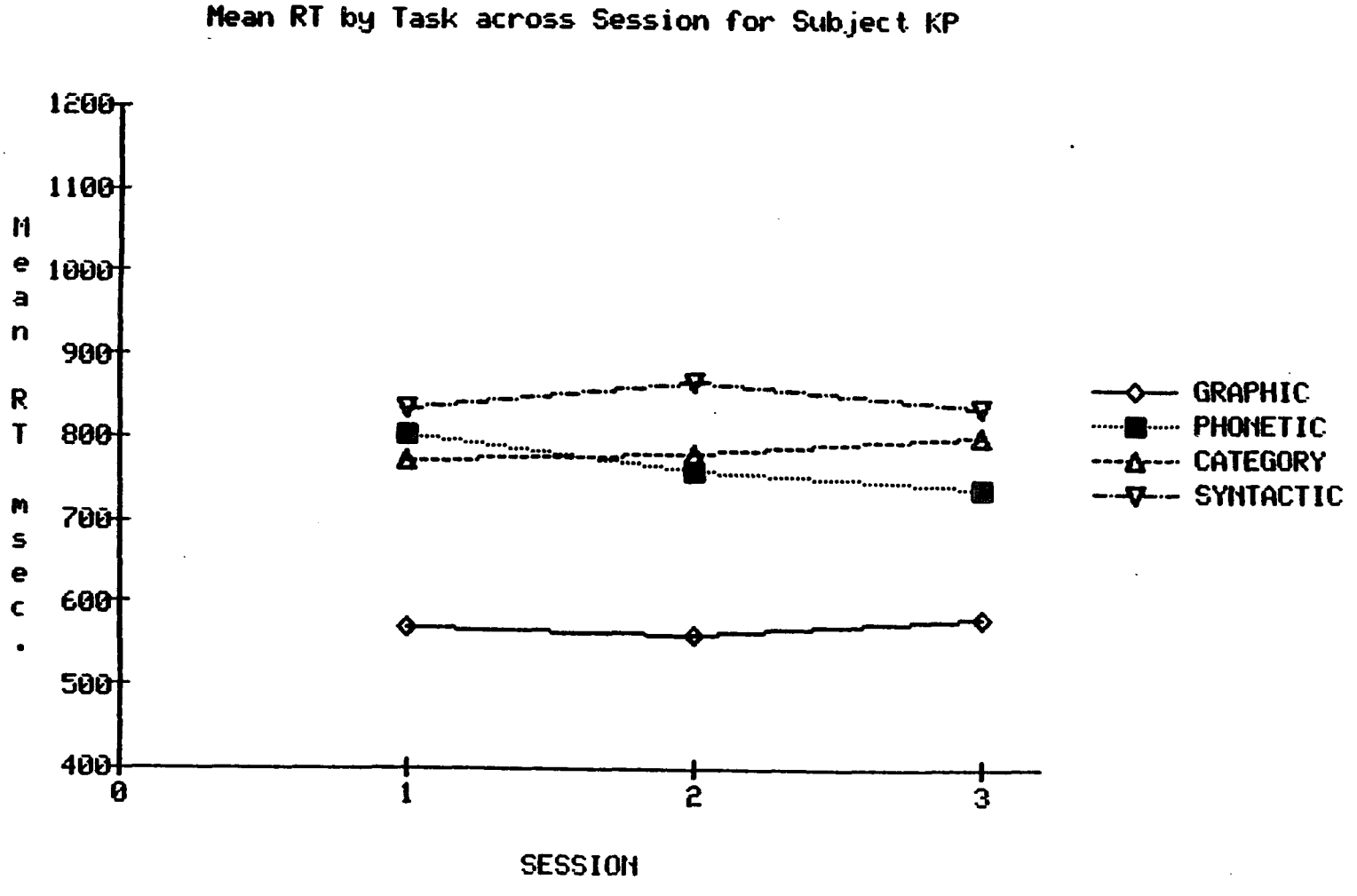

Mean RT by Task across Session for Subject KP
1200
1100
1000
900
800
700
600
500
400
Mean RT msec.
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 13

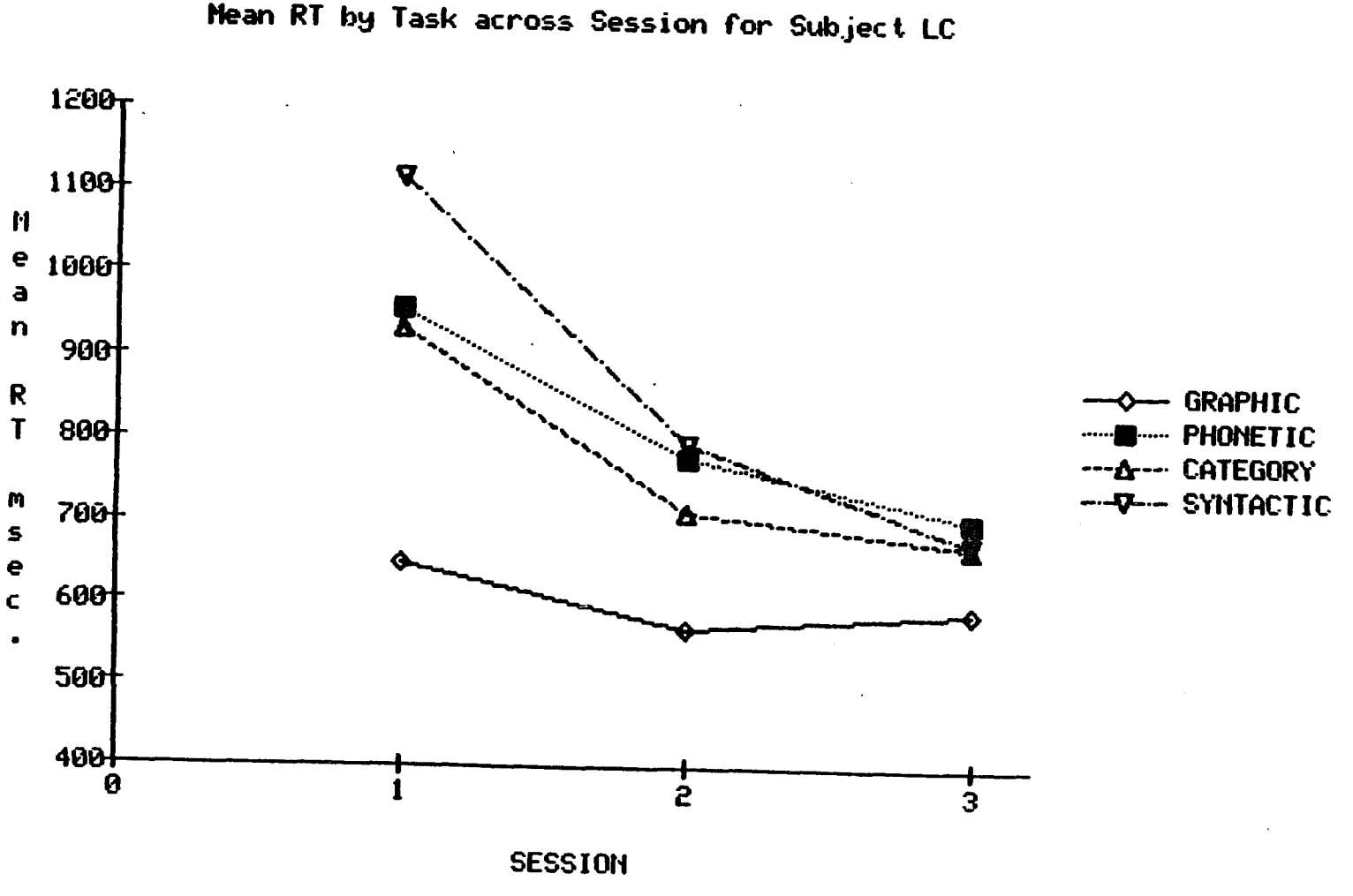

Mean RT by Task across Session for Subject LC
1200
1100
1000
900
800
700
600
500
400
Mean RT msec.
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 14

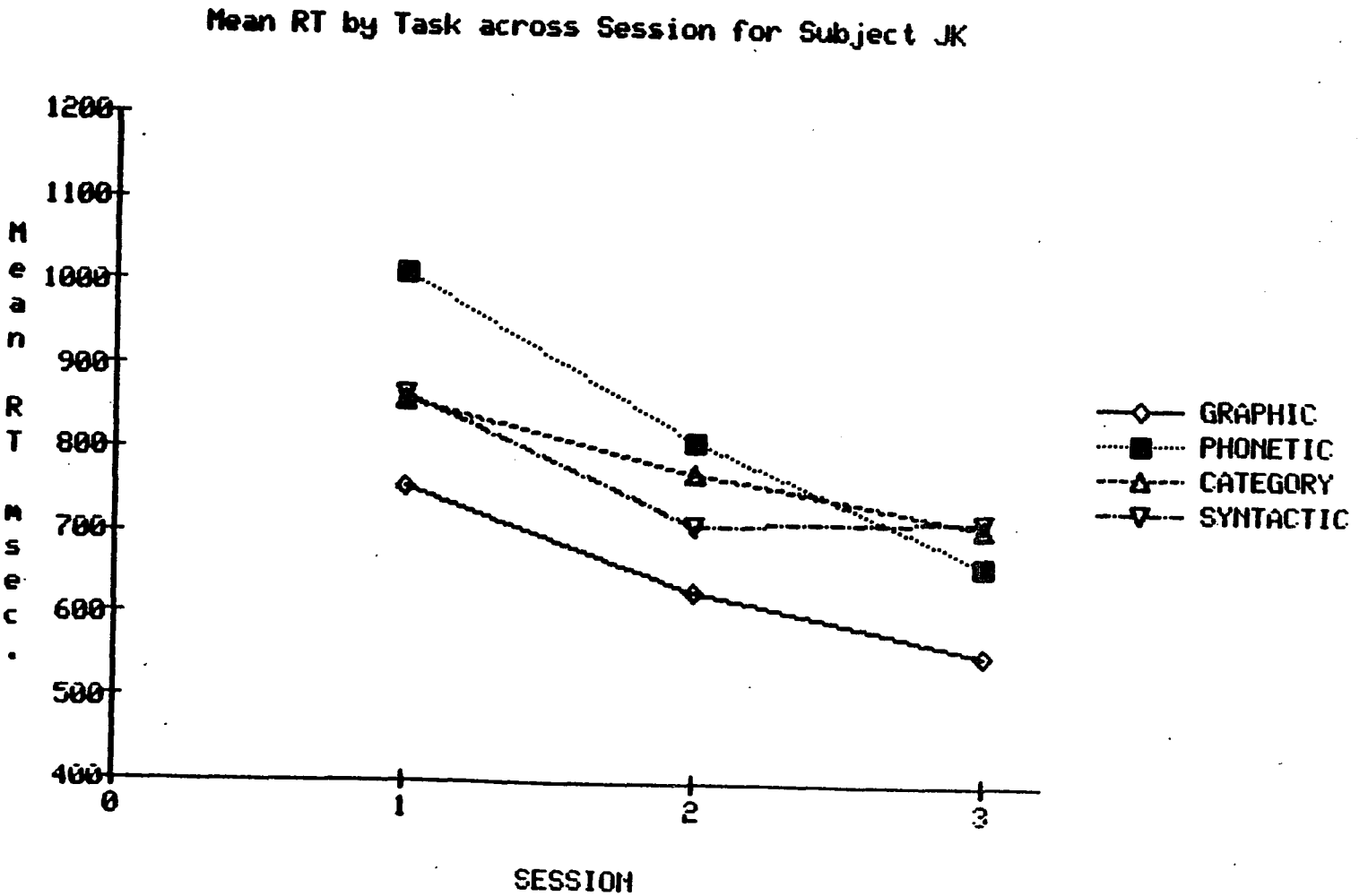

Mean RT by Task across Session for Subject JK
1200
1100
1000
900
800
700
600
500
400
Mean RT msec.
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 15

Mean RT by Task across Session for Subject RI

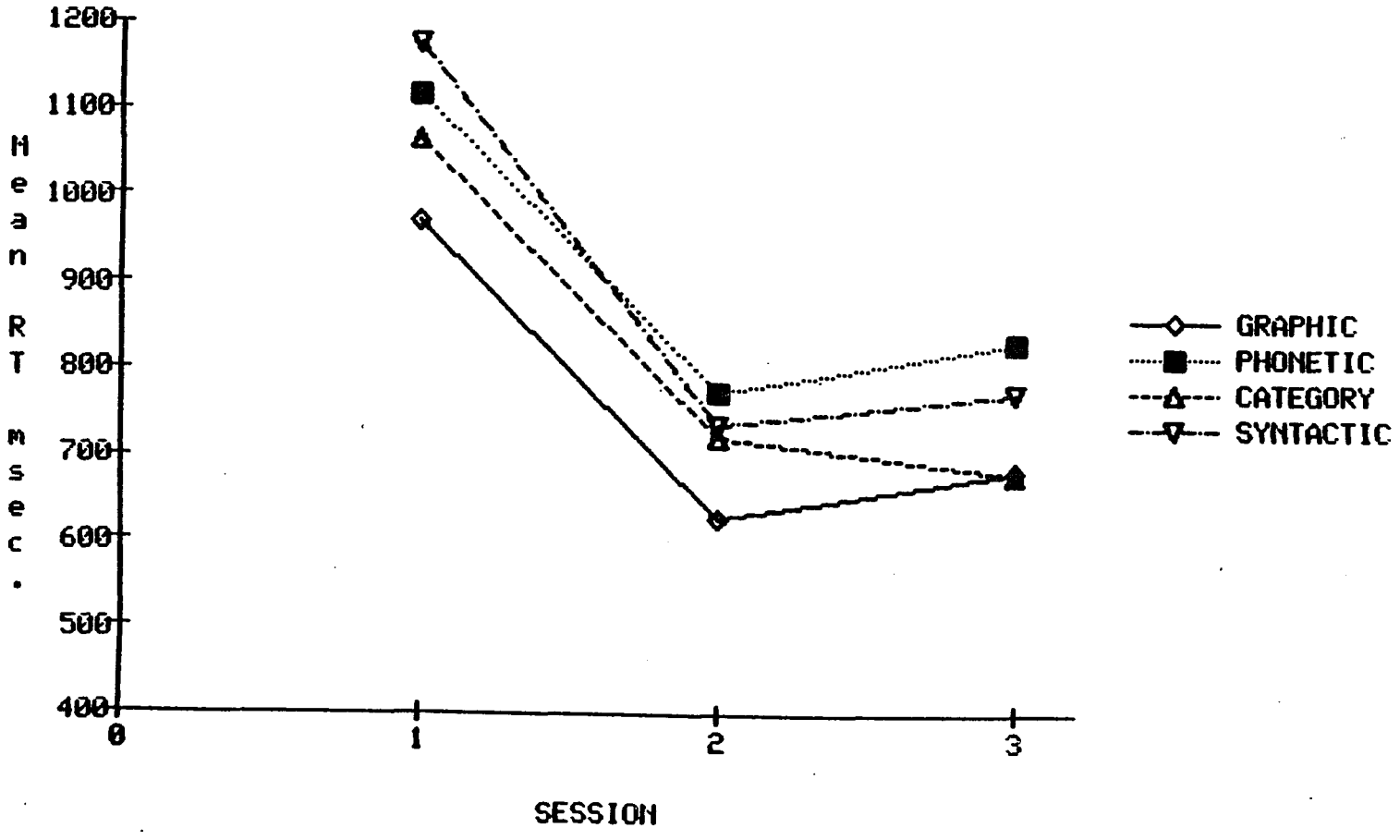


Figure 16

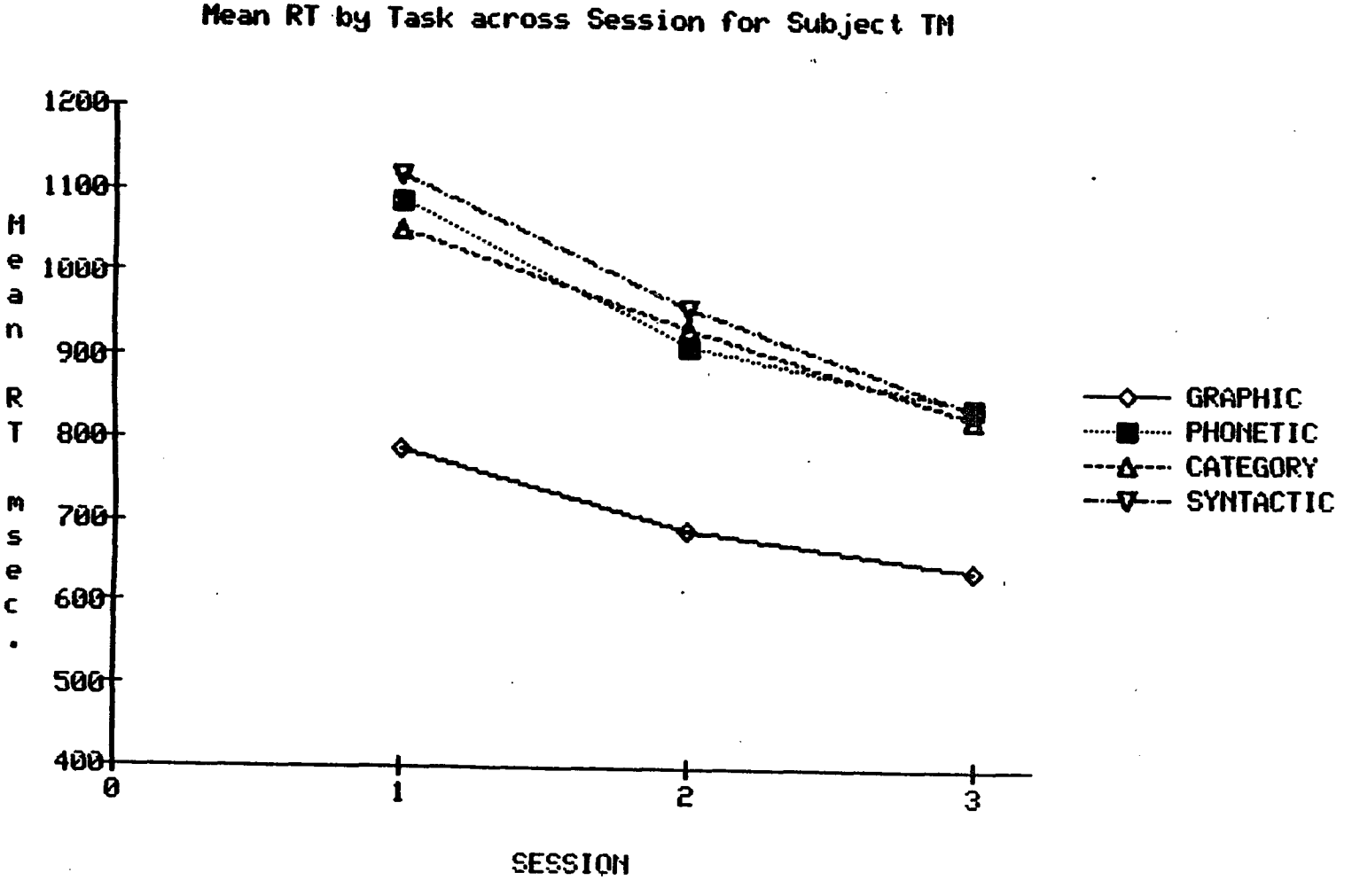
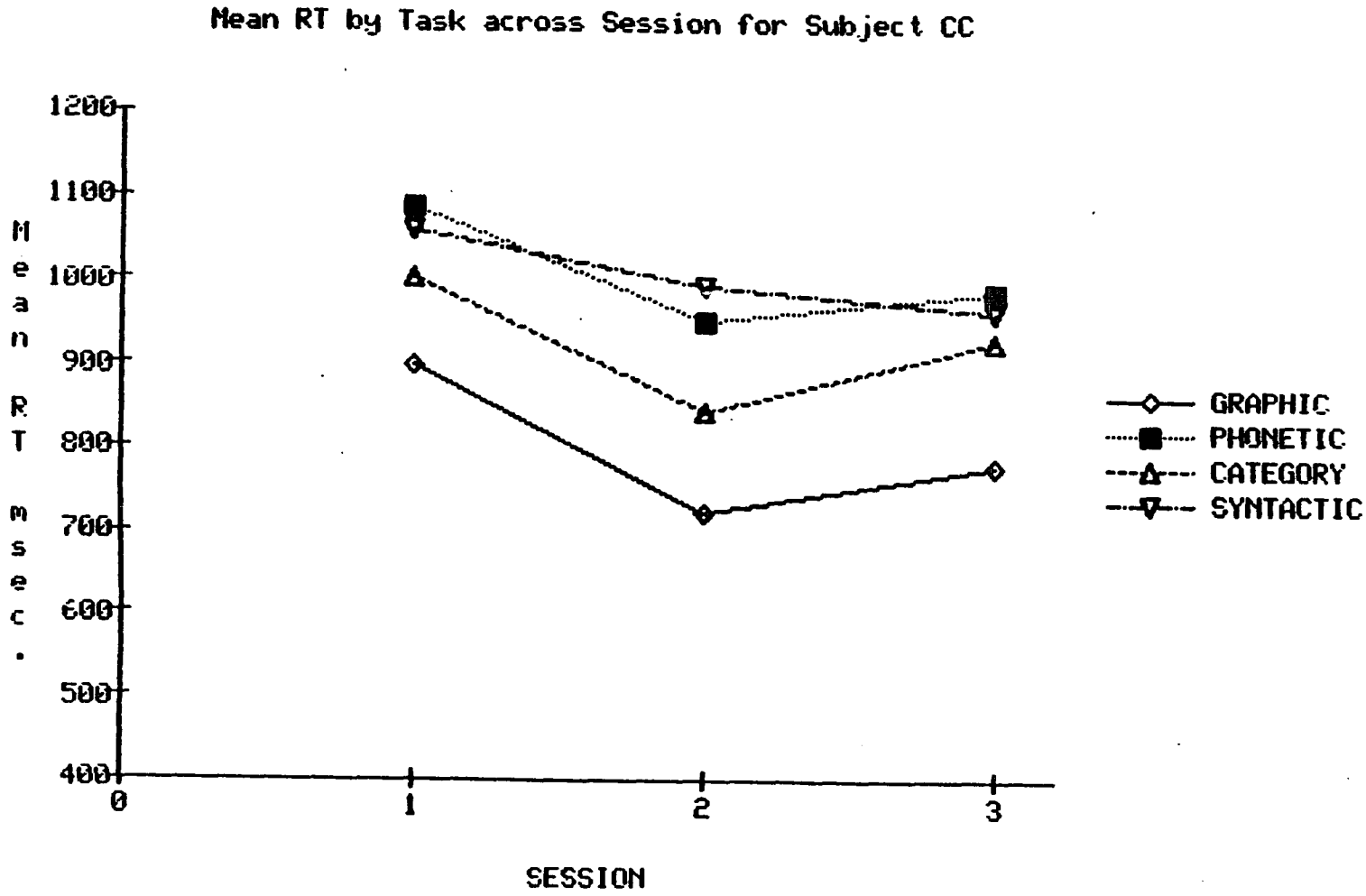

Mean RT by Task across Session for Subject TM
Mean RT msec.
1200
1100
1000
900
800
700
600
500
400
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

Figure 17


Mean RT by Task across Session for Subject CC
1200
1100
1000
900
800
700
600
500
400
Mean RT msec.
0
1
2
3
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

B. Analysis of Individual Differences

The highly significant interaction between the Subjects and the design components of Task, Session, and Category indicated that individual subject performances should be examined more closely. The rate of responses and the accuracy of responses to the tasks, over the experimental sessions, were examined.

Mean reaction time scores for the four tasks and the three sessions were combined and used to order the twelve subjects. Each subject was assigned a rank with the fastest subject assigned a rank of one and the slowest subject a rank of twelve (see Table 3). In this way, subjects were ordered based upon the rate at which they were able to perform the four tasks, which were designed to represent the different processing which can occur in word recognition.

At a finer level of analysis, it was decided to study the reaction time performances of subjects in sessions two and three. In this way, it was possible to view changes in performance over time, but exclude the initial session where response times were more variable (see Appendix D). Mean reaction times were calculated for each subject at these two sessions and subjects were rank ordered on the basis of these performances (see Table 4).

Accuracy measures for the twelve subjects were developed in a fashion similar to the reaction time

Table 3

Subjects Ranked by Mean Correct Reaction Time

Over All Tasks and Sessions

RANK	SUBJECT	MEAN RT	N	STD. DEV.
1	MH	576.1	948	175.6
2	JW	617.4	932	147.3
3	BB	627.7	946	160.1
4	MR	644.8	935	165.1
5	AM	704.7	923	227.6
6	DB	708.9	830	185.7
7	KP	722.5	878	178.6
8	LC	742.0	934	258.1
9	JK	752.0	901	260.4
10	RI	838.6	913	279.7
11	TM	875.5	838	286.9
12	CC	917.3	803	252.5

Table 4

Subjects Ranked by Mean Correct Reaction Time Over All Tasks: Sessions 2 & 3

RANK	SUBJECT	MEAN RT
1	MH	527.9
2	JW	611.4
3	BB	623.9
4	MR	644.2
5	AM	647.2
6	DB	683.7
7	LC	687.8
8	JK	700.2
9	RI	730.0
10	KP	742.9
11	TM	831.6
12	CC	897.1

measures. Subjects were rank ordered based upon their total number of errors, on all of the tasks, over all three of the sessions; generating a coarse representation of the error data (see Table 5). Error scores were then identified for the Category and Phonetic tasks at sessions two and three, permitting a further level of analysis of the accuracy measures (see Table 6).

Finally, an attempt was made to describe the patterns of performance subjects demonstrated on the tasks, over the experimental sessions. These patterns can be seen in the visual representations of the data (see Figures 6-17). As the Syntactic task introduced an imbalance to the design, and the resulting significant effect for Category, it was decided to compare the performances of individual subjects on the Graphic, Phonetic, and Category tasks. While subjects performed most rapidly on the Graphic task, they differed as to their patterns of performance on the remaining tasks. Some subjects were faster on the Phonetic task than the Category task (Graphic*Phonetic*Category or G-P-C) while others were faster on the Category task than the Phonetic task (Graphic*Category*Phonetic or G-C-P). Mean reaction times for each subject were used to create a G-P-C or G-C-P pattern which would describe their performances. The ordering of these three tasks, based upon mean reaction time, provided a coarse representation of the interrelationships between the tasks. Subjects were

Table 5

Errors on Category and Phonetic Tasks

Over Sessions 2 & 3

SUBJECT	SESSION #2		SESSION #3	
	C	P	C	P
JW	3	3	5	2
MR	5	3	2	6
MH	7	6	5	5
BB	5	5	5	7
KP	17	10	12	7
JK	9	7	2	4
AM	4	10	2	6
LC	3	3	0	12
DB	9	16	8	12
CC	16	21	19	24
TM	16	16	11	22
RI	4	12	10	15

Table 6

Subjects Rank Ordered by Total Errors

Over All Tasks and Sessions

RANK	SUBJECT	TOTAL ERRORS	G	C	P	S
1	JW	52	13	17	12	10
2	BB	57	08	14	18	17
3	MH	58	06	22	19	11
4	LC	62	09	07	30	16
5	AM	63	05	15	31	12
6	MR	68	18	14	15	21
7	JK	80	20	22	28	10
8	RI	82	12	21	34	15
9	DB	103	07	31	47	18
10	KP	123	11	46	32	34
11	TM	161	30	45	53	33
12	CC	196	38	53	70	35

identified by one of two patterns of performance on the tasks.

The effects of Session, and its interactions with Task and Subject, indicated that the patterns of performance for groups of subjects will differ based upon the session being looked at. These differences in patterns of performance can be seen in Figures 6 through 17. The G-P-C and G-C-P patterns were then created for each subject at sessions two and three. For some subjects, such as subject MH, there was no change in the order of performances on the tasks (G-P-C remained G-P-C). For another subject, subject DB, there was a change in the order of the mean reaction time performances on the tasks (G-C-P became G-P-C).

To provide an easily understandable descriptor of the separation between the Graphic, Phonetic, and Category mean reaction times within a subject's performance, the Student-t statistic was chosen as a measure of the separation. This provided a measure of the mean inter-task difference relative to intra-task variability.

While a subject may have maintained the same relationship between the tasks (G-P-C or G-C-P), the t-tests indicated the extent of the shift in the relative distance between those tasks. For example, in subject KP, patterns of performance for sessions two and three remained G-P-C. By adding the information provided by Table 7, it became clear that the performances had, in

Table 7

Student t-Test Between Tasks: 2-Tailed Probabilities

(Session 2 * Session 3)

SUBJECT	P < C	G < C	G < P
AM	NS * NS	.001 * .001	.001 * .001
BB	.05 * .01	.001 * .001	.01 * .001
CC	.01 * NS	.001 * .001	.001 * .001
DB	.001 * NS	.05 * .001	.001 * .001
JK	NS * NS	.001 * .001	.001 * .001
JW	.001 * NS	.01 * .05	NS * NS
KP	NS * .01	.001 * .001	.001 * .001
LC	.05 * NS	.001 * .001	.001 * .001
MH	.05 * .01	.001 * .001	.001 * .001
MR	NS * .05	.001 * .001	.001 * NS
RI	NS * .001	.001 * NS	.001 * .001
TM	NS * NS	.001 * .001	.001 * .001

C = Category
G = Graphic
P = Phonetic

NS = not significant

Results in **bold face** type are for mean reaction times in opposite direction indicated

fact, changed. At session two, the mean Graphic task performance was different from the mean Phonetic task performance which was not different from the mean Category task performance relative to the intra-task variability. At session three, the mean Graphic, Phonetic, and Category tasks were all different from one another.

Given my original premise where I posited that the ability to process the phonetic information in words constitutes a major factor in the development of rapid and accurate word recognition, I ordered my subjects based upon this dimension. Initially, subjects were divided into three groups. In the first group were five subjects who consistently demonstrated the G-P-C pattern of performance on sessions two and three. One subject demonstrated a G-C-P pattern at session two and a G-P-C pattern at session three. The remaining six subjects consistently demonstrated the G-C-P pattern. Two members of the G-P-C group, JW and MR, performed the Graphic and Phonetic tasks at rates which were not different from each other. In these subjects, the performance on the Phonetic task was so rapid that it became indistinguishable from the Graphic task. Performance on the Category task, for these individuals was slower than performance on the Graphic and Phonetic tasks. In a similar vein, one subject was identified in the G-C-P group, RI, whose performance on the Category task was not different than performance on the Graphic task, while performance on the Phonetic task

was slower. It was possible for subjects to be so effective on the Phonetic task or the Category task that their performances approximated the rate at which they could make a physical match or mismatch on the Graphic task.

The patterns demonstrated by subjects often changed from session two to session three. For example, one of the subjects who attained a performance on the Phonetic task which approximated the Graphic task, JW, did so by the second session, while another subject, MR, demonstrated a similar performance but did not attain this performance until session three. A number of transition states became evident in the patterns of the subjects' performances. For example, the pattern of performance of subject AM, at session three, was the same as the performance of subject JK at session two. The performance of subject JK at session three was the same as the performance attained by subject KP at session two. The results were arrayed as a continuum with subjects ranging from those who were extremely rapid in responding to the Phonetic task relative to the Graphic and Category tasks and those subjects who responded more rapidly to the Category task relative to the Graphic and the Phonetic tasks. The subject, JW, who exhibited the most rapid performance on the Phonetic task relative to the Graphic and Category task, in the shortest period of time, was ranked as number one. The subject, RI, who exhibited the most rapid

performance on the Category task, relative to the Graphic and Phonetic tasks was ranked as number twelve (see Table 8; Figure 18).

If these patterns of performance represented two different types of subjects, who have different relative abilities in their processing of the orthographic, phonetic, and semantic information in words, then it became reasonable to predict that there could be a correlation between the rank order of subjects based upon their patterns of performance and the rank order of subjects based upon the speed and accuracy of their overall performances.

A Spearman Rank Order correlation indicated that the order of subjects based upon their patterns of performance on the Graphic, Phonetic, and Category tasks and the order based upon their rate of responding to all of the tasks was highly correlated; $r=.87$, $p=.001$ (see Figure 19). Subjects who demonstrated a pattern of performance in which the rate of response to the Phonetic task was rapid relative to the Graphic and Category tasks were fastest on all of the tasks. The rank order of subjects based upon their patterns of performance was also highly correlated to the ordering of subjects based upon the total number of errors on all of the tasks; $r=.64$, $p=.012$ (see Figure 20). The subjects who performed best on the Phonetic task relative to the Graphic and Category tasks made the fewest errors on all of the tasks. A Spearman Rank Order

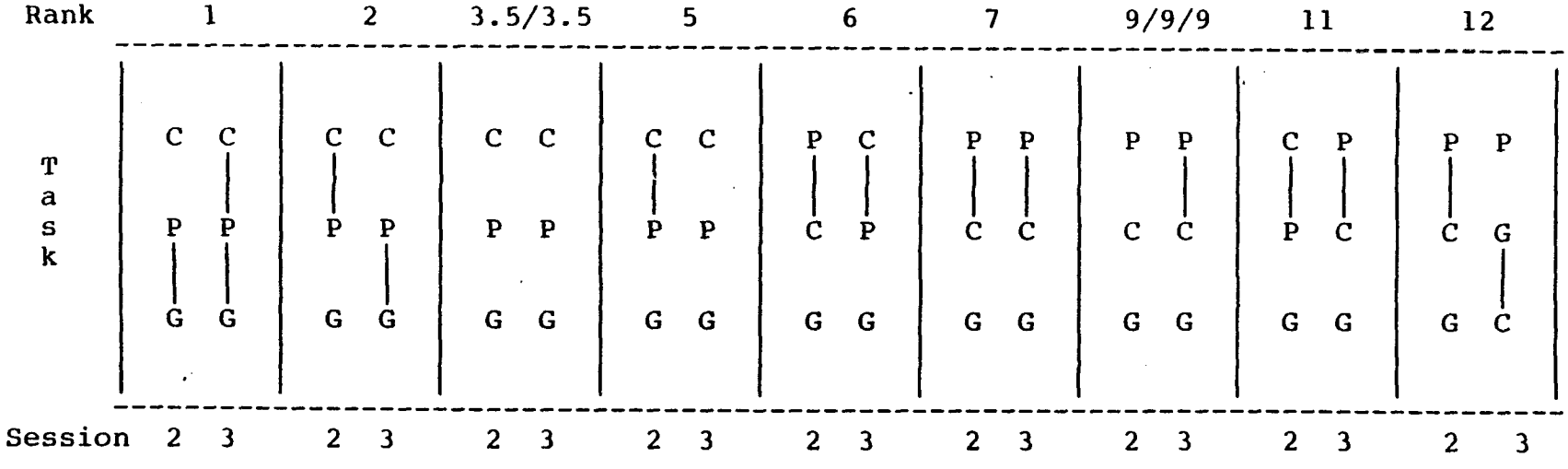
Table 8

Subjects Ranked According to the Pattern Analysis of Reaction Time Performances

RANK	SUBJECT
1	JW
2	MR
3.5	MH
3.5	BB
5	KP
6	JK
7	AM
9	DB
9	LC
9	CC
11	TM
12	RI

Figure 18

PATTERN ANALYSIS OF REACTION TIME PERFORMANCES



G = Graphic
P = Phonetic
C = Category

Mean reaction times for tasks which are connected are not different from one another

Figure 19

Mean Individual Reaction Time: All Tasks, All Sessions

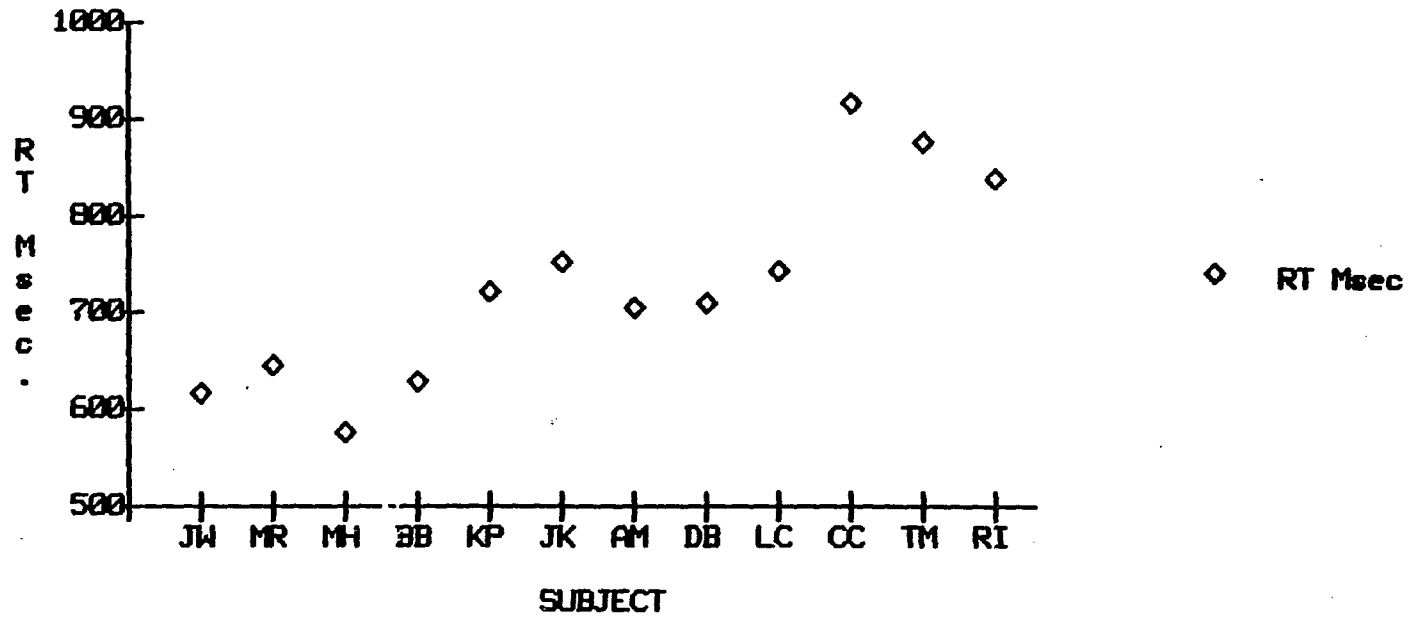
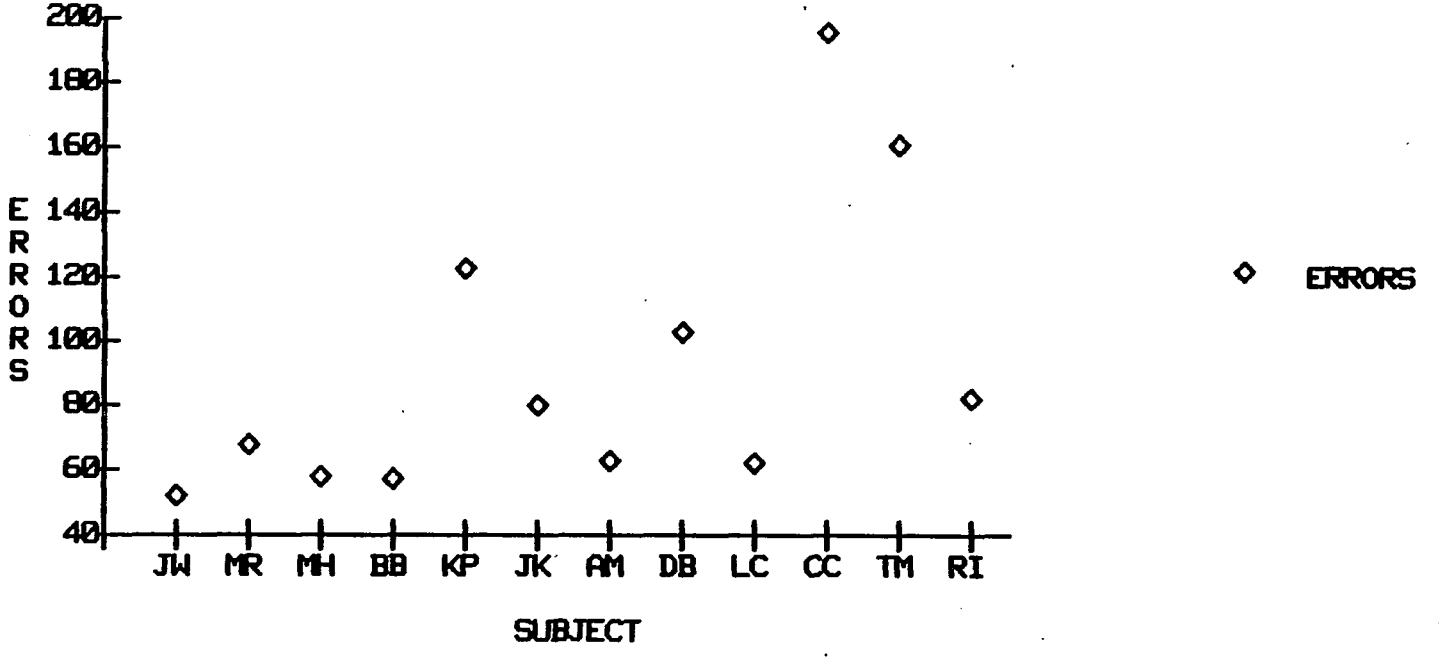


Figure 20

Individual Error Scores: All Tasks, All Sessions



correlation demonstrated that the order of subjects based upon reaction time to all of the tasks, over all of the sessions, and the rank order based upon the total number of errors to all of the tasks, over all of the sessions, was highly correlated; r=.82, p=.001 (see Figure 21). This finding could have been anticipated, as a skilled reader can be considered both rapid and accurate.

When the data is collapsed over sessions two and three, these relationships remained the same. Ordering of subjects based upon mean reaction time performances and the patterns of performance on the tasks were highly correlated; r=.82, p=.001 (see Figure 22). Accuracy measures were analyzed for errors on the Phonetic and the Category tasks (see Table 5). A Spearman Rank Order correlation demonstrated a significant relationship between the order of subjects based upon their patterns of performance and the number of errors on the phonetic task; r=.84, p=.001 (see Figure 23). The relationship between the patterns of performance on the tasks and the number of category errors was not significant; r=.38, p=.111 (see Figure 24). The number of errors on the Phonetic task were correlated to those subjects who were the fastest and most accurate on all of the tasks, while the number of errors on the Category task did not correlate to the fastest and most accurate subjects.

The mean reaction times for the fourth session were analyzed to determine whether there was any impact of the

Figure 21

TOTAL ERRORS BY REACTION TIME: ALL SUBJECTS, ALL SESSIONS

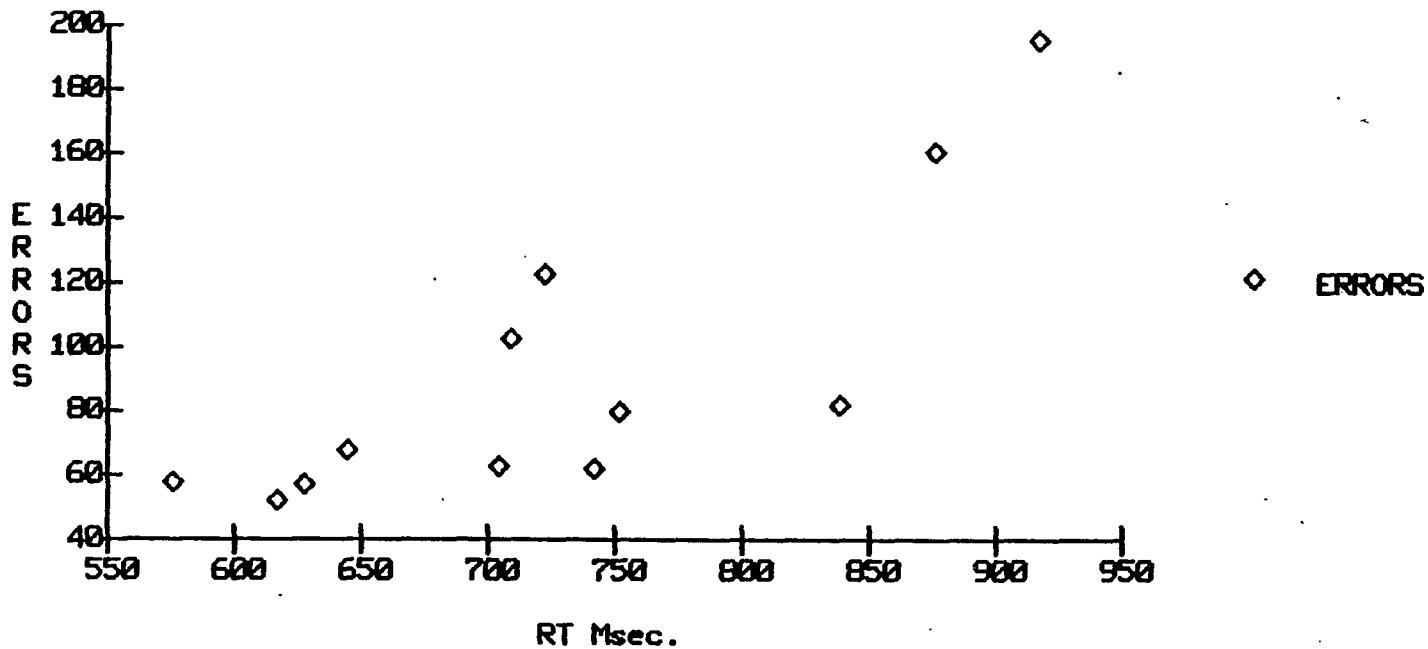


Figure 22

Mean Individual Reaction Time: All Tasks, Sessions 2 and 3

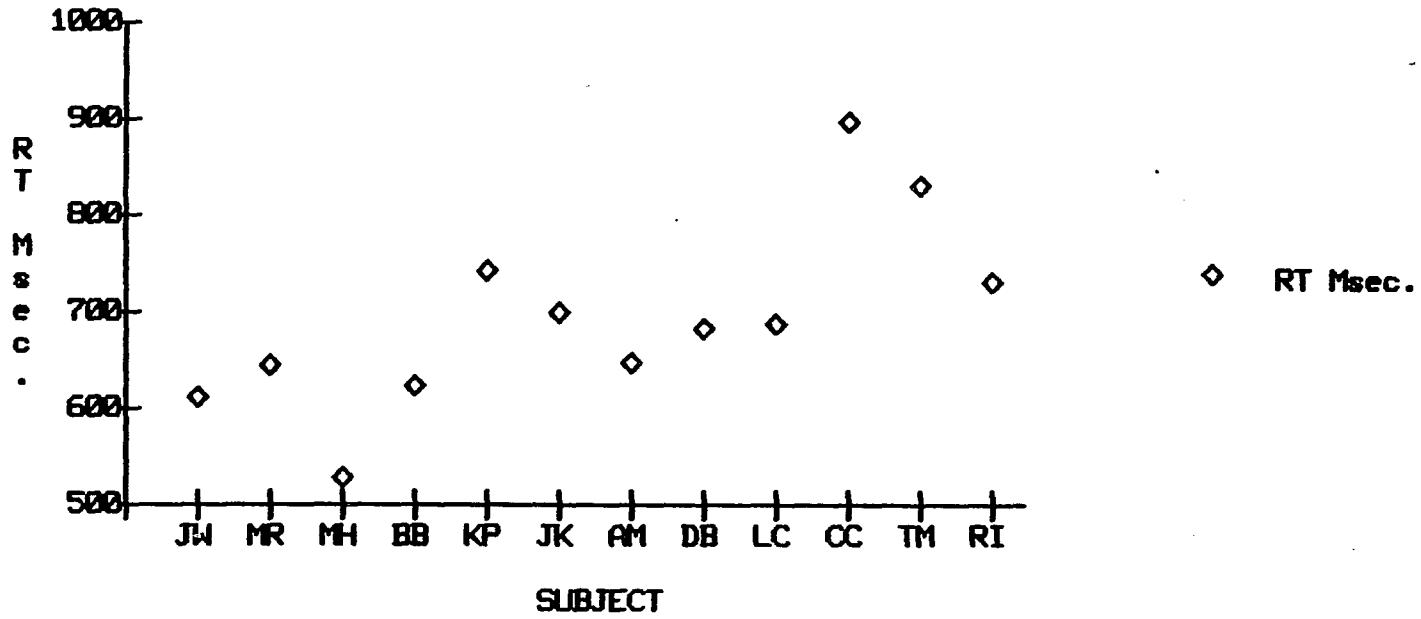


Figure 23

Individual Error Scores: Phonetic Task, Sessions 2 and 3

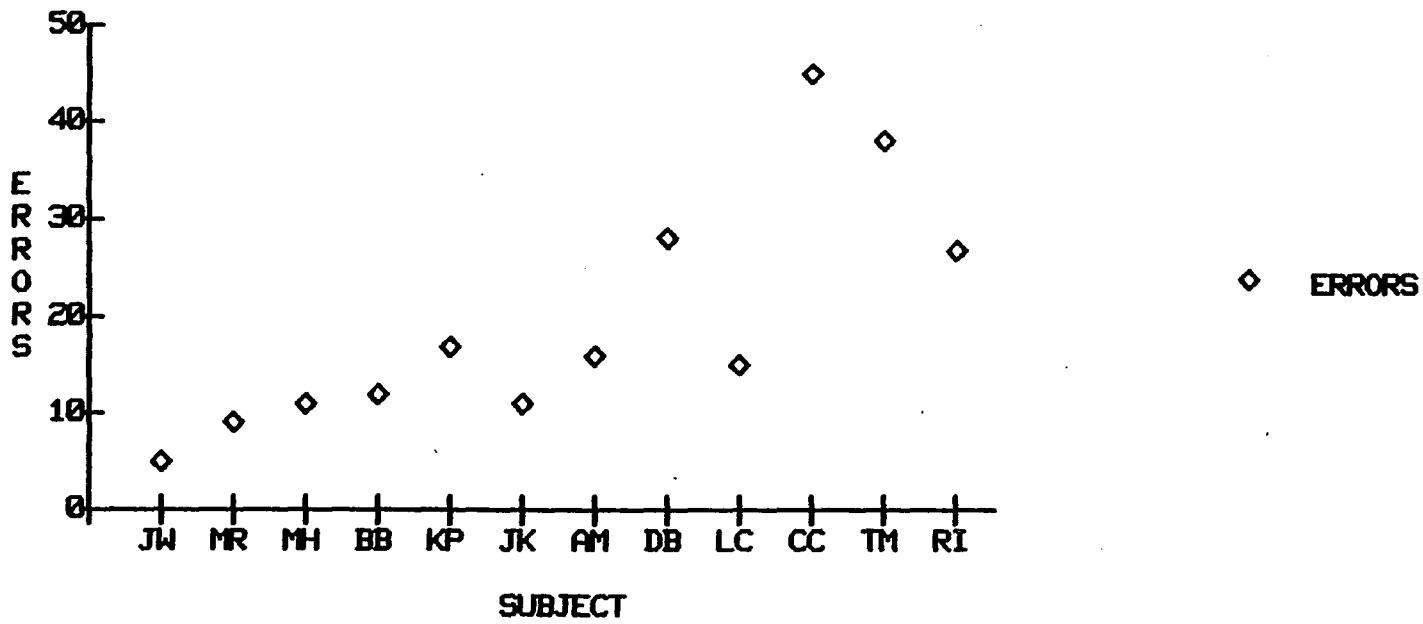
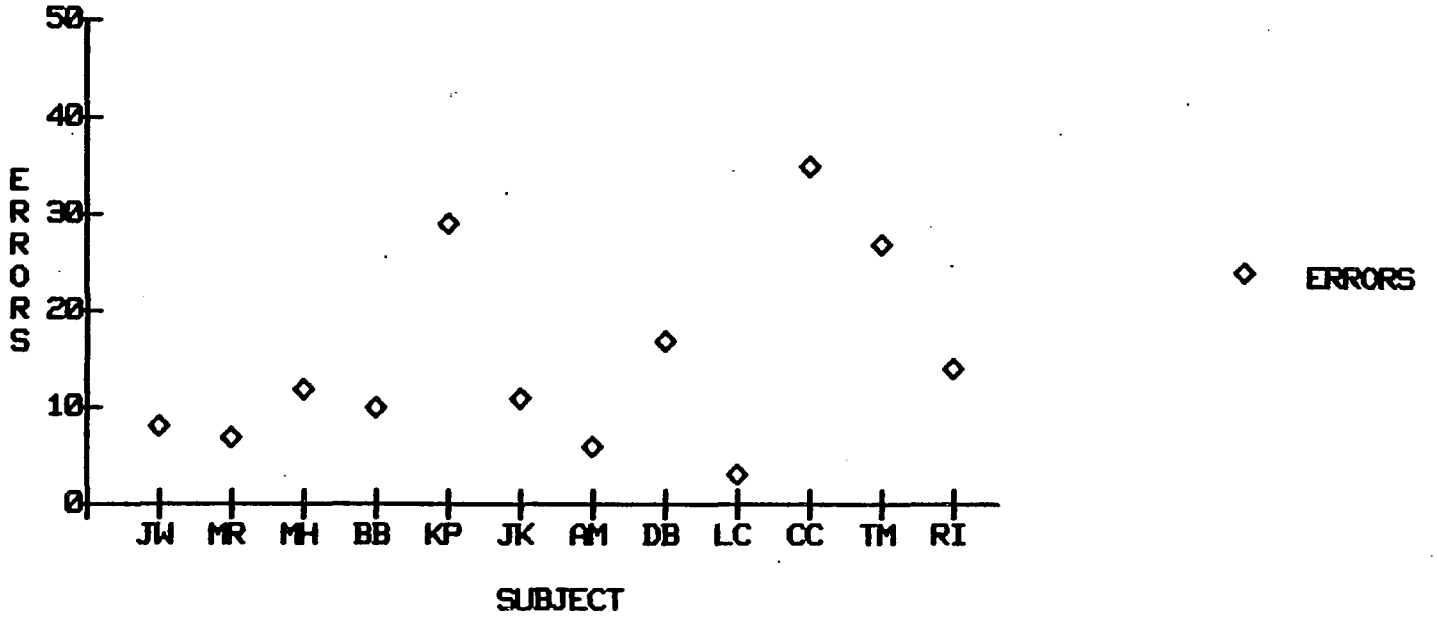


Figure 24

Individual Error Scores: Category Task, Sessions 2 and 3



introduction of uncertainty in the stimulus set. The items which were altered, so that the cue did not relate to the task which followed, were excluded from the analysis. As with the exclusion of items on which subjects did not respond correctly, the type of processing which occurred on these trials was indeterminate. In addition, there was not a sufficient number of items to analyze independently. The results demonstrated that the overall mean reaction time on session four was significantly slower than on session three (see Appendix D).

Reaction times for each subject, comparing sessions three and four, were then charted (see Appendix D). Inspection of the data demonstrated that the patterns of performance did not predict who would respond to the uncertainty introduced by this session. For example, subjects who were rank ordered at number two (subject MR) and number nine (subject DB) both demonstrated slowed reaction times as a result of the new condition. Subjects ranked number one (JW) and number eleven (TM), based upon their patterns of performance on the tasks, did not respond to the uncertainty introduced in the session.

C. Evoked Potentials

Evoked potential data was collected for each subject during session three. One sweep of the evoked potential was collected while subjects viewed the cue which preceded the presentation of the word pair. Correct

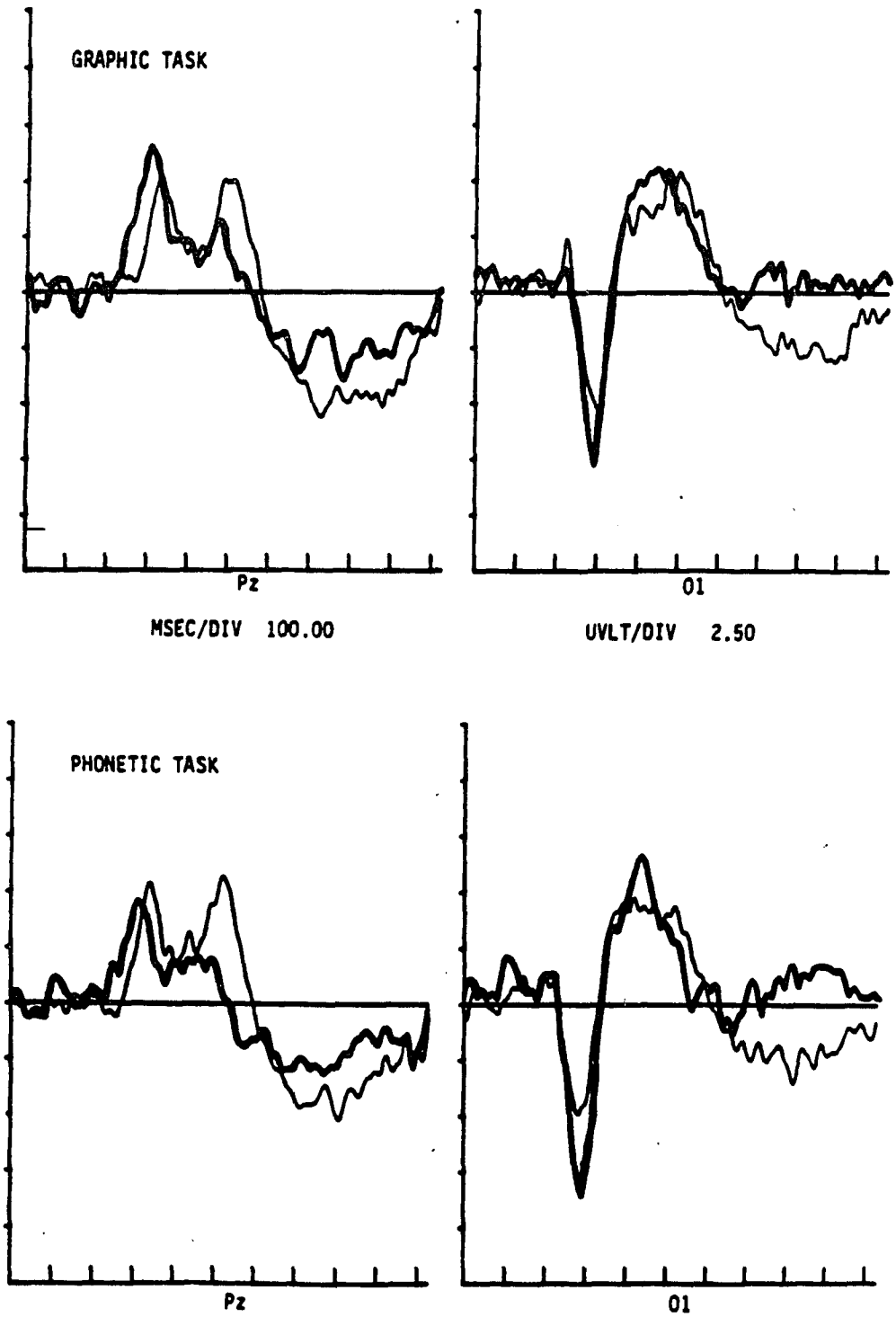
responses, those for which it can be assumed the required processing was engaged in, were averaged for each of the four tasks. The resulting waveforms were used to determine amplitude and latency measures at P2, P3, and the late negativity. As N2 was not evidenced for most subjects, measures were not determined for this component of the waveforms. (see Appendix E).

Using the behavioral data to guide the analysis of the evoked potentials, those subjects who represented the two patterns of performance on the tasks which were the most different were compared. Those subjects who demonstrated a performance pattern of G-P-C on sessions two and three and those who demonstrated a pattern of G-C-P on sessions two and three were compared. In so doing, the analysis focused on the two groups for which, it could be assumed, there would be the greatest differences. Grand averages were created for the two groups of subjects and the four tasks (see Figure 25).

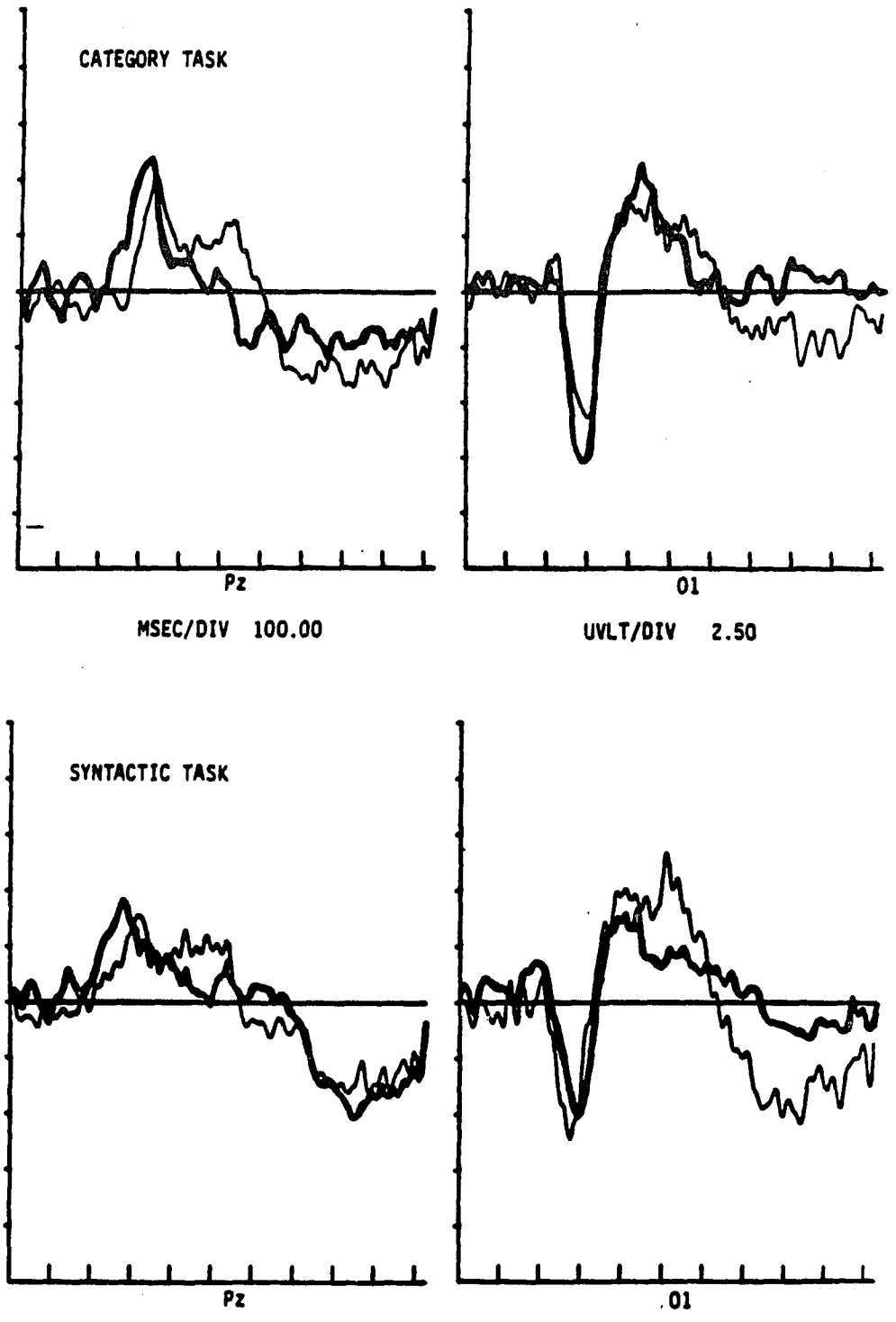
The waveforms which represented the G-P-C and the G-C-P groups were measured for amplitudes and latencies at P2, P3, and the late negativity (see Appendix E). The Randomization test for two independent samples (Siegel, 1956) was performed on the amplitude and latency measures for these evoked potential waveform components between the two groups. In most cases, amplitudes and latencies were measured for each subject at the point on the waveform which represented the maximum amplitude for

Figure 25

Grand Averages, by Task, for G-P-C and G-C-P Groups



Grand Averages, by Task, for G-P-C and G-C-P Groups



the component of interest. Measures of the later negativity were taken at the maximum (negative) amplitude identified in the grand averages for the groups of subjects. This test is a robust nonparametric technique for testing the significance of the difference between the means of two independent samples when n_1 and n_2 are small.

No significant differences were evident for the amplitudes or latencies of P3 or the later negativity on any of the tasks. While no significant effect was found for the amplitude of P2, the latency of P2 for the G-P-C group was significantly faster than that for the G-C-P group in each of the four tasks (see Figure 26).

As no significant difference could be found between the four tasks, a grand average was created which constituted a compilation of these waveforms. The increase in the number of sweeps of the evoked potential results in a waveform with increased resolution (Spehlman, 1985). No significant differences were demonstrated for the amplitudes and latencies of N2, P3, and the later negativity, as well as for the amplitude of P2. The latency of P2 was, once again, significantly different for the G-P-C and the G-C-P groups. In subjects who demonstrated the G-P-C pattern of performance, the P2 wave of the evoked potential occurred significantly earlier than for those subjects who demonstrated the G C P pattern of performance (see Table 9).

Figure 26

Grand Averages, Across Task, for G-P-C and G-C-P Groups

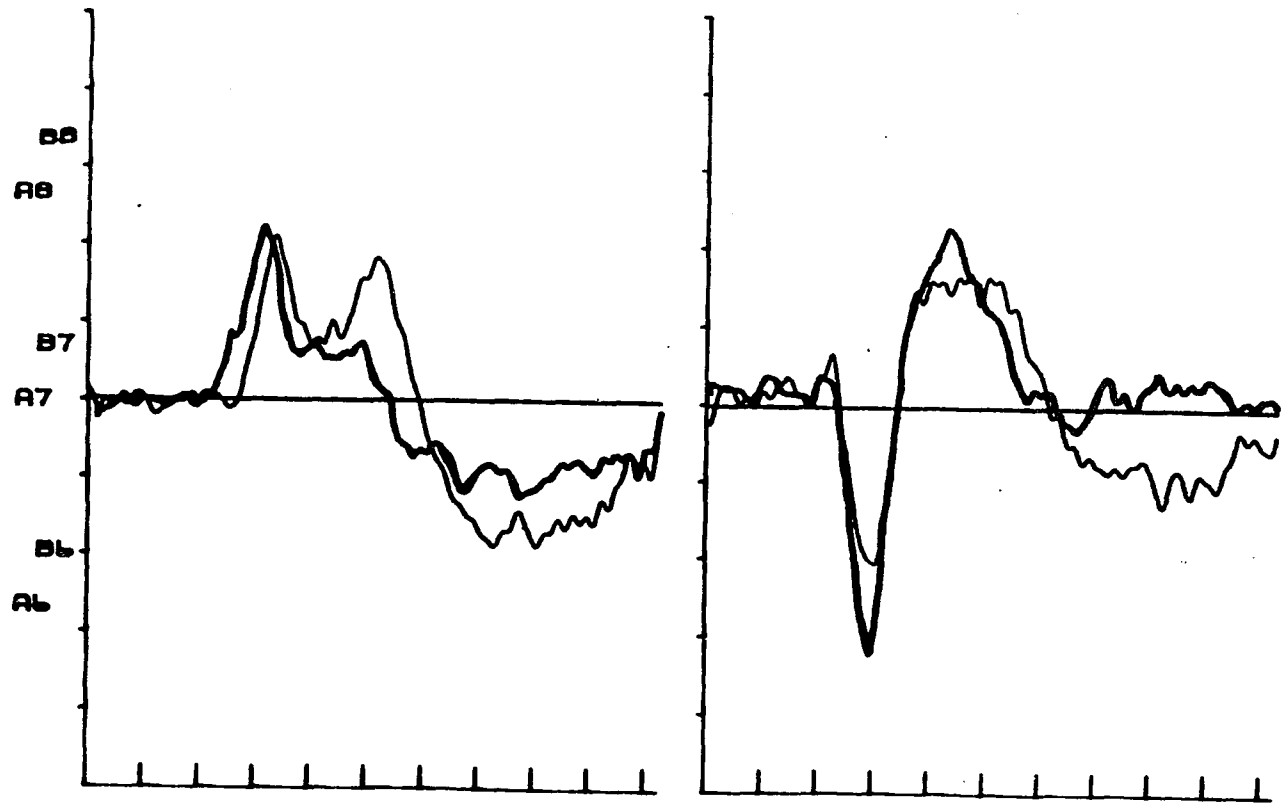


Table 9

Amplitude and Latency Measures of P2 Waves

Group: G-P-C		Latency (msec.)	Amplitude (uvlt.)
Subject:	JW	214.0	7.59
	MR	234.0	5.17
	MH	212.0	5.49
	BB	188.0	6.29
Group: G-C-P			
Subject:	DB	246.0	4.98
	LC	218.0	7.50
	CC	260.0	5.78
	TM	236.0	3.02
	RI	238.0	5.94

V. DISCUSSION

The skill of reading provides an example of a complex cognitive skill which requires a number of subskills or component processes in it's performance. There is evidence from cognitive psychology, neuropsychology, and developmental psychology which supports the notion that the different types of information that can be derived from words involve distinct, and in some cases isolable, components which interact during word recognition. This dissertation has attempted to investigate the processing of the graphic, phonetic, semantic, and syntactic information which can be derived from words.

A major aim of this study was to eliminate many of the factors which could make it difficult to interpret the data. To this end, an appropriate task and experimental conditions were developed. For example, in the task which required subjects to make comparisons of word pairs based upon orthographic, phonetic, semantic, and syntactic dimensions, word lists were developed which controlled for word frequency and length. Further, the stimuli required subjects to engage a particular type of processing. An example can be found in the choice of stimuli for which a

visual, or orthographic, match or mismatch was required. By using a direct match between two words (GOAT...GOAT), or a mismatch which involved the insertion of a non-letter symbol (GOAT...G*AT), the task could be completed without utilizing the other information which can be available in the words. The orthographic, phonetic, semantic, and syntactic stimuli were constructed to require, as much as possible, that their completion involve processing the type of information being investigated.

The design of the experimental conditions, which included the presentation parameters, session length, and number of sessions, were considered in the attempt to minimize the "noise" that could make the resulting responses difficult to interpret. The stimuli were presented in quasi-random order, following a cue, and in a sequential manner. The subjects were cued as to the type of processing which would be required on a particular task. This information, in conjunction with the information provided by the appearance of the first word, greatly constrained the possibilities which could follow. The quasi-random ordering of the stimuli required that subjects constantly switch from one type of processing to another. In order to minimize the variability of responses to the task, subjects viewed the stimuli over three experimental sessions. The reaction times and error rates for session one were not included in some of the subsequent analyses as this session constituted a training

trial, and the remaining sessions represented the point at which a steadier state of behavior had been attained (see Appendix C). The necessary number of trials and sessions required to minimize the variability of responses were identified in the pilot study. Reaction time and accuracy measures were collected to all sessions, while evoked potential responses were measured during the third session.

It is acknowledged that there are many factors which can affect the reaction time performances of individuals who are responding to tasks such as those used in this dissertation. The study attempted to control as many of these factors as possible. Certain choices, such as the introduction of the syntactic task and the imbalance which resulted in the design, would not have been made with the awareness that hindsight provides. It is also important to note that there is no independent data base with which to compare the results. Neuropsychological testing was not used as an independent measure because the reading ability exhibited by the subjects was at a higher level than the sensitivity of the measures which were available. In spite of these issues, let us consider the patterns of performance which resulted as if they were truely an expression of the interaction between subjects' abilities in performing tasks which require orthographic, phonetic, semantic, and syntactic processing.

The first goal of the data analysis was to consider

the relative contributions of the four tasks, the four word categories, the three sessions (later the fourth), and the twelve subjects to the reaction time performances. The performances of the twelve subjects resulted in an extremely significant effect of Task, a result which was of fundamental importance to the investigation. It was the ability to discriminate between the four tasks, tasks that were carefully designed to require orthographic, phonetic, semantic, or syntactic processing, that enables one to consider that subjects were, in fact, engaging in different modes of processing in the successful completion of the tasks. Further analysis demonstrated that, when looking at the entire data set, the arrangement of the four tasks, as measured by reaction time, was somewhat different than the results of the Pilot Study. The Graphic task was consistently the fastest, a finding which was predicted by the proposed organization of the visual language system. The task was constructed in a manner that would permit its successful completion on the basis of a visual match or mismatch and not require further processing. Unlike the results of the pilot study, in which the Phonetic and Category tasks were indistinguishable, the Category task was responded to at a significantly faster rate than the Phonetic task. As in the pilot study, the Syntactic task required the most time to complete. The difference between the Category and Phonetic tasks was consonant with the unsolicited reports

of subjects that the Phonetic task was more difficult and effortful. By the third session, however, the Graphic task remained the fastest but the Category and Phonetic tasks were indistinguishable from one another, as hypothesized.

The highly significant effect of Session also constituted a fundamental finding in the investigation. Subjects were provided with an environment in which they could practice the task, and it was assumed that such practice would lead to reduced response times as well as a reduction in the variability of responses. Reaction time data demonstrated that the three sessions were significantly different from one another. Further analysis demonstrated that the sessions differed in a predictable manner. That is, sessions one, two, and three were significantly different from one another with a progressive decrement in the speed and variability of responses. Further, the variability of responses in session one was significantly different than the variability of responses in sessions two and three. No significant difference was noted in the variability of sessions two and three. Unlike the results of the pilot study, the data indicated that subjects were continuing to improve and that, while responses were less variable, steady-state behavior had not been attained.

The significant effect of Word Category constituted another departure from the data analyzed in the pilot study. When the stimuli were originally developed, the

four word categories were equally represented in the four tasks. However, in attempting to create a task which, more reliably, would require syntactic processing to complete, an imbalance was entered into the design. As previously discussed, the Animal word category is the only word category represented in the Syntactic task. Post hoc comparison of means demonstrated that responses to the Animal word category were significantly different than those to the other three word categories. It is also important to note that the responses to the Animal word category were slower than those to the other categories of words. This is important, as the difference is not the result of the over respresentation of the set of Animal words. Rather, the Syntactic task required the longest time to complete and, as a result, skewed the mean performance time on the Animal word category. By the third session, there was not a significant effect of Word Category. While the Animal word category appeared the most often in the stimulus set, the word pairs in the Syntactic task were under-represented. With sufficient experience on the task, and the subsequent improvement in reaction time, the Word Category effect was not significant.

The significant effect of Task by Session represents an important finding in the present study. This interaction indicated that the performances on the four tasks varied over the experimental sessions. The effects of the practice which was provided can be seen in this

interaction. As the sessions progressed, performances on the tasks became more rapid and less variable.

While a significant Task by Category interaction was demonstrated, this was predictable considering the unique representation of the Animal word category in the Syntactic task. The lack of significance in the Session by Category interaction demonstrated that the imbalance caused by the Syntactic task is a stable effect, which does not change from session to session. The significant three way interaction of Task by Session by Category can also be understood when one considers the contribution of the significant Task by Session and Task by Category interactions.

Perhaps most important to the present study was the significant effect of Task by Session by Category by Subject. This finding suggests that, not only do performances on the tasks differ from session to session, but that subjects demonstrated different patterns of performance on the tasks over the sessions. While the data set, as a whole, confirmed the hypothesized structure of the visual language system which was posited, observation of the individual performances indicated that the twelve subjects were demonstrating different patterns of performance on the tasks. An appreciation for this effect can be derived from visual inspection of the charted mean reaction times for each subject on the four tasks over the three sessions (see Figures 6-17). These results led to

a realization that the data needed to be understood in terms of the relationships between the performances for each subject on the four tasks, over the experimental sessions.

To achieve this end, mean reaction time performances for each subject were calculated and plotted. An analysis of an individual subject's performance patterns was used to describe the relationships between reaction time performance on the Orthgraphic (G), Phonetic (P), and Category (C) tasks. The Syntactic task was not included in this analysis because of the lack of equal representation of the word categories in the stimuli. Further, there were fewer trials on this task. Subjects were assigned a rank which was based upon performances on the Graphic, Phonetic and, Category tasks. Spearman rank order correlations were then performed between the rank orderings based on the pattern analysis and rank orderings based upon reaction time and accuracy measures.

The results demonstrated that, those subjects whose performances were characterized by a relationship between the three tasks in which the response speed to the Phonetic task approximated the Graphic task, relative to the Category task, were the fastest and most accurate on all tasks. Those subjects who demonstrated the opposite pattern of performance, one in which responses on the Category task approximated the Graphic task, relative to the Phonetic task, were the slowest and least accurate on

all of the tasks. Subjects were placed on a continuum which described the relationships between the three tasks.

The results indicated that there was a significant correlation between the relationship of the three tasks, as expressed in the pattern analysis, with the number of errors on the task. Subjects who presented with a G-P-C pattern of performance made fewer errors than those who presented with a G-C-P pattern of performance. The G-P-C group was faster and more accurate on all of the tasks. In addition, there was a significant relationship between the pattern analysis and the number of errors on the phonetic task. This is important as there was <u>not</u> a similar finding with regard to the errors on the category task. In other words, the number of errors in the phonetic task predicted where an individual would be ranked in the pattern analysis, while the errors on the category task made no prediction as to how a particular subject would perform.

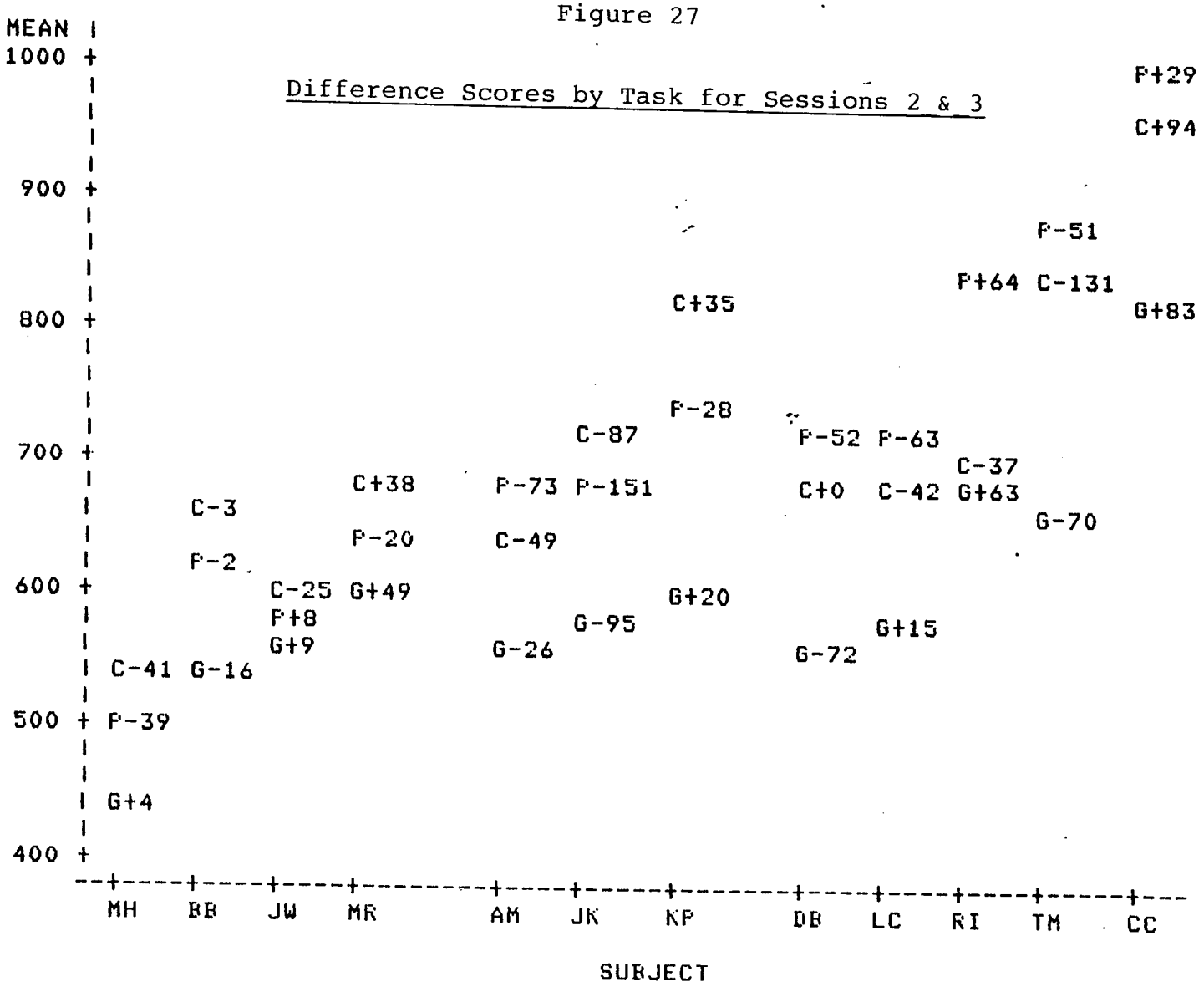
The analysis of the patterns of performance for the twelve subjects were compared to reaction time measures which included the performances on the phonetic task. In order to account for the possibility that the correlation between the pattern analysis and reaction time was due entirely to the responses on the phonetic task, mean reaction time scores for each subject at sessions two and three were calculated excluding responses for the phonetic task. A Spearman Rank Order correlation demonstrated a significant relationship between the order of subjects

based upon their patterns of performance and the mean reaction times which excluded the phonetic task; $r=.71$, $p<.05$.

The data which indicated that subjects were continuing to improve on the tasks at the third session raises an interesting set of questions. If given sufficient time on task, would those subjects who were slowest and least accurate on the tasks , the G-C-P group, eventually attain a performance pattern of G-P-C? Would there be a difference between the subject who would eventually demonstrate a G-P-C pattern and subjects who maintained a G-C-P pattern. To consider this issue, difference scores were calculated for each task between sessions 2 and 3. The results were then plotted according to the pattern analysis of reaction time performances. The result of this exercise (see Figure 27) seems to indicate that some individuals (e.g., subjects AM & DB) were making disproportionate gains in reaction time on responses to the Phonetic task and that, given sufficient time, a G-P-C pattern of performance would be attained. Other subjects (e.g., RI & TM) were making gains on the Category task, suggesting that they would continue to demonstrate a G-C-P pattern.

While not included in the pattern analysis, visual inspection indicates that the responses to the Syntactic task approximate the Category task by the third session. In fact, the coarse assignation of G-P-C or G-C-P patterns

Figure 27


Difference Scores by Task for Sessions 2 & 3
MEAN
1000
900
800
700
600
500
400
P+29
C+94
P-51
P+64
C-131
C+35
G+83
P-28
C-87
P-52
P-63
C-37
C+38
P-73
P-151
C+0
C-42
G+63
C-3
G-70
P-20
C-49
P-2
C-25
G+49
G+20
P+8
G-95
G+15
G+9
G-26
G-72
C-41
G-16
P-39
G+4
MH
BB
JW
MR
AM
JK
KP
DB
LC
RI
TM
CC
SUBJECT

of performance would remain the same if the Syntactic task (S) was inserted in place of the Category task. It is possible that this result was due to subjects performing the task as a high order category task. For example, a "yes" response is always a noun and a verb, while a "no" response will always consist of two nouns. The diminished number of trials on this task, due to the difficulties in constructing the task, made both the reaction time data and the evoked potential data more variable than that for the other three tasks.

The results of the final session, session four, were difficult to interpret. It was expected that the introduction of uncertainty would have the greatest impact upon the most vulnerable subjects. In this case, the most vulnerable subjects would be those with the G-C-P pattern of performance. This did not turn out to be the case. Subjects who were very rapid and accurate on the tasks were affected as well as subjects who were not rapid and accurate. Further, subjects were not affected who were ranked at both ends of the continuum based upon the pattern analysis of performance. It was not possible to identify a pattern which would explain the behaviors on this session.

The results of the evoked potentials collected during the task demonstrated no significant effects P3 or the later negativity. On reflection, this is not terribly suprising. Initially, it was hoped that a difference in

the allocation of resources for the different tasks could be demonstrated. However, subjects were only exposed to four different words (LOOK, SOUND, GROUP, SPEECH) and they viewed them repeatedly. The one consistent and significant difference in the waveforms between the G-P-C and the G-C-P groups was in the latency of the P2 wave. This wave is usually considered an exogenous, or data driven waveform. While there is little reported data on the relationship between P2 latency and skilled word identification, Kok and Rooijakkers (1985) reported latency differences in children and adults on a word recognition task. Presented as a minor finding in the study, 5 and 6 year old children demonstrated a mean latency of P2 at 280 milliseconds while the mean latency for a group of adults, aged 20-32, was 240 milliseconds. In the group of sophisticated readers who participated in this dissertation, the slower and less accurate group (G-C-P) demonstrated a mean P2 latency of 240 milliseconds while the mean latency for the faster and more accurate group (G-P-C) was 212 milliseconds. While there is some evidence that P2 latency can decrease during adolesence (Spehlmann, 1985) it is interesting to consider the fact that the more skilled readers exhibited a P2 wave at an earlier latency than less skilled readers. Perhaps the earlier P2 in skilled readers represents an early integration which is utilized in the later processing of the visual form.

The results of the study are consonant with a

neuropsychological approach to the study of cognitive processes. This approach, which posits that all behavior is mediated by the brain and the central nervous system, views individuals as representing varying degrees of cerebral, or cognitive, function. Individuals who are exceptional, normal, or impaired, can all be viewed as existing on a continuum of functioning which is supported by the brain. This is quite different than the view that once a skill is acquired in a "normal" manner it becomes a unitary entity. For example, once an individual becomes a skilled reader he performs that task in the same manner as any other skilled reader.

The present study suggests that, within a group of individuals that are highly sophisticated readers, there are different abilities in the processing of words based upon their orthographic, phonetic, semantic, or syntactic characteristics. The transition states which were demonstrated in the rank ordering of the twelve subjects supports the notion of a continuum of abilities. In addition, a configuration of those relative abilities was discerned which identified the subjects who were the fastest and most accurate on all of the word comparison tasks. The results suggest that even a group of highly sophisticated readers can be placed on a continuum which represents varying degrees of functioning.

The findings of the study also provide some insight into the data on the development of skilled reading. There

are numerous indications that children who experience a variety of difficulties with the processing of phonetic information (Mitchell, 1982) are at risk of not developing into skilled readers. This does not mean that the processing of words during reading must pass through a stage of phonological decoding. It suggests that phonological processing capability plays a role in the development of skilled reading. The data indicates that those individuals who are most efficient as phonological processors are the fastest and most accurate at performing all of the tasks.

In attempting to describe the information processing which is necessary for reading to occur, researchers have constructed elaborate schematic models which identify the many steps required to complete the task. These models have gained some popularity in the study of reading disorders (Coltheart et. al., 1980). The models which result from such an approach generate so many steps, and so many individal routes, as to make them unlikely representations of brain function. The number of steps required in such models, which are presented sequentially, would result in extremely slow processing. While being able to process information at impressive rates, the brains "hardware" is not rapid enough to support such models (Feldman & Ballard, 1982). In addition, the information processing capabilities of the brain provide an impressive example of "efficiency." Researchers have

noted the capacity of neural systems to accomodate an enormous amount of data and process it rapidly and accurately (Treisman & Gelade, 1980; Gibson, 1971). The elaborate models which create sepArate routes and many sequential steps for the completion of a complex task suggest mechanisms that are both cumbersome and inefficient.

An alternative means to the understanding of a complex cognitive function such as reading can be found in the investigation of the relationships between the different types of information which are involved in the successful completion of the task. In this dissertation, orthographic, phonetic, semantic, and syntactic information were identified as sources of knowledge which are involved in the recognition of words in reading. The identification of these knowledge sources was effected through evidence provided by the study of individuals who have lost the ability to read, study of the development of the reading process, and experimental studies of cognition. The present study was designed to study the interplay between these different, multiple, sources of knowledge.

The processing of each of these four types of information, orthographic, phonetic, semantic, and syntactic, can be viewed as a "unit." They are similar to other neural processing units as they accept an input, perform an operation on it, and pass the information along

to other units. Such units have been described by Allen (1983) as subprocessors. In his subprocessor based system there exist a finite number of entities which are engaged in the performance of all psychological tasks. A particular task (i.e., phonetic decoding) could be the result of a single subprocessor or the result of several subprocessors interacting with one another. As it is unlikely that any complex task is a unitary function, the information processing required to complete a complex task becomes a dynamic term describing the interplay between the units or subprocessors.

The question which remains concerns the nature of the interplay between these subprocessors. Grossberg & Stone (1986) have proposed a model for word recognition in which an input generates a spatial pattern of activation in the brain. This pattern is then processed through a filter which is based upon top-down sources of information. In other words, the stimuli elicit a pattern of activation which is modified by the many top-down influences which, in the present case, include the constraining effects of the pretrial cue, training on the task, etc. The resulting modified pattern of activation then interacts with the incoming bottom-up information. They have termed the resulting interactive model as adaptive resonance.

In the adaptive resonance model, the speed of response would reflect the degree of match between the

pattern of activation generated by the input and the signal which is developed from top-down processes. Time on task enables the degree of match between two patterns of activation to become more and more precise; the result being a signal which becomes stronger and stronger as the patterns become more similar. Experience results in the development of filters which can act on the processing of the input.

The time on task experienced by each subject over the three sessions, provided an opportunity for such filters to develop and for the fine tuning of top-down and bottom-up patterns of activation. By providing the opportunity for subjects to function with as precise a degree of match between these two patterns of activation as they can achieve and, from this, inferring that they are functioning at their maximum efficiency, it becomes possible to investigate the structure of these subprocessors.

In word recognition, research has demonstrated that orthographic, phonetic, semantic, and syntactic processing can occur even though an individual may not be aware of that processing, and that these different types of processing can occur in parallel (Rumelhart & McClelland, 1986; Davidson, 1986; Humphreys, Evett, & Taylor, 1982). Using an adaptive resonance model, the patterns of activation which are generated when viewing a word would be compared to top-down, knowledge driven sources of

information.

Consider the development of the skill of reading, in which phonological processing is posited as being necessary to the development of direct access to words. In the child who is learning to read, the efficiency of phonological processing could constitute a determining factor in the development of a pattern of activation which permits more automatic, direct access in word recognition.

The results of the study have implications for the way in which one interprets the research which has been carried out on individuals who have suffered acquired reading disorders. Researchers have discussed whether a lexical or direct processing route could be affected in isolation. While there are indications that such a dissociation exists, the data is often confusing. The data in the present study indicate that a group of highly skilled readers have different relative abilities in the processing of orthographic, phonetic, and semantic information. Imagine if the most rapid and accurate G-P-C subject experienced the same cerebral insult as the least rapid and accurate G-C-P subject. If one processing route, such as direct access, were differentially affected, it is reasonable to assume that the two subjects would present with differing degrees of impairment. The G-C-P subject, who relies on direct access and has a less efficient phonological processor with which to compensate for the loss, could be more impaired than the subject who has

an efficient phonological processor to fall back on. If one does not assume that all individuals who acquire a complex skill "normally" do so in the same manner, it becomes possible to consider the many differences which may express themselves following brain injury. The impairment becomes an overlay which must be understood in the context of the pre-exisiting structure.

Suggested Future Studies

A number of studies are suggested by the results of the investigation:

1) The Syntactic task proved to be the most problematic in the construction of the stimulus set. It was difficult to generate a syntactic task based on word pairs. As all of the items were in the "Animals" word category, the task created an imbalance in the word list with "Animals" appearing more often than the other word categories. Further, the under-representation of the items on the Syntactic task resulted in less training than on the other three tasks. The data was eventually viewed in terms of the relationships between the Graphic, Phonetic, and Catgeory tasks and it would be appropriate to create a data set which excludes the syntactic task. It would be expected that performances on the three remaining tasks should not be affected by the removal of the syntactic task.

2) A potential criticism of the present study

involves the degree to which items on the task could have been memorized. I consider this to be unlikely due to the large number of items which are administered, the fact that the words appear many times with different pairings, and that the three experimental sessions were spread over a period of two weeks. However, this could be investigated by a study in which the fourth, and final, session involved the presentation of a stimulus set on which different word pairings were developed. In such a study, the same cue and first word would be presented as in the original stimulus set. The word which then followed would conform to all of the conditions described in the development of the stimulus set. For example, in the phonetic task, different homophones would be developed. This study would demonstrate a "transfer of learning" from the original stimulus set and answer the question as to whether the results of the present study are due to the development of differential associations to the stimuli.

3) If the efficiency of phonological processing is a critical element in the development of a highly skilled reader, it would be of interest to investigate phonological processing abilties of subjects in the auditory, as well as the visual, modality. It would then be possible to compare subjects to an independent source of information. Do the most rapid and accurate subjects on the visual language tasks also exhibit the greatest ability on tasks of auditory discrimination?

4) In the attempt to provide an independent data base with which to compare the pattern analysis of subject performances, an attempt could be made to find an appropriate neuropsychological measure of skilled reading. One such task, The Watson-Glaser Critical Thinking Appraisal (Watson & Glaser, 1952) is designed for college aged, skilled readers, and might be appropriate for this purpose.

5) As subjects did not reach a steady-state on reaction time measures, with performances getting faster over the three sessions, the word pairs could be presented until no more gains were accrued from training. It would then be possible to investigate whether subjects would attain a G-P-C pattern of performance with sufficient practice. It might also be possible differentiate between individuals who would attain the G-P-C pattern with sufficient practice and individuals whose difficulties with phonetic processing would make this impossible.

6) Evoked potentials should be collected to the word pairs during the interval when subjects are making orthographic, phonetic, or semantic decisions. existing stimulus set. If the earlier P2 wave identified in the G-P-C group represents an early integration which is used in the later processing of the visual form, this finding should be evident when the evoked potentials are collected to the word at which decisions must be made. While only P2 latency was effected when the evoked potentials were

collected to the cue, it may be possible to identify evoked potential correlates of the different types of processing. For example, the P3 wave of the evoked potential has been shown to reflect the processing capacity or resources required for the completion of a task (Israel et. al., 1980; Wickens, Vanasse, & Donchin, 1983). Does the phonetic task, require more resources to perform than the category task? Does the allocation of resources match the relative efficiencies as identified by the relationships between the three tasks?

7) It would be of great interest to evaluate the performance of individuals who are identified as learning disabled readers. In general, such readers should demonstrate a discrepancy between their performances on the phonetic task relative to the orthographic and semantic tasks. These individuals should maintain a G-C-P pattern of performance regardless of the amount of time on task. Individuals who are not skilled readers but which have no identifiable learning disability. If the inability to read is due to educational factors, and not an impaired ability with phonological processing, such subjects should present as inefficient readers but continue to improve with continued time on task.

APPENDIX A

Word Frequencies and Test Orders

Figure

Figure A

Word Frequencies of Stimuli

Thorndike & Lorge (1963)

Animals		Groceries	
Bird	100	Milk	100
Horse	100	Eggs	100
Fish	100	Meat	100
Goat	050	Salt	100
Lion	050	Flour	050
Wolf	050	Bread	050
Sheep	050	Corn	050
Lamb	045	Rice	038
Deer	035	Juice	037
Tiger	030	Jelly	019
Snake	028	Spice	017
Frog	025	Syrup	006

Clothes		Body Parts	
Shoe	100	Nose	100
Suit	100	Hand	100
Dress	100	Foot	100
Coat	100	Face	100
Skirt	050	Teeth	050
Belt	048	Brain	050
Shirt	047	Cheek	050
Glove	043	Chest	041
Gown	038	Elbow	026
Vest	021	Ankle	021
Shawl	009	Wrist	017
Beret	001	Thigh	013

Figure B

Experimental Stimuli for "Animals" Word Category

Y/N	Graphic	Phonetic	Category
Y	Bird	Byrd	Goat
N	Bi*d	Bind	Dress
Y	Horse	Hoarse	Lamb
N	H*rse	Host	Syrup
Y	Fish	Phish	Wolf
N	F*sh	Finish	Shoe
Y	Goat	Gote	Tiger
N	G*at	Golf	Flour
Y	Lion	Lyon	Bird
N	Li*n	Line	Glove
Y	Wolf	Wulf	Frog
N	*olf	Word	Meat
Y	Sheep	Sheap	Lion
N	Sh*ep	Shout	Belt
Y	Lamb	Lam	Horse
N	La*b	Last	Suit
Y	Deer	Dear	Sheep
N	*eer	Dent	Bread
Y	Tiger	Tyger	Snake
N	Ti*er	Timer	Shirt
Y	Snake	Snaik	Tiger
N	S*ake	Snack	Juice
Y	Frog	Phrog	Deer
N	Fr*g	Front	Milk

Figure C

Experimental Stimuli for "Groceries" Word Category

Y/N	Graphic	Phonetic	Category
Y	Milk	Millk	Salt
N	Mi*k	Mist	Gown
Y	Eggs	Eghs	Corn
N	E*gs	Eager	Ankle
Y	Meat	Meet	Eggs
N	M*at	Melt	Foot
Y	Salt	Sault	Spice
N	Sa*t	Sand	Glove
Y	Flour	Flower	Jelly
N	*lour	Flirt	Wolf
Y	Bread	Bred	Syrup
N	Br*ad	Brown	Vest
Y	Corn	Courn	Milk
N	*orn	Court	Nose
Y	Rice	Ryce	Juice
N	R*ce	Rile	Elbow
Y	Juice	Joose	Rice
N	J*ice	Jump	Hand
Y	Jelly	Jelee	Flour
N	*elly	Jetty	Lion
Y	Spice	Spyce	Bread
N	Sp*ce	Spend	Face
Y	Syrup	Sirup	Meat
N	Sy*up	Surge	Scarf

Figure D

Experimental Stimuli for "Body Parts" Word Category

Y/N	Graphic	Phonetic	Category
Y	Nose	Noze	Face
N	No*e	Node	Flour
Y	Face	Faese	Brain
N	F*ce	Fail	Suit
Y	Neck	Neque	Ankle
N	*eck	Neat	Tiger
Y	Teeth	Teath	Elbow
N	T*eth	Tenth	Fish
Y	Brain	Brane	Hand
N	B*ain	Brave	Gown
Y	Cheek	Cheke	Nose
N	Ch*ek	Cheat	Rice
Y	Chest	Chehst	Thigh
N	*hest	Chose	Sheep
Y	Elbow	Elbo	Wrist
N	El*ow	Elate	Flour
Y	Heart	Hart	Cheek
N	He*rt	Here	Eggs
Y	Ankle	Ankel	Chest
N	An*le	Anger	Bird
Y	Wrist	Rist	Foot
N	W*ist	Write	Spice
Y	Thigh	Thye	Teeth
N	T*igh	Those	Shoe

Figure E

Experimental Stimuli for "Clothing" Word Category

Y/N	Graphic	Phonetic	Category
Y	Shoe	Shoo	Skirt
N	S*oe	Ship	Goat
Y	Suit	Sute	Vest
N	Su*t	Sulk	Milk
Y	Dress	Drehs	Glove
N	D*ess	Dream	Elbow
Y	Coat	Cote	Belt
N	*oat	Cope	Snake
Y	Skirt	Skert	Scarf
N	Sk*rt	Skip	Wolf
Y	Belt	Bellt	Gown
N	B*lt	Bend	Corn
Y	Shirt	Shert	Dress
N	S*irt	Shift	Face
Y	Glove	Gluv	Shoe
N	*love	Glue	Meat
Y	Gown	Goun	Suit
N	G*wn	Gone	Rice
Y	Vest	Vesst	Coat
N	Ve*t	Vent	Lion
Y	Shawl	Shaul	Beret
N	Sh*wl	Scour	Salt
Y	Beret	Beray	Shirt
N	B*ret	Beer	Lamb

Figure F

Experimental Stimuli for Syntactic Condition

Pilot Study

	Animal	**Groceries**	**Body Parts**	**Clothing**
	Bird	Milk	Nose	Shoe
Y	Girl	Road	Lens	Movie
N	Speak	Hate	Filch	Erect
	Horse	Eggs	Face	Suit
Y	Mayor	Hero	Movie	April
N	Clean	Read	Yell	Flee
	Fish	Meat	Neck	Dress
Y	Bulb	Mayor	Road	Filch
N	Vary	Filch	Erect	Ocean
	Goat	Salt	Teeth	Coat
Y	Tent	April	April	Night
N	Erect	Speak	Vary	Speak
	Lion	Flour	Brain	Skirt
Y	April	Lens	Ocean	Alley
N	Filch	Flee	Clean	Vary
	Wolf	Bread	Cheek	Belt
Y	Movie	Bulb	Night	Hero
N	Flee	Refer	Bathe	Yell
	Sheep	Corn	Chest	Shirt
Y	Night	Movie	Alley	Lens
N	Refer	Learn	Learn	Learn
	Lamb	Rice	Elbow	Glove
Y	Road	Lens	Tent	Mayor
N	Yell	Clean	Flee	Hate
	Deer	Juice	Heart	Gown
Y	Ocean	Tent	Girl	Girl
N	Bathe	Yell	Read	Read
	Tiger	Jelly	Ankle	Vest
Y	Hero	Girl	Hero	Road
N	Learn	Vary	Speak	Clean
	Snake	Spice	Wrist	Shawl
Y	Lens	Ocean	Bulb	Tent
N	Read	Erect	Hate	Refer
	Frog	Syrup	Thigh	Beret
Y	Alley	Night	Mayor	Bulb

Figure G

Experimental Stimuli for Syntactic Condition

Main Experiment

	Bird	Lion	Deer
Y	Eat	Walk	Jump
N	Girl	April	Ocean
Y	Sleep	Prey	Trot
N	Road	Road	Lens
	Horse	Wolf	Tiger
Y	Feed	Roam	Bite
N	April	Ocean	Alley
Y	Trot	Kill	Kill
N	Mayor	Movie	Hero
	Fish	Sheep	Snake
Y	Swim	Eat	Bite
N	Bulb	Night	Movie
Y	Jump	Walk	Prey
N	Night	Tent	Lens
	Goat	Lamb	Frog
Y	Rest	Sleep	Swim
N	Tent	Road	Bulb
Y	Roam	Feed	Rest
N	Hero	Mayor	Alley

Figure H

Practice Stimuli in Order of Presentation

Task	Correct Response	Word #1	Word #2
G	Y	PONY	PONY
P	Y	SHOE	SHOO
C	N	SHOE	BEAR
G	N	PONY	PO*Y
P	Y	BEAR	BARE
S	Y	PONY	SWIM
S	N	PONY	DOOR
C	N	BEAR	SALT
C	Y	BEAR	FISH
P	Y	PONY	PONEE
G	N	SHOE	SH*E
P	N	SHOE	SHIP
S	Y	BEAR	PUSH
G	Y	SHOE	SHOE
S	N	PONY	PAIL
P	N	PONY	POUND
G	Y	BEAR	BEAR
P	N	BEAR	BEND
C	N	PONY	RICE
S	N	PONY	MUSIC
G	N	BEAR	BE*R
C	Y	PONY	FISH
S	Y	BEAR	LOPE
C	Y	SHOE	COAT

Figure I

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word #2
G	C	N	RICE	ELBOW
BP	C	Y	WRIST	FOOT
BP	S	N	NECK	ERECT
A	G	N	FROG	FR*G
G	S	Y	BREAD	BULB
A	P	Y	LION	LYON
A	G	Y	LAMB	LAMB
C	S	Y	DRESS	OCEAN
G	P	N	JUICE	JUMP
C	C	N	SHOE	GOAT
C	G	N	SHAWL	SH*WL
G	G	N	CORN	*ORN
A	C	N	SHEEP	BELT
C	C	N	COAT	SNAKE
C	C	N	GOWN	RICE
BP	P	N	ANKLE	ANGER
A	S	Y	DEER	OCEAN
G	P	Y	JUICE	JOOSE
BP	S	N	BRAIN	CLEAN
G	P	N	JELLY	JETTY
A	C	Y	FROG	DEER
A	G	N	GOAT	G*AT
G	C	Y	JELLY	FLOUR
C	P	Y	DRESS	DREHS
BP	S	Y	BRAIN	OCEAN
BP	G	N	TEETH	T*ETH
A	G	N	HORSE	H*RSE
G	C	Y	BREAD	SYRUP
C	C	Y	GOWN	SUIT
G	P	Y	JELLY	JELEE
C	C	Y	SHIRT	DRESS
A	S	Y	FISH	BULB
A	C	Y	SHEEP	LION
BP	G	Y	THIGH	THIGH
C	S	N	BELT	YELL
C	G	N	GOWN	G*WN
C	C	N	GLOVE	MEAT
G	S	N	JELLY	VARY
G	C	Y	EGGS	CORN
BP	G	Y	ELBOW	ELBOW
C	G	N	BELT	B*LT
G	C	N	SYRUP	SCARF
G	C	Y	SPICE	BREAD
A	C	N	BIRD	DRESS

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
G	G	N	MEAT	M*AT
C	G	N	SUIT	SU*T
BP	S	N	NOSE	FILCH
BP	C	Y	THIGH	TEETH
A	S	N	TIGER	LEARN
C	G	N	DRESS	D*ESS
A	G	N	FISH	F*SH
BP	P	N	TEETH	TENTH
C	S	N	BERET	BATHE
G	C	Y	MEAT	EGGS
G	S	Y	JELLY	GIRL
BP	S	N	WRIST	HATE
C	S	N	SHAWL	REFER
C	C	N	DRESS	ELBOW
G	S	Y	SALT	APRIL
C	S	Y	BERET	BULB
A	G	Y	WOLF	WOLF
C	G	Y	BERET	BERET
G	C	Y	JUICE	RICE
C	G	Y	GLOVE	GLOVE
A	G	Y	BIRD	BIRD
BP	S	Y	ELBOW	TENT
A	P	N	SHEEP	SHOUT
A	P	N	WOLF	WORD
C	S	N	DRESS	FILCH
A	P	Y	SNAKE	SNAIK
C	P	N	BELT	BEND
G	G	Y	BREAD	BREAD
C	S	Y	SKIRT	ALLEY
BP	G	Y	CHEEK	CHEEK
G	S	N	SYRUP	BATHE
G	G	Y	RICE	RICE
A	P	N	HORSE	HOST
G	P	N	MILK	MIST
G	G	Y	EGGS	EGGS
G	P	Y	MEAT	MEET
A	S	N	LION	FILCH
G	S	N	BREAD	REFER
BP	G	Y	ANKLE	ANKLE
BP	P	Y	TEETH	TEATH
C	C	Y	VEST	COAT
G	S	Y	SYRUP	NIGHT
C	G	Y	BELT	BELT
C	C	Y	SKIRT	SCARF

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
G	G	Y	JELLY	JELLY
BP	P	Y	CHEST	CHEHST
G	G	Y	SALT	SALT
C	S	Y	COAT	NIGHT
G	G	N	SPICE	SP*CE
A	C	N	GOAT	FLOUR
G	G	N	JUICE	J*ICE
BP	G	N	FACE	F*CE
A	C	N	SNAKE	JUICE
C	G	Y	VEST	VEST
BP	G	Y	TEETH	TEETH
C	P	N	GLOVE	GLUE
A	C	Y	GOAT	TIGER
BP	P	Y	HEART	HART
G	G	Y	SYRUP	SYRUP
G	P	N	EGGS	EAGER
G	S	N	JUICE	YELL
A	G	Y	TIGER	TIGER
BP	P	Y	FACE	FAESE
BP	P	N	FACE	FAIL
G	C	N	FLOUR	WOLF
A	G	Y	GOAT	GOAT
G	C	N	MILK	GOWN
C	G	Y	SUIT	SUIT
C	P	N	SHIRT	SHIFT
BP	C	N	NOSE	FLOUR
G	P	Y	MILK	MILLK
A	S	Y	FROG	ALLEY
G	S	Y	EGGS	HERO
BP	C	Y	TEETH	ELBOW
C	C	Y	DRESS	GLOVE
A	C	Y	WOLF	FROG
A	C	N	LION	GLOVE
G	G	N	FLOUR	*LOUR
BP	P	N	THIGH	THOSE
G	C	N	CORN	NOSE
BP	P	Y	THIGH	THYE
C	P	Y	GOWN	GOUN
A	P	N	BIRD	BIND
C	P	Y	SHAWL	SHAUL
BP	P	N	BRAIN	BRAVE
C	S	Y	GLOVE	MAYOR
G	P	N	RICE	RILE
G	S	Y	FLOUR	LENS

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
BP	G	N	CHEEK	CH*EK
A	S	N	BIRD	SPEAK
A	S	Y	LAMB	ROAD
C	P	N	DRESS	DREAM
C	S	Y	SHAWL	TENT
C	P	Y	SKIRT	SKERT
BP	S	N	HEART	READ
C	P	N	COAT	COPE
G	G	N	MILK	MI*K
BP	P	Y	ELBOW	ELBO
G	P	N	SALT	SAND
A	P	Y	DEER	DEAR
BP	C	Y	NOSE	FACE
A	S	Y	LION	APRIL
BP	G	N	ELBOW	EL*OW
BP	C	N	WRIST	SODA
G	C	N	BREAD	VEST
G	P	Y	SPICE	SPYCE
A	P	Y	HORSE	HOARSE
BP	G	Y	FACE	FACE
G	S	N	SALT	SPEAK
BP	C	Y	NECK	ANKLE
C	C	Y	COAT	BELT
A	P	N	SNAKE	SNACK
A	S	N	FISH	VARY
BP	C	N	TEETH	FISH
BP	S	Y	NOSE	LENS
C	C	N	SHIRT	FACE
A	C	N	FROG	MILK
BP	S	Y	CHEST	ALLEY
BP	G	N	ANKLE	AN*LE
BP	C	N	NECK	TIGER
C	S	N	COAT	SPEAK
BP	G	N	THIGH	T*IGH
A	S	N	DEER	BATHE
G	S	N	MILK	HATE
A	C	Y	LAMB	HORSE
A	S	Y	BIRD	GIRL
BP	P	N	CHEEK	CHEAT
A	P	Y	GOAT	GOTE
C	G	N	VEST	VE*T
A	S	N	SNAKE	READ
C	P	Y	SHOE	SHOO
C	S	N	SKIRT	VARY

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
BP	C	Y	HEART	CHEEK
A	G	Y	FROG	FROG
BP	S	Y	NECK	ROAD
A	C	Y	BIRD	GOAT
A	P	N	FROG	FRONT
BP	C	N	HEART	EGGS
A	G	N	WOLF	*OLF
BP	S	Y	THIGH	MAYOR
A	G	N	TIGER	TI*ER
C	G	Y	COAT	COAT
C	P	Y	VEST	VESST
C	P	N	BERET	BEER
BP	S	N	ANKLE	SPEAK
G	P	Y	FLOUR	FLOWER
BP	C	N	THIGH	SHOE
A	P	Y	BIRD	BYRD
C	S	Y	SHIRT	LENS
C	G	Y	GOWN	GOWN
A	G	N	SHEEP	SH*EP
C	C	N	SUIT	MILK
BP	S	N	FACE	YELL
A	C	Y	LION	BIRD
A	S	N	WOLF	FLEE
C	C	N	BELT	CORN
A	C	N	WOLF	MEAT
BP	S	N	CHEST	LEARN
A	G	N	LAMB	LA*B
BP	G	N	HEART	HE*RT
C	S	N	VEST	CLEAN
C	P	N	SHAWL	SCOUR
G	S	N	CORN	LEARN
BP	C	N	ANKLE	BIRD
BP	P	Y	WRIST	RIST
BP	C	N	CHEST	SHEEP
A	P	N	LAMB	LAST
G	P	N	FLOUR	FLIRT
G	S	N	MEAT	FILCH
C	P	Y	SHIRT	SHERT
A	P	Y	FROG	PHROG
A	S	N	SHEEP	REFER
C	G	N	BERET	B*RET
G	S	Y	JUICE	TENT
A	G	Y	SNAKE	SNAKE
A	P	Y	FISH	PHISH

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
A	C	N	FISH	SHOE
A	G	Y	DEER	DEER
BP	P	N	NECK	NEAT
C	C	N	SKIRT	WOLF
G	C	Y	FLOUR	JELLY
A	P	Y	TIGER	TYGER
C	C	Y	GLOVE	SHOE
A	C	N	LAMB	SUIT
BP	S	Y	HEART	GIRL
G	G	Y	JUICE	JUICE
G	S	N	EGGS	READ
C	G	N	COAT	*OAT
G	G	Y	MEAT	MEAT
G	P	Y	SALT	SAULT
G	S	N	SPICE	ERECT
G	C	N	EGGS	ANKLE
G	C	Y	SYRUP	MEAT
BP	G	N	CHEST	*HEST
BP	S	N	ELBOW	FLEE
A	S	Y	GOAT	TENT
A	S	Y	HORSE	MAYOR
C	S	Y	SUIT	APRIL
BP	C	Y	ELBOW	WRIST
A	C	N	DEER	BREAD
BP	C	N	BRAIN	GOWN
G	P	N	BREAD	BROWN
C	S	Y	BELT	HERO
C	P	N	SHOE	SHIP
BP	S	Y	FACE	MOVIE
C	P	N	VEST	VENT
C	S	N	SUIT	FLEE
C	P	Y	GLOVE	GLUV
BP	G	Y	CHEST	CHEST
A	S	Y	SHEEP	NIGHT
BP	S	N	TEETH	VARY
G	G	N	RICE	R*CE
A	P	N	FISH	FINISH
G	C	N	SPICE	FACE
C	S	N	SHOE	ERECT
BP	G	Y	NECK	NECK
BP	C	N	FACE	SUIT
A	S	Y	SNAKE	LENS
G	P	Y	SYRUP	SIRUP
C	G	N	SHOE	S*OE

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
BP	P	N	WRIST	WRITE
C	C	N	SHAWL	SALT
G	P	N	MEAT	MELT
A	P	N	DEER	DENT
A	S	N	FROG	HATE
BP	G	N	NECK	*ECK
G	G	N	SALT	SA*T
C	G	Y	SHOE	SHOE
G	G	N	BREAD	BR*AD
A	C	Y	SNAKE	TIGER
C	P	N	GOWN	GONE
C	C	Y	SHAWL	BERET
G	S	Y	SPICE	OCEAN
BP	C	N	ELBOW	FLOUR
BP	S	N	THIGH	REFER
C	S	Y	SHOE	MOVIE
G	P	Y	EGGS	EGHS
C	P	Y	SUIT	SUTE
BP	G	Y	NOSE	NOSE
BP	C	N	CHEEK	RICE
C	G	Y	SKIRT	SKIRT
G	P	N	SPICE	SPEND
C	S	Y	GOWN	GIRL
A	C	Y	FISH	WOLF
G	G	Y	FLOUR	FLOUR
C	C	N	BERET	LAMB
C	C	Y	SHOE	SKIRT
G	G	N	SYRUP	SY*UP
G	P	Y	CORN	COURN
C	G	N	GLOVE	*LOVE
A	C	Y	HORSE	LAMB
C	P	Y	BELT	BELLT
C	S	N	GOWN	READ
BP	G	N	WRIST	W*IST
A	S	Y	TIGER	HERO
G	G	Y	SPICE	SPICE
A	G	N	SNAKE	S*AKE
G	S	Y	MEAT	MAYOR
A	G	N	DEER	*EER
G	P	N	SYRUP	SURGE
A	G	Y	FISH	FISH
C	P	Y	COAT	COTE
G	C	N	JUICE	HAND
BP	S	Y	TEETH	APRIL

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
A	P	N	TIGER	TIMER
G	C	N	JELLY	LION
C	G	Y	SHIRT	SHIRT
BP	C	Y	FACE	BRAIN
G	C	N	SALT	GLOVE
BP	P	N	NOSE	NODE
G	C	Y	SALT	SODA
A	G	N	BIRD	BI*D
BP	G	Y	BRAIN	BRAIN
G	G	Y	CORN	CORN
G	P	Y	RICE	RYCE
A	G	Y	LION	LION
BP	G	N	NOSE	NO*E
G	P	N	CORN	COURT
G	S	Y	CORN	MOVIE
C	P	Y	BERET	BERAY
C	S	Y	VEST	ROAD
G	C	Y	RICE	JUICE
BP	C	Y	CHEEK	NOSE
G	S	Y	RICE	LENS
C	G	N	SKIRT	SK*RT
BP	G	Y	WRIST	WRIST
BP	G	N	BRAIN	B*AIN
A	G	Y	SHEEP	SHEEP
BP	P	Y	NECK	NEQUE
A	C	N	HORSE	SYRUP
C	C	N	VEST	LION
A	C	Y	TIGER	SNAKE
C	C	Y	SUIT	VEST
C	C	Y	BELT	GOWN
G	C	Y	CORN	MILK
G	G	Y	MILK	MILK
BP	C	Y	CHEST	THIGH
C	G	Y	DRESS	DRESS
BP	C	Y	BRAIN	HAND
C	G	Y	SHAWL	SHAWL
BP	S	Y	WRIST	BULB
C	P	N	SUIT	SULK
BP	P	Y	ANKLE	ANKEL
C	S	N	SHIRT	LEARN
A	P	Y	LAMB	LAM
G	S	Y	MILK	ROAD
BP	P	N	CHEST	CHOSE
G	S	N	RICE	CLEAN

Experimental Stimuli in Order of Presentation

Pilot Study

Word Category	Task	Correct Response	Word#1	Word#2
BP	P	Y	BRAIN	BRANE
A	C	Y	DEER	SHEEP
BP	S	Y	ANKLE	HERO
A	S	N	GOAT	ERECT
A	S	N	LAMB	YELL
BP	S	Y	CHEEK	NIGHT
C	C	Y	BERET	SHIRT
G	G	N	EGGS	E*GS
A	P	N	GOAT	GOLF
G	C	N	MEAT	FOOT
A	P	Y	WOLF	WULF
C	S	N	GLOVE	HATE
BP	C	Y	ANKLE	CHEST
A	S	Y	WOLF	MOVIE
G	G	N	JELLY	*ELLY
BP	P	N	HEART	HERE
C	P	N	SKIRT	SKIP
BP	P	Y	NOSE	NOZE
A	P	N	LION	LINE
G	C	Y	MILK	SALT
C	G	N	SHIRT	S*IRT
A	G	N	LION	LI*N
BP	P	Y	CHEEK	CHEKE
A	S	N	HORSE	CLEAN
G	P	Y	BREAD	BRED
A	C	N	TIGER	SHIRT
A	P	Y	SHEEP	SHEAP
BP	P	N	ELBOW	ELATE
G	S	N	FLOUR	FLEE
BP	G	Y	HEART	HEART
A	G	Y	HORSE	HORSE
BP	S	N	CHEEK	BATHE

Figure J

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct Response	Word#1	Word#2
G	C	N	RICE	ELBOW
BP	C	Y	WRIST	FOOT
A	G	N	FROG	FR*G
A	S	Y	WOLF	ROAM
A	P	Y	LION	LYON
A	G	Y	LAMB	LAMB
G	P	N	JUICE	JUMP
C	C	N	SHOE	GOAT
C	G	N	SHAWL	SH*WL
G	G	N	CORN	*ORN
A	C	N	SHEEP	BELT
C	C	N	COAT	SNAKE
C	C	N	GOWN	RICE
BP	P	N	ANKLE	ANGER
A	S	N	DEER	OCEAN
G	P	Y	JUICE	JOOSE
G	P	N	JELLY	JETTY
A	C	Y	FROG	DEER
A	G	N	GOAT	G*AT
G	C	Y	JELLY	FLOUR
C	P	Y	DRESS	DREHS
BP	G	N	TEETH	T*ETH
A	G	N	HORSE	H*RSE
G	C	Y	BREAD	SYRUP
C	C	Y	GOWN	SUIT
G	P	Y	JELLY	JELEE
C	C	Y	SHIRT	DRESS
A	S	N	FISH	BULB
A	C	Y	SHEEP	LION
BP	G	Y	THIGH	THIGH
C	G	N	GOWN	G*WN
C	C	N	GLOVE	MEAT
A	S	Y	LAMB	SLEEP
G	C	Y	EGGS	CORN
BP	G	Y	ELBOW	ELBOW
C	G	N	BELT	B*LT
G	C	N	SYRUP	SCARF
G	C	Y	SPICE	BREAD
A	C	N	BIRD	DRESS
G	G	N	MEAT	M*AT
C	G	N	SUIT	SU*T
BP	C	Y	THIGH	TEETH
A	S	Y	TIGER	BITE
C	G	N	DRESS	D*ESS
A	G	N	FISH	F*SH
BP	P	N	TEETH	TENTH
A	S	N	DEER	LENS

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct Response	Word#1	Word#2
G	C	Y	MEAT	EGGS
C	C	N	DRESS	ELBOW
A	S	Y	SNAKE	BITE
A	G	Y	WOLF	WOLF
C	G	Y	BERET	BERET
G	C	Y	JUICE	RICE
C	G	Y	GLOVE	GLOVE
A	G	Y	BIRD	BIRD
A	P	N	SHEEP	SHOUT
A	P	N	WOLF	WORD
A	S	N	FISH	NIGHT
A	P	Y	SNAKE	SNAIK
C	P	N	BELT	BEND
G	G	Y	BREAD	BREAD
BP	G	Y	CHEEK	CHEEK
G	G	Y	RICE	RICE
A	P	N	HORSE	HOST
G	P	N	MILK	MIST
G	G	Y	EGGS	EGGS
G	P	Y	MEAT	MEET
A	S	Y	LION	WALK
BP	G	Y	ANKLE	ANKLE
BP	P	Y	TEETH	TEATH
C	C	Y	VEST	COAT
A	S	N	WOLF	OCEAN
C	G	Y	BELT	BELT
C	C	Y	SKIRT	SCARF
G	G	Y	JELLY	JELLY
BP	P	Y	CHEST	CHEHST
G	G	Y	SALT	SALT
A	S	Y	GOAT	REST
G	G	N	SPICE	SP*CE
A	C	N	GOAT	FLOUR
G	G	N	JUICE	J*ICE
BP	G	N	FACE	F*CE
A	C	N	SNAKE	JUICE
C	G	Y	VEST	VEST
BP	G	Y	TEETH	TEETH
C	P	N	GLOVE	GLUE
A	C	Y	GOAT	TIGER
BP	P	Y	HEART	HART
G	G	Y	SYRUP	SYRUP
G	P	N	EGGS	EAGER
A	S	N	FROG	BULB
A	G	Y	TIGER	TIGER
BP	P	Y	FACE	FAESE

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct	Word#1	Word#2
BP	P	N	FACE	FAIL
G	C	N	FLOUR	WOLF
A	G	Y	GOAT	GOAT
G	C	N	MILK	GOWN
C	G	Y	SUIT	SUIT
C	P	N	SHIRT	SHIFT
BP	C	N	NOSE	FLOUR
G	P	Y	MILK	MILLK
A	S	N	FROG	ALLEY
BP	C	Y	TEETH	ELBOW
C	C	Y	DRESS	GLOVE
A	C	Y	WOLF	FROG
A	C	N	LION	GLOVE
G	G	N	FLOUR	*LOUR
BP	P	N	THIGH	THOSE
G	C	N	CORN	NOSE
BP	P	Y	THIGH	THYE
C	P	Y	GOWN	GOUN
A	P	N	BIRD	BIND
C	P	Y	SHAWL	SHAUL
BP	P	N	BRAIN	BRAVE
G	P	N	RICE	RILE
BP	G	N	CHEEK	CH*EK
A	S	Y	BIRD	EAT
A	S	N	LAMB	ROAD
C	P	N	DRESS	DREAM
C	P	Y	SKIRT	SKERT
A	S	N	LION	APRIL
C	P	N	COAT	COPE
G	G	N	MILK	MI*K
BP	P	Y	ELBOW	ELBO
G	P	N	SALT	SAND
A	P	Y	DEER	DEAR
BP	C	Y	NOSE	FACE
A	S	N	LION	ROAD
BP	G	N	ELBOW	EL*OW
BP	C	N	WRIST	SODA
G	C	N	BREAD	VEST
G	P	Y	SPICE	SPYCE
A	P	Y	HORSE	HOARSE
BP	G	Y	FACE	FACE
BP	C	Y	NECK	ANKLE
C	C	Y	COAT	BELT
A	P	N	SNAKE	SNACK
A	S	Y	FISH	SWIM
BP	C	N	TEETH	FISH
C	C	N	SHIRT	FACE

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct Response	Word#1	Word#2
A	C	N	FROG	MILK
BP	G	N	ANKLE	AN*LE
BP	C	N	NECK	TIGER
BP	G	N	THIGH	T*IGH
A	S	Y	DEER	JUMP
A	C	Y	LAMB	HORSE
A	S	N	BIRD	GIRL
BP	P	N	CHEEK	CHEAT
A	P	Y	GOAT	GOTE
C	G	N	VEST	VE*T
A	S	Y	SNAKE	PREY
C	P	Y	SHOE	SHOO
BP	C	Y	HEART	CHEEK
A	G	Y	FROG	FROG
A	C	Y	BIRD	GOAT
A	P	N	FROG	FRONT
BP	C	N	HEART	EGGS
A	G	N	WOLF	*OLF
A	S	N	BIRD	ROAD
A	G	N	TIGER	TI*ER
C	G	Y	COAT	COAT
C	P	Y	VEST	VESST
C	P	N	BERET	BEER
A	S	N	SNAKE	MOVIE
G	P	Y	FLOUR	FLOWER
BP	C	N	THIGH	SHOE
A	P	Y	BIRD	BYRD
A	S	N	HORSE	APRIL
C	G	Y	GOWN	GOWN
A	G	N	SHEEP	SH*EP
C	C	N	SUIT	MILK
A	C	Y	LION	BIRD
A	S	Y	WOLF	KILL
C	C	N	BELT	CORN
A	C	N	WOLF	MEAT
A	G	N	LAMB	LA*B
BP	G	N	HEART	HE*RT
A	S	Y	BIRD	SLEEP
C	P	N	SHAWL	SCOUR
BP	C	N	ANKLE	BIRD
BP	P	Y	WRIST	RIST
BP	C	N	CHEST	SHEEP
A	P	N	LAMB	LAST
G	P	N	FLOUR	FLIRT
C	P	Y	SHIRT	SHERT
A	P	Y	FROG	PHROG

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct	Word#1	Word#2
A	S	Y	SHEEP	EAT
C	G	N	BERET	B*RET
A	G	Y	SNAKE	SNAKE
A	P	Y	FISH	PHIS
A	C	N	FISH	SHOE
A	G	Y	DEER	DEER
BP	P	N	NECK	NEAT
C	C	N	SKIRT	WOLF
G	C	Y	FLOUR	JELLY
A	P	Y	TIGER	TYGER
C	C	Y	GLOVE	SHOE
A	C	N	LAMB	SUIT
A	S	Y	HORSE	FEED
G	G	Y	JUICE	JUICE
C	G	N	COAT	*OAT
G	G	Y	MEAT	MEAT
G	P	Y	SALT	SAULT
G	C	N	EGGS	ANKLE
G	C	Y	SYRUP	MEAT
BP	G	N	CHEST	*HEST
A	S	N	GOAT	TENT
A	S	N	HORSE	MAYOR
A	S	N	TIGER	ALLEY
BP	C	Y	ELBOW	WRIST
A	C	N	DEER	BREAD
BP	C	N	BRAIN	GOWN
G	P	N	BREAD	BROWN
C	P	N	SHOE	SHIP
C	P	N	VEST	VENT
A	S	N	GOAT	HERO
C	P	Y	GLOVE	GLUV
BP	G	Y	CHEST	CHEST
A	S	N	SHEEP	NIGHT
G	G	N	RICE	R*CE
A	P	N	FISH	FINISH
G	C	N	SPICE	FACE
BP	G	Y	NECK	NECK
BP	C	N	FACE	SUIT
A	S	N	SNAKE	LENS
G	P	Y	SYRUP	SIRUP
C	G	N	SHOE	S*OE
BP	P	N	WRIST	WRITE
C	C	N	SHAWL	SALT
G	P	N	MEAT	MELT
A	P	N	DEER	DENT
A	S	Y	FROG	SWIM
BP	G	N	NECK	*ECK

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct Response	Word#1	Word#2
G	G	N	SALT	SA*T
C	G	Y	SHOE	SHOE
G	G	N	BREAD	BR*AD
A	C	Y	SNAKE	TIGER
C	P	N	GOWN	GONE
C	C	Y	SHAWL	BERET
BP	C	N	ELBOW	FLOUR
A	S	Y	LION	PREY
G	P	Y	EGGS	EGHS
C	P	Y	SUIT	SUTE
BP	G	Y	NOSE	NOSE
BP	C	N	CHEEK	RICE
C	G	Y	SKIRT	SKIRT
G	P	N	SPICE	SPEND
A	S	Y	FISH	JUMP
A	C	Y	FISH	WOLF
G	G	Y	FLOUR	FLOUR
C	C	N	BERET	LAMB
C	C	Y	SHOE	SKIRT
G	G	N	SYRUP	SY*UP
G	P	Y	CORN	COURN
C	G	N	GLOVE	*LOVE
A	C	Y	HORSE	LAMB
C	P	Y	BELT	BELLT
BP	G	N	WRIST	W*IST
A	S	N	TIGER	HERO
G	G	Y	SPICE	SPICE
A	G	N	SNAKE	S*AKE
A	G	N	DEER	*EER
G	P	N	SYRUP	SURGE
A	G	Y	FISH	FISH
C	P	Y	COAT	COTE
G	C	N	JUICE	HAND
A	S	N	SHEEP	TENT
A	P	N	TIGER	TIMER
G	C	N	JELLY	LION
C	G	Y	SHIRT	SHIRT
BP	C	Y	FACE	BRAIN
G	C	N	SALT	GLOVE
BP	P	N	NOSE	NODE
G	C	Y	SALT	SPICE
A	G	N	BIRD	BI*D
BP	G	Y	BRAIN	BRAIN
G	G	Y	CORN	CORN
G	P	Y	RICE	RYCE

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct Response	Word#1	Word#2
A	G	Y	LION	LION
BP	G	N	NOSE	NO*E
G	P	N	CORN	COURT
A	S	Y	FROG	REST
C	P	Y	BERET	BERAY
G	C	Y	RICE	JUICE
BP	C	Y	CHEEK	NOSE
A	S	Y	TIGER	KILL
C	G	N	SKIRT	SK*RT
BP	G	Y	WRIST	WRIST
BP	G	N	BRAIN	B*AIN
A	G	Y	SHEEP	SHEEP
BP	P	Y	NECK	NEQUE
A	C	N	HORSE	SYRUP
C	C	N	VEST	LION
A	C	Y	TIGER	SNAKE
C	C	Y	SUIT	VEST
C	C	Y	BELT	GOWN
G	C	Y	CORN	MILK
G	G	Y	MILK	MILK
BP	C	Y	CHEST	THIGH
C	G	Y	DRESS	DRESS
BP	C	Y	BRAIN	HAND
C	G	Y	SHAWL	SHAWL
A	S	Y	SHEEP	WALK
C	P	N	SUIT	SULK
BP	P	Y	ANKLE	ANKEL
A	S	N	LAMB	MAYOR
A	P	Y	LAMB	LAM
BP	P	N	CHEST	CHOSE
BP	P	Y	BRAIN	BRANE
A	C	Y	DEER	SHEEP
A	S	Y	GOAT	ROAM
A	S	Y	LAMB	FEED
C	C	Y	BERET	SHIRT
G	G	N	EGGS	E*GS
A	P	N	GOAT	GOLF
G	C	N	MEAT	FOOT
A	P	Y	WOLF	WULF
BP	C	Y	ANKLE	CHEST
A	S	N	WOLF	MOVIE
G	G	N	JELLY	*ELLY
BP	P	N	HEART	HERE
C	P	N	SKIRT	SKIP
BP	P	Y	NOSE	NOZE

Experimental Stimuli in Order of Presentation

Main Experiment

Word Category	Task	Correct Response	Word#1	Word#2
A	P	N	LION	LINE
G	C	Y	MILK	SALT
C	G	N	SHIRT	S*IRT
A	G	N	LION	LI*N
BP	P	Y	CHEEK	CHEKE
A	S	Y	HORSE	TROT
G	P	Y	BREAD	BRED
A	C	N	TIGER	SHIRT
A	P	Y	SHEEP	SHEAP
BP	P	N	ELBOW	ELATE
BP	G	Y	HEART	HEART
A	G	Y	HORSE	HORSE
A	S	Y	DEER	TROT

APPENDIX B

Computer Control Programs and Instruction Set

Figure

K. Instruction Set

L. Program for Apple II/E Interface System:

Tachistoscope with RT Clock and Error Check

Figure K

Instruction Set

YOU WILL SEE THREE WORDS ON THE SCREEN
THE FIRST WILL TELL YOU HOW TO COMPARE
THE TWO THAT WILL FOLLOW
THERE ARE FOUR TYPES OF QUESTIONS
THEY ARE:
WORDS THAT LOOK THE SAME
WORDS THAT SOUND THE SAME
WORDS THAT BELONG TO THE SAME GROUP
WORDS THAT CAN BE IN A SUBJECT/PREDICATE RELATIONSHIP

THE FIRST WORD WILL BE:
**********LOOK**********
**********SOUND**********
**********GROUP**********
**********SPEECH**********
FOR EACH THERE WILL BE
**********YES**********
AND
**********NO**********
RESPONSES

HERE ARE SOME EXAMPLES:

LOOK	BEAR	BEAR = YES
LOOK	BEAR	B*AR = NO
SOUND	BEAR	BARE = YES
SOUND	BEAR	BEST = NO
GROUP	BEAR	MOUSE = YES
GROUP	BEAR	SHOE = NO
SPEECH	BEAR	LOPE = YES
SPEECH	BEAR	ROAD = NO

YOU WILL SEE THE THREE WORDS
THEN YOU MUST USE THE SWITCH TO ANSWER
**********YES**********
OR
**********NO**********
IF YOU TAKE A LONG TIME TO ANSWER
YOU WILL GET A MESSAGE ON THE SCREEN

PLEASE PLEASE PLEASE PLEASE PLEASE
TRY NOT TO BLINK TRY NOT TO BLINK
TRY TO MOVE AS LITTLE AS POSSIBLE
WE CAN ALWAYS TAKE A BREAK BETWEEN TRIALS
THANKS THANKS THANKS THANKS

Figure L

Program for Apple II/E Interface System

Tachistoscope with RT Clock and Error Check

```
INPUT/INTERFACE CARD                    TRIGGER TRIAL
VIDEO VERTICAL                          BLANK
OUTPUT TO PATHFINDER (10 usec.)         +3 VOLT TRIGGER
VIDEO VERTICAL                          FIXATION FIELD BLANK
DELAY (100 msec.)                       EP BASELINE
VIDEO VERTICAL                          CUE STIMULUS
DELAY (50 msec.)                        CUE DURATION
VIDEO VERTICAL                          CUE BLANK
DELAY (1000 msec.)                      INTERSTIMULUS INTERVAL
VIDEO VERTICAL                          STIMULUS #1
DELAY (50 msec.)                        STIMULUS #1 DURATION
VIDEO VERTICAL                          STIMULUS #1 BLANK
DELAY (1000 msec.)                      INTERSTIMULUS INTERVAL
VIDEO VERTICAL                          STIMULUS #2
CLOCK READ #1                           START REACTION TIME CLOCK
DELAY (50 msec.)                        STIMULUS #2 DURATION
VIDEO VERTICAL                          STIMULUS #2 BLANK
INPUT/INTERFACE CARD                    RESPONSE INPUT YES/NO
CHECK INPUT                             ERROR CHECK EVENT #18
CLOCK READ #2                           STOP RT CLOCK
DELAY (1000 msec.)                      INTER-TRIAL INTERVAL
CALCULATE REACTION TIME                 RT (CLOCK #2 - CLOCK #1)
BRANCH.RT (1200 msec.)                  RT BRANCH TO EVENT 25
BRANCH.FORCED                           AUTO BRANCH TO EVENT #28
VIDEO HORIZONTAL                        RT PROMPT
DELAY (1000 msec.)                      PROMPT DURATION
VIDEO HORIZONTAL                        PROMPT BLANK
QUIT
```

APPENDIX C

STATISTICAL TABLES

Table

Table A

Results of GLM Analysis of Reaction Time Data

SOURCE	df	SS	MS	F
Subject	11	14300.31	1300.02	
Session	2	5132.82	2566.41	20.46*
Session*Subject	22	2759.71	125.44	
Task	3	6564.60	2188.20	71.77*
Task*Subject	33	1006.11	30.49	
Category	3	134.58	44.86	6.71*
Category*Subject	33	220.78	6.69	
Session*Task	6	396.56	69.09	7.59*
Session*Task*Subject	66	575.16	8.71	
Session*Category	6	32.05	5.34	1.76 ns
Session*Category*Subject	66	200.74	3.04	
Task*Category	6	103.55	17.26	4.15*
Task*Category*Subject	66	274.53	4.16	
Session*Task*Category	36	12328.04	342.45	4.93*
Session*Task*Category*Subject	467	32420.25	69.42	17.01*
Error	11059	45122.91	4.08	
Corrected Total	11885	77543.16		

ns = not significant * = p<.001

Table B

Subject Mean Correct Reaction Times and Standard Deviations

Sessions 1, 2, 3, 4

SUBJECT: JW

	SESSION			
TASK	1	2	3	4
GRAPHIC	580.0 98.4	564.4 167.3	566.6 108.3	516.6 84.3
PHONETIC	653.0 159.8	577.9 110.0	589.1 114.1	530.9 102.8
CATEGORY	649.6 152.3	635.1 131.0	603.7 110.0	575.7 94.9
SYNTACTIC	786.7 194.8	725.2 176.1	629.2 157.0	580.4 108.8

SUBJECT: MR

	SESSION			
TASK	1	2	3	4
GRAPHIC	577.9 139.1	550.7 124.9	601.3 161.2	747.7 163.8
PHONETIC	685.6 115.1	645.3 175.1	623.6 149.9	824.8 202.5
CATEGORY	683.6 175.7	629.6 117.5	681.5 169.1	878.1 243.7
SYNTACTIC	775.9 180.6	736.2 192.1	685.3 136.8	849.0 263.7

Subject Mean Correct Reaction Times and Standard Deviations

Sessions 1, 2, 3, 4

SUBJECT: MH

TASK	SESSION 1	2	3	4
GRAPHIC	538.1	433.6	437.2	472.2
	160.1	88.8	67.1	119.5
PHONETIC	752.9	536.9	503.2	472.3
	196.4	129.7	102.2	89.0
CATEGORY	718.8	581.5	546.4	529.3
	140.5	106.0	93.2	122.3
SYNTACTIC	886.6	597.3	587.0	553.3
	233.6	105.4	115.2	109.6

SUBJECT: BB

TASK	SESSION 1	2	3	4
GRAPHIC	555.3	559.1	543.2	540.7
	131.1	140.1	129.5	099.0
PHONETIC	682.4	614.0	605.5	577.1
	176.8	122.5	109.7	120.3
CATEGORY	664.8	664.6	656.0	649.1
	168.5	161.3	144.7	132.3
SYNTACTIC	782.8	653.9	695.8	659.3
	216.7	176.3	140.9	187.3

Subject Mean Correct Reaction Times and Standard Deviations

Sessions 1, 2, 3, 4

SUBJECT: KP

TASK	SESSION 1	2	3	4
GRAPHIC	572.3	562.8	584.6	623.8
	113.5	111.5	135.9	107.7
PHONETIC	808.4	760.9	740.0	731.5
	184.0	146.0	140.8	138.5
CATEGORY	774.8	783.4	803.1	734.1
	153.5	135.3	171.3	118.8
SYNTACTIC	836.7	871.1	837.2	810.7
	152.0	141.0	162.4	165.9

SUBJECT: JK

TASK	SESSION 1	2	3	4
GRAPHIC	758.1	634.1	559.0	553.6
	225.1	224.8	158.5	102.3
PHONETIC	1015.0	814.9	669.4	616.9
	294.4	259.6	206.2	110.0
CATEGORY	864.0	776.6	712.6	670.1
	240.6	265.2	214.4	166.1
SYNTACTIC	869.8	714.0	721.4	719.9
	250.2	187.9	251.3	165.2

Subject Mean Correct Reaction Times and Standard Deviations

Sessions 1, 2, 3, 4

SUBJECT: AM

	SESSION			
TASK	1	2	3	4
GRAPHIC	702.5	569.7	551.9	585.1
	188.0	109.9	129.8	161.5
PHONETIC	904.3	723.0	669.8	680.8
	287.1	171.4	191.5	208.5
CATEGORY	896.9	689.4	641.2	635.8
	283.8	176.0	176.5	210.6
SYNTACTIC	976.2	704.9	627.5	579.8
	254.5	200.1	126.4	124.0

SUBJECT: LC

	SESSION			
TASK	1	2	3	4
GRAPHIC	649.4	570.9	590.3	642.2
	205.3	124.3	149.8	123.6
PHONETIC	958.3	780.4	702.6	782.1
	320.1	191.6	152.7	188.5
CATEGORY	934.4	714.6	672.6	769.2
	313.5	185.2	174.5	193.5
SYNTACTIC	1115.6	797.9	673.4	812.9
	346.8	252.7	144.6	242.4

Subject Mean Correct Reaction Times and Standard Deviations

Sessions 1, 2, 3, 4

SUBJECT: DB

	SESSION			
TASK	1	2	3	4
GRAPHIC	638.6 132.8	623.7 171.6	548.1 107.5	721.9 138.8
PHONETIC	848.7 179.0	758.8 139.8	715.0 132.1	765.9 144.0
CATEGORY	755.2 192.8	679.1 162.9	674.9 145.9	807.8 254.4
SYNTACTIC	938.9 212.2	768.0 178.2	701.7 197.5	763.7 135.2

SUBJECT: CC

	SESSION			
TASK	1	2	3	4
GRAPHIC	900.7 300.5	724.0 157.6	779.7 165.9	800.4 198.9
PHONETIC	1090.4 279.0	952.8 220.2	986.5 206.1	955.8 159.9
CATEGORY	1005.0 311.2	846.1 198.2	929.1 211.1	932.8 251.1
SYNTACTIC	1060.27 272.2	995.5 188.9	963.4 203.3	975.2 240.9

Subject Mean Correct Reaction Times and Standard Deviations

Sessions 1, 2, 3, 4

SUBJECT: TM

	SESSION			
TASK	1	2	3	4
GRAPHIC	790.7	692.7	643.2	637.8
	270.7	221.0	144.3	159.7
PHONETIC	1090.0	914.9	842.2	789.8
	259.0	217.2	206.5	223.4
CATEGORY	1054.3	935.5	827.3	747.0
	295.8	267.3	261.9	214.1
SYNTACTIC	1118.9	958.8	837.7	773.2
	340.6	287.3	247.2	262.7

SUBJECT: RI

	SESSION			
TASK	1	2	3	4
GRAPHIC	975.2	629.3	685.0	799.3
	256.9	133.5	178.7	284.9
PHONETIC	1119.9	774.8	835.4	852.4
	252.8	188.8	192.2	242.0
CATEGORY	1068.0	722.6	680.6	757.1
	312.3	208.4	172.6	199.8
SYNTACTIC	1180.2	737.5	775.1	768.8
	303.8	169.0	219.7	247.4

Table C

Scheffe Post Hoc Analysis of Task

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RTA
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN TUKEY'S FOR ALL-PAIRWISE COMPARISONS.

ALPHA=0.05 CONFIDENCE=0.95 DF=11778 MSE=4.02592
CRITICAL VALUE OF F=2.60566

COMPARISONS SIGNIFICANT AT THE 0.05 LEVEL ARE INDICATED BY '***'

TASK COMPARISON	SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT	
S - P	0.20435	0.45149	0.61864	***
S - C	0.52103	0.68810	0.85518	***
S - G	1.86175	2.02873	2.19572	***
P - S	-0.61864	-0.45149	-0.28435	***
P - C	0.10044	0.23661	0.37278	***
P - G	1.44118	1.57724	1.71330	***
C - S	-0.85518	-0.68810	-0.52103	***
C - P	-0.37278	-0.23661	-0.10044	***
C - G	1.20466	1.34063	1.47660	***
G - S	-2.19572	-2.02873	-1.86175	***
G - P	-1.71330	-1.57724	-1.44118	***
G - C	-1.47660	-1.34063	-1.20466	***

Table D

Post Hoc Analysis of Task - Session 3

SESSION=3

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RTA
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN TUKEY'S
FOR ALL PAIRWISE COMPARISONS.

ALPHA=0.05 CONFIDENCE=0.95 DF=3832 MSE=2.94173
CRITICAL VALUE OF F=2.60723

COMPARISONS SIGNIFICANT AT THE 0.05 LEVEL ARE INDICATED BY '***'

TASK COMPARISON		SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT	
S	- P	-0.00262	0.24575	0.49412	
S	- C	0.06136	0.30974	0.55822	***
S	- G	1.19256	1.44104	1.68952	***
P	- S	-0.49412	-0.24575	0.00262	
P	- C	-0.13875	0.06399	0.26674	
P	- G	0.99254	1.19529	1.39804	***
C	- S	-0.55822	-0.30974	-0.06126	***
C	- P	-0.26674	-0.06399	0.13875	
C	- G	0.92841	1.13130	1.33418	***
G	- S	-1.68952	-1.44104	-1.19256	***
G	- P	-1.39804	-1.19529	-0.99254	***
G	- C	-1.33418	-1.13130	-0.92841	***

Table E

Scheffe Post Hoc Analysis of Session Reaction Time

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RTA
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN TUKEY'S FOR ALL PAIRWISE COMPARISONS.

ALPHA=0.05 CONFIDENCE=0.95 DF=11778 MSE=4.02592
CRITICAL VALUE OF F=2.99649

COMPARISONS SIGNIFICANT AT THE 0.05 LEVEL ARE INDICATED BY '***'

SESSION COMPARISON		SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT	
1	- 2	1.14933	1.25937	1.36941	***
1	- 3	1.36441	1.47507	1.58573	***
2	- 1	-1.36941	-1.25937	-1.14933	***
2	- 3	0.10581	0.21570	0.32609	***
3	- 1	-1.58573	-1.47507	-1.36441	***
3	- 2	-0.32609	-0.21570	-0.10531	***

Table F

Scheffe Post Hoc Analysis of Session Variability

ANALYSIS OF VARIANCE PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: STD
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=33 MSE=0.275543
CRITICAL VALUE OF F=3.28492
MINIMUM SIGNIFICANT DIFFERENCE=.54928

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE GROUPING	MEAN	N	SESSION
A	2.5100	12	1
B	1.9582	12	2
B			
B	1.7831	12	3

Table G

Scheffe Post Hoc Analysis of Word Category

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RTA
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN TUKEY'S FOR ALL PAIRWISE COMPARISONS.

ALPHA=0.05 CONFIDENCE=0.95 DF=11778 MSE=4.02592
CRITICAL VALUE OF F=2.60566

COMPARISONS SIGNIFICANT AT THE 0.05 LEVEL ARE INDICATED BY '***'

CATEGORY COMPARISON		SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT	
A	- BP	0.04700	0.18749	0.32799	***
A	- C	0.11424	0.25483	0.39541	***
A	- G	0.18529	0.32603	0.46677	***
BP	- A	-0.32799	-0.18749	-0.04700	***
BP	- C	-0.08970	0.06733	0.22436	
BP	- G	-0.01863	0.13853	0.29570	
C	- A	-0.39541	-0.25483	-0.11424	***
C	- BP	-0.22436	-0.06733	0.08970	
C	- G	-0.08605	0.07120	0.22845	
G	- A	-0.46677	-0.32603	-0.18529	***
G	- BP	-0.29570	-0.13853	0.01863	
G	- C	-0.22845	-0.07120	0.08605	

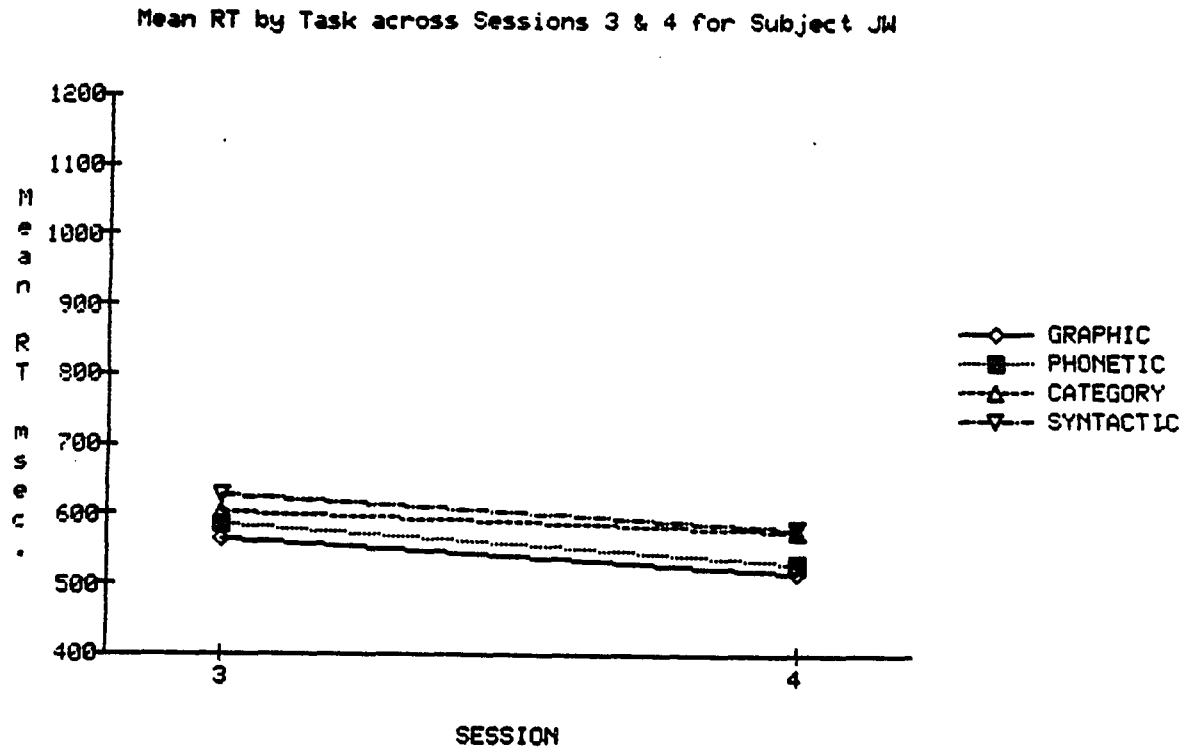
APPENDIX D

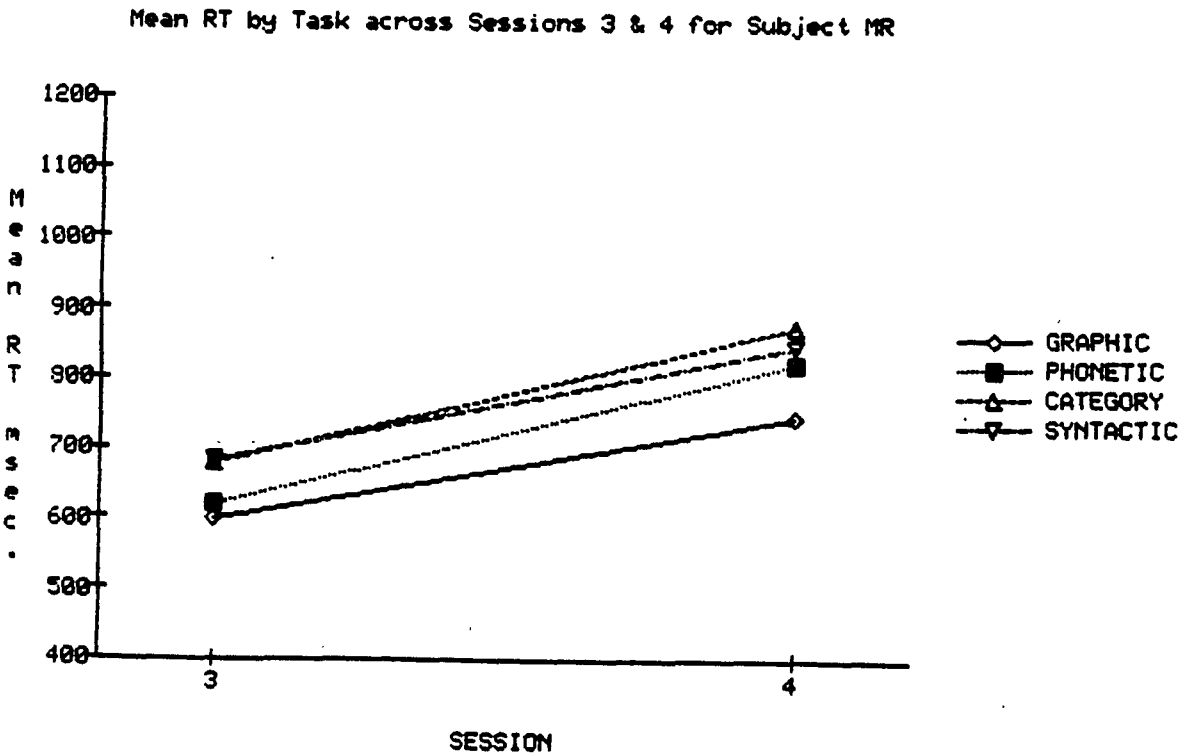
Graphic Comparisons of Sessions 3 vs. 4

Figure

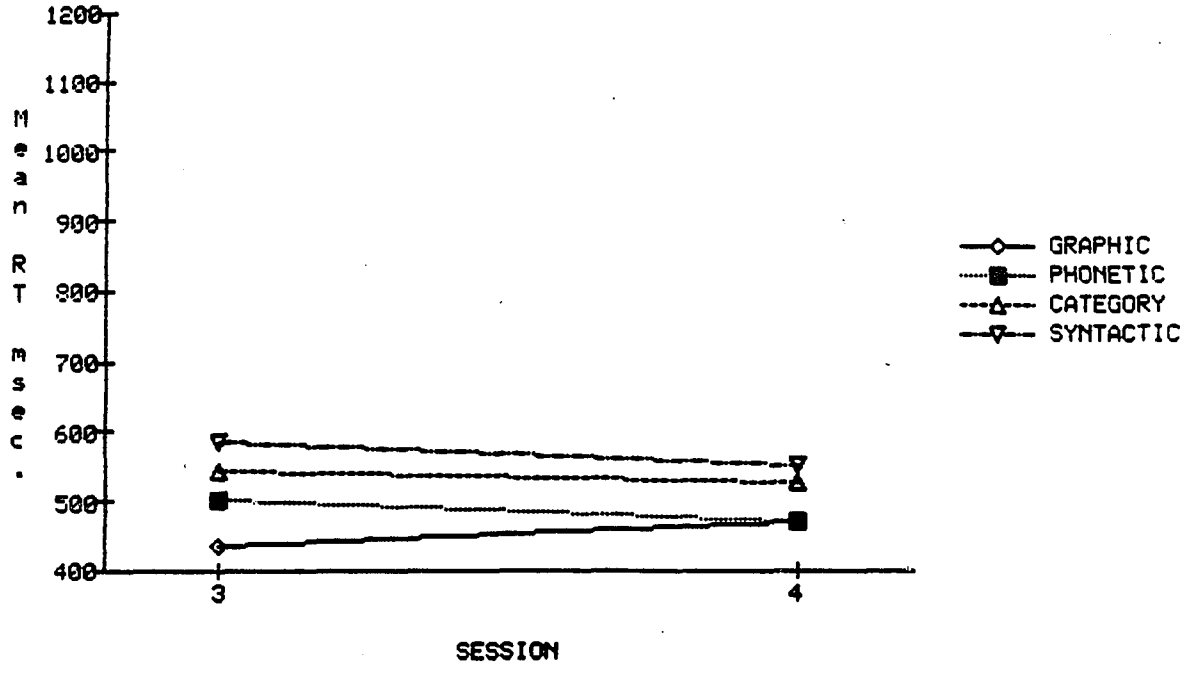
M. Mean RT by Task across Sessions 3 & 4 for Individual Subjects

Figure M

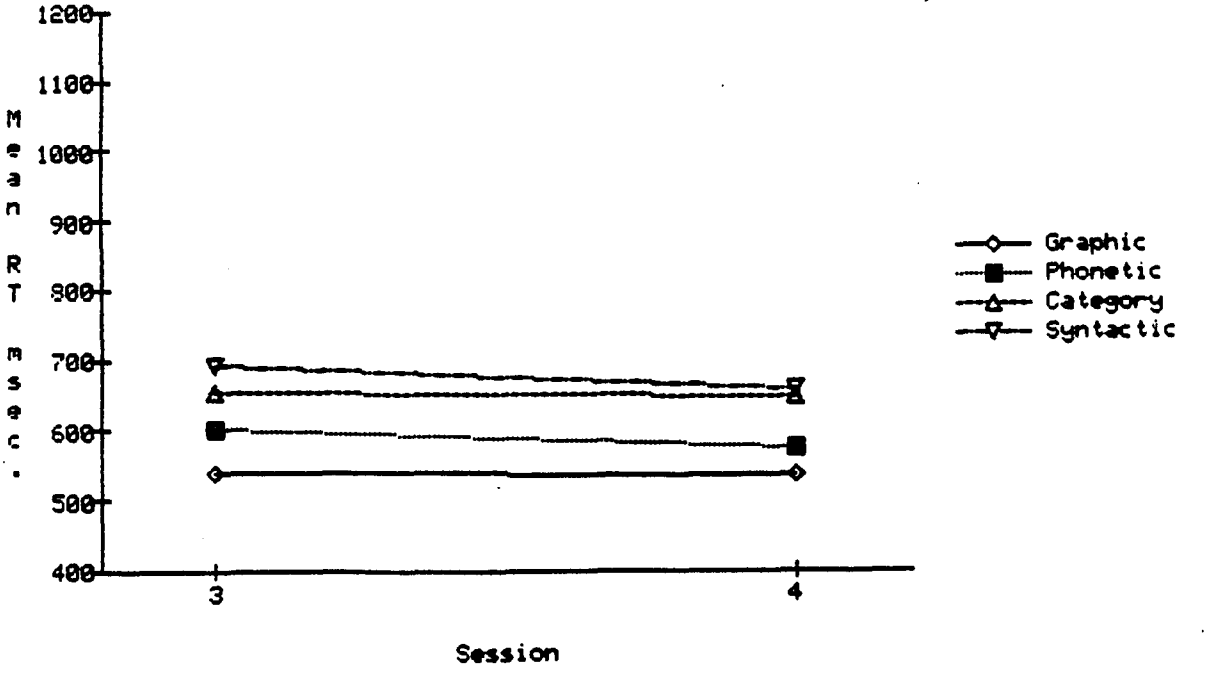

Mean RT by Task across Sessions 3 & 4 for Subject JW
Mean RT msec.
1200
1100
1000
900
800
700
600
500
400
3
4
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC


Mean RT by Task across Sessions 3 & 4 for Subject MR
Mean RT msec.
1200
1100
1000
900
800
700
600
500
400
3
4
SESSION
GRAPHIC
PHONETIC
CATEGORY
SYNTACTIC

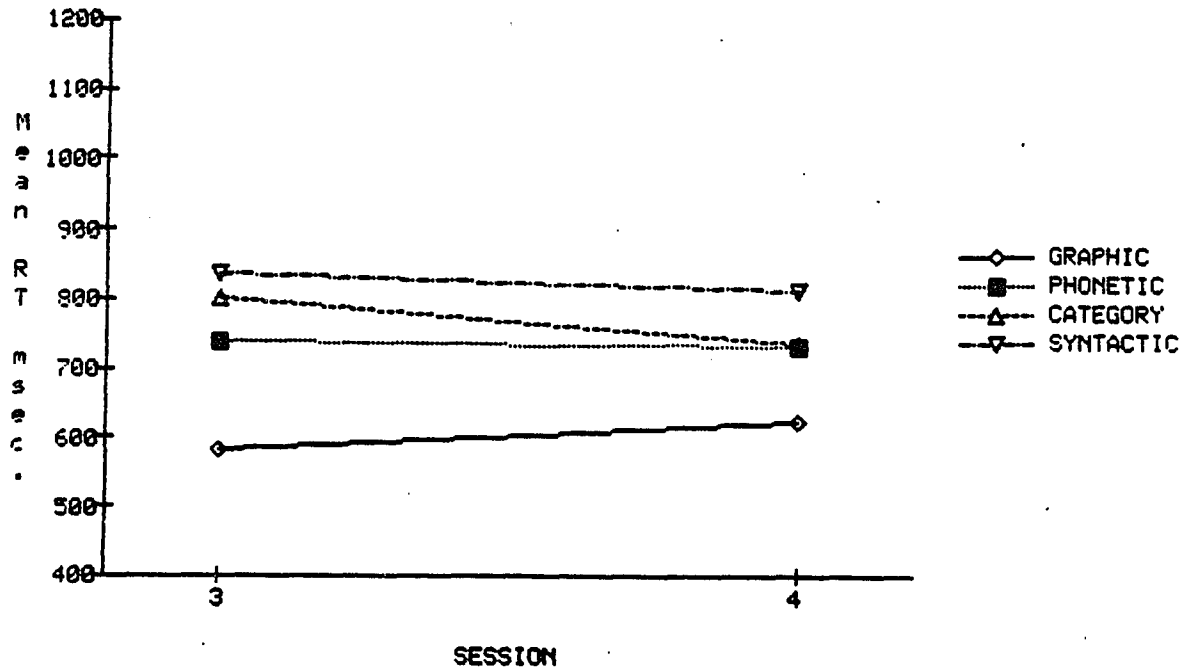
Mean RT by Task across Sessions 3 & 4 for Subject MH



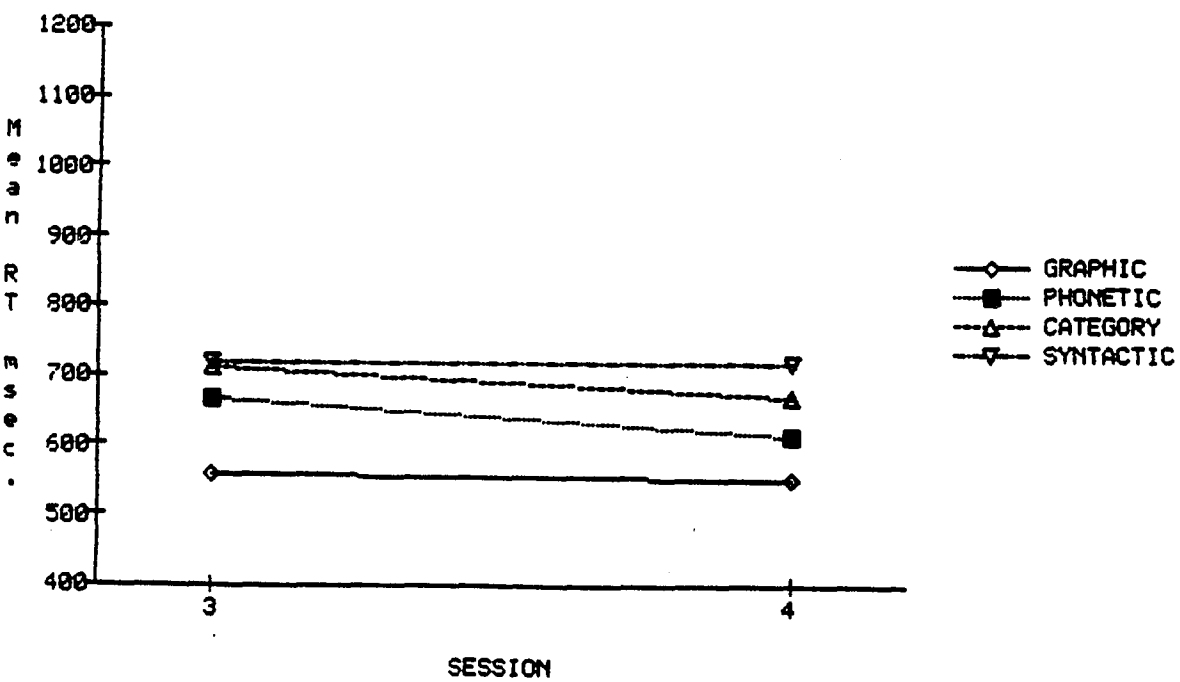
Mean RT by Task across Sessions 3 & 4 for Subject BB



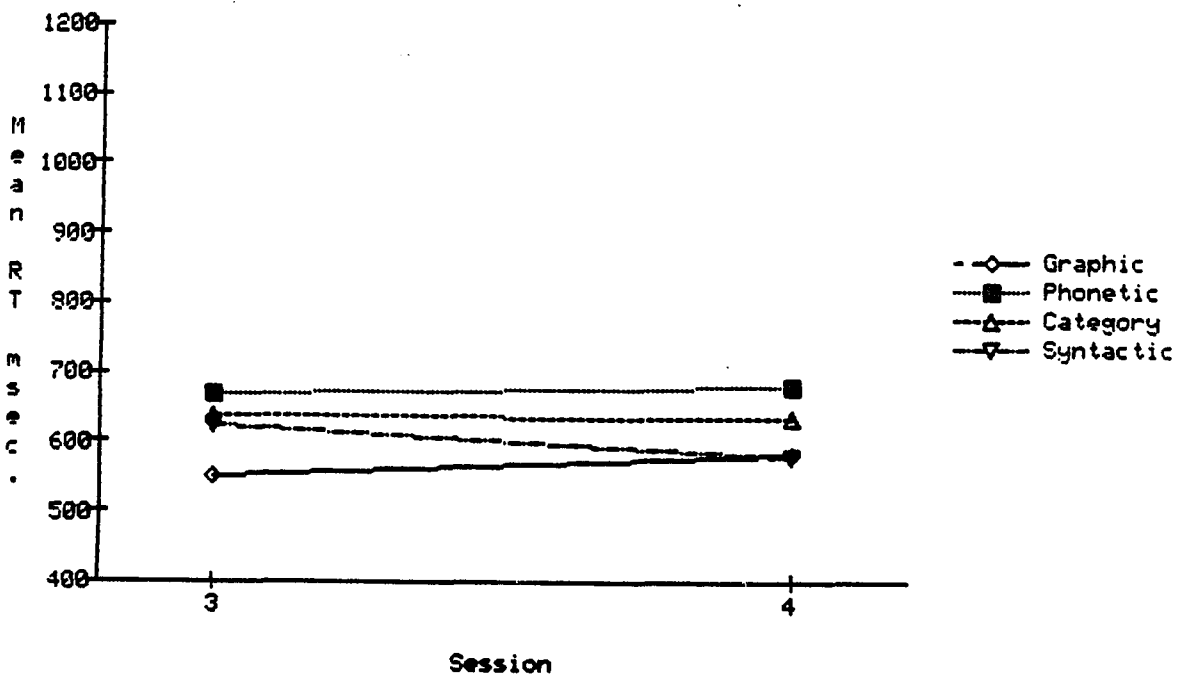
Mean RT by Task across Sessions 3 & 4 for Subject KP



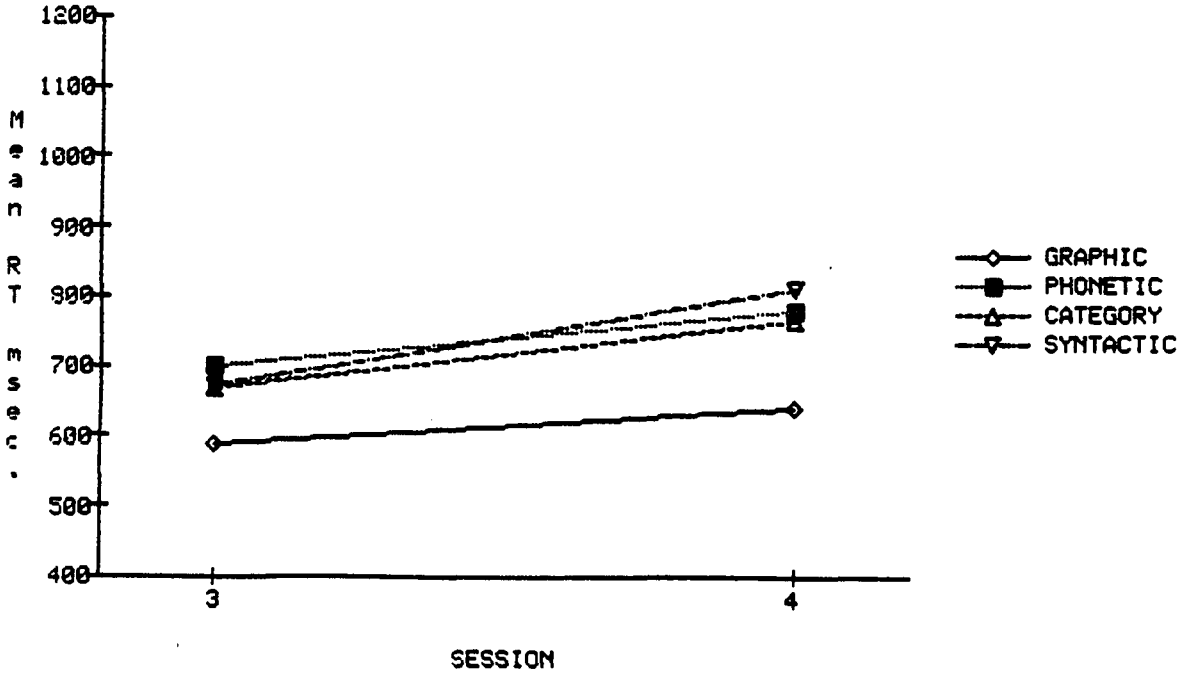
Mean RT by Task across Sessions 3 & 4 for Subject JK



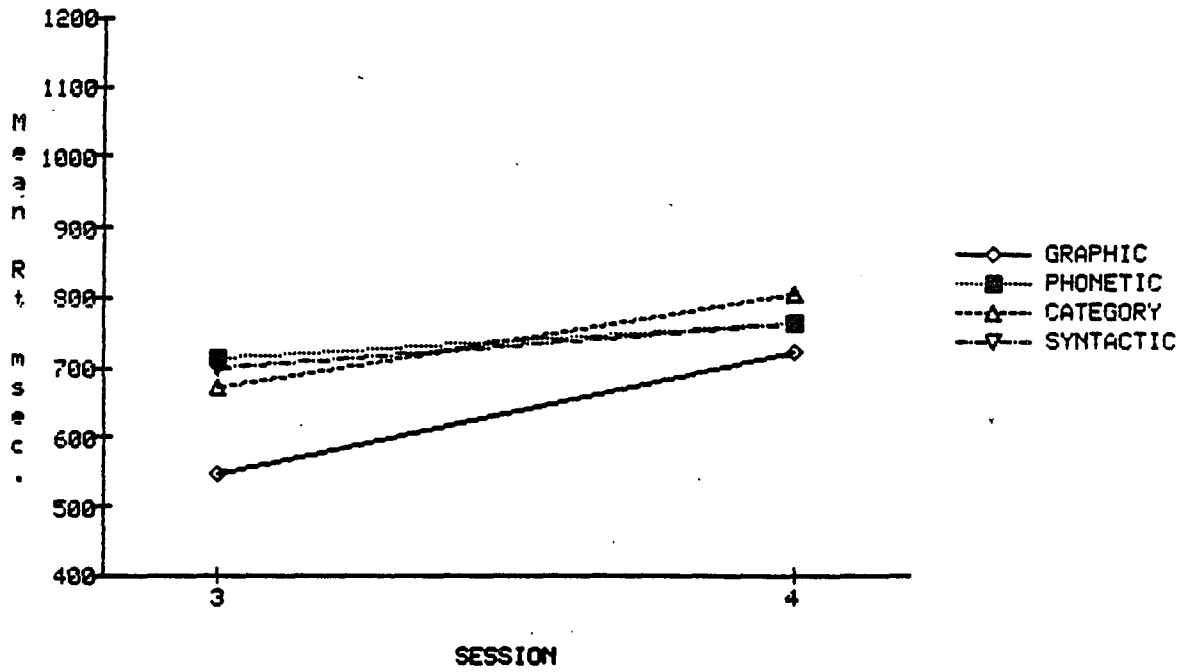
Mean RT by Task across Sessions 3 & 4 for Subject AM



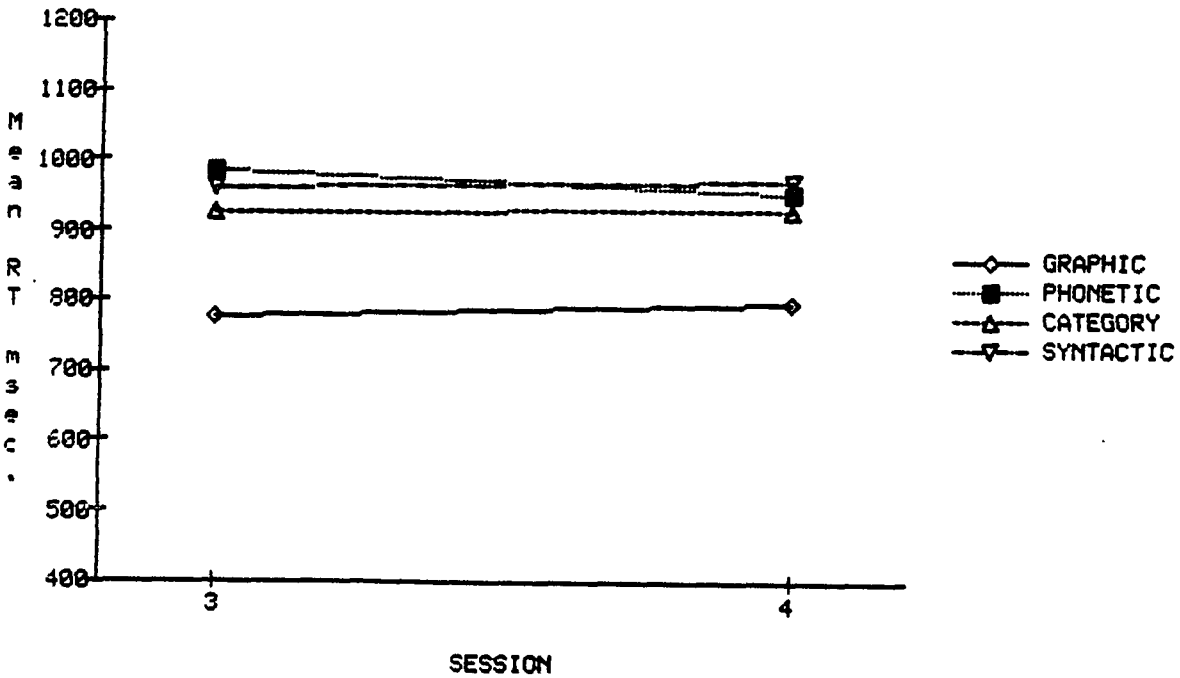
Mean RT by Task across Sessions 3 & 4 for Subject LC



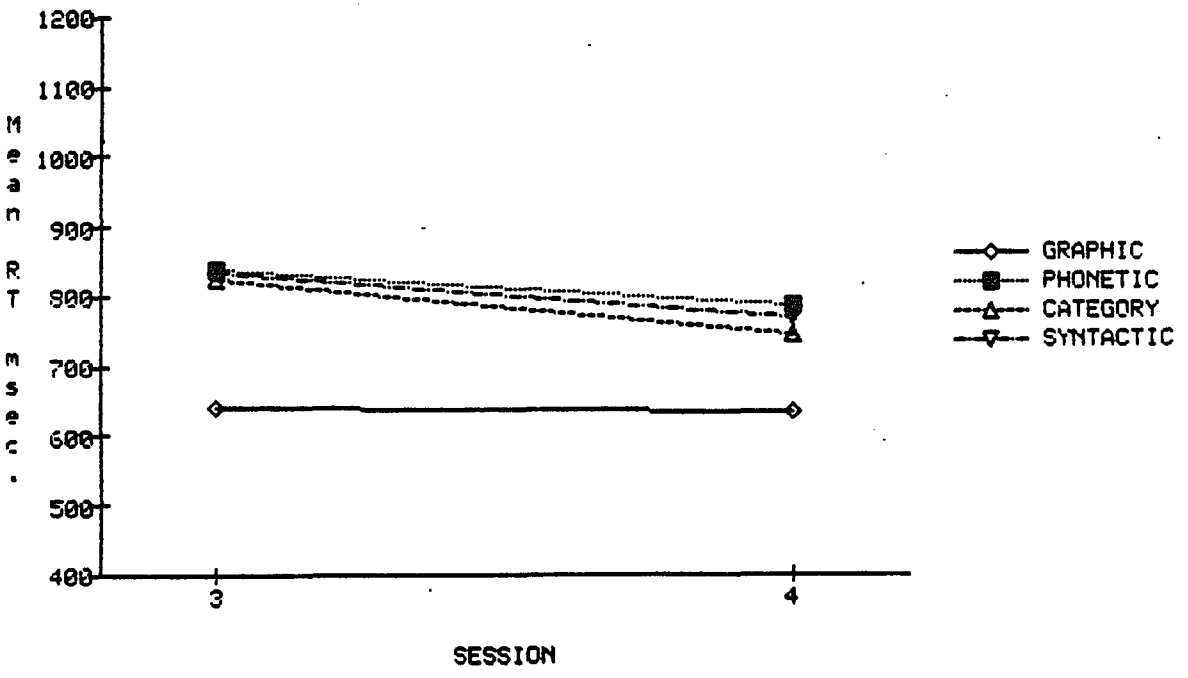
Mean RT by Task across Sessions 3 & 4 for Subject DB



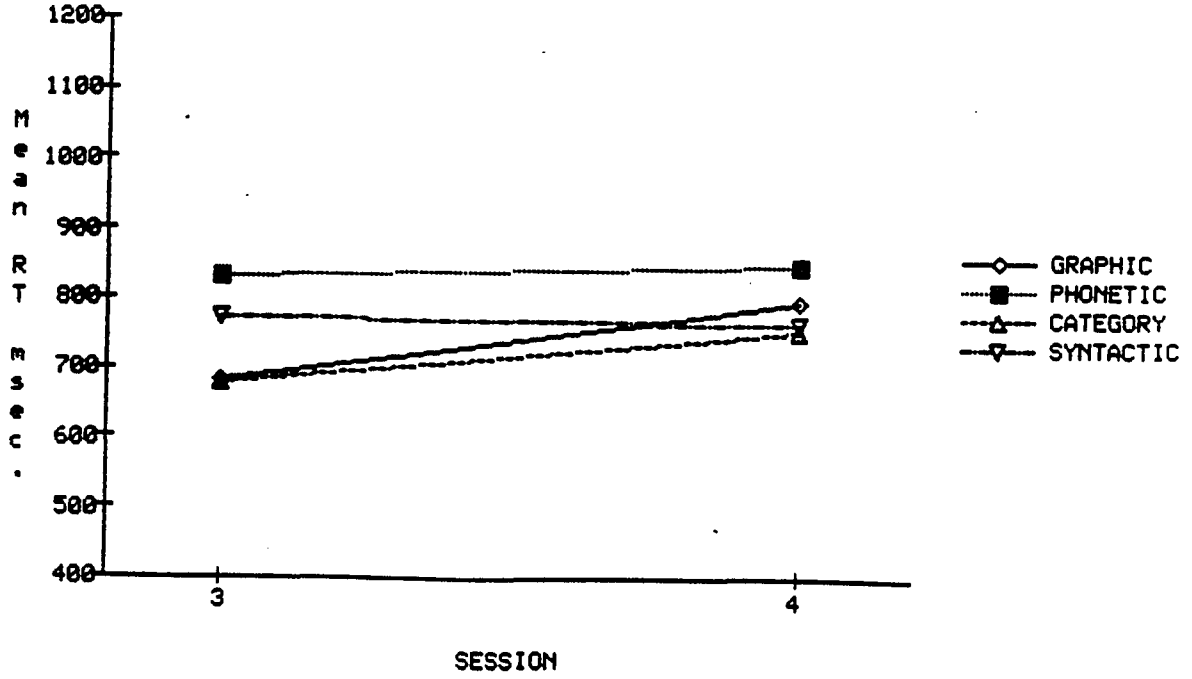
Mean RT by Task across Sessions 3 & 4 for Subject CC



Mean Rt by Task across Sessions 3 & 4 for Subject TM



Mean Rt by Task across Sessions 3 & 4 for Subject RI



APPENDIX E

Evoked Potentials

Figure N

International 10/20 System for Electrode Placement

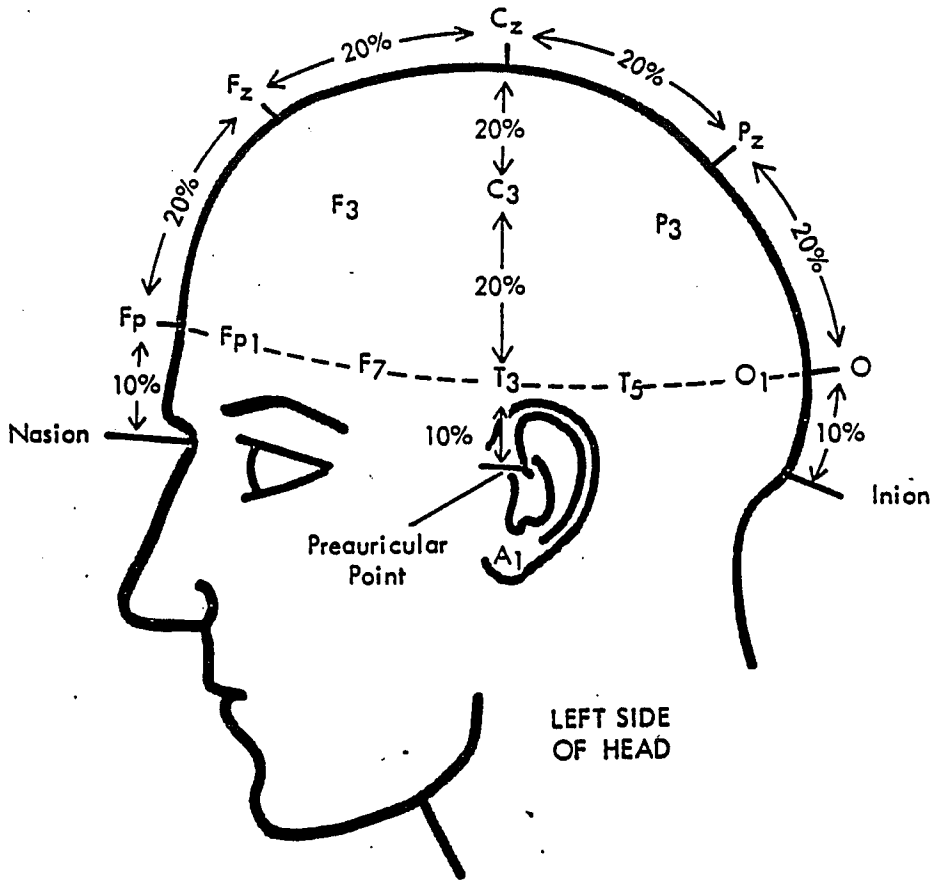


Figure O

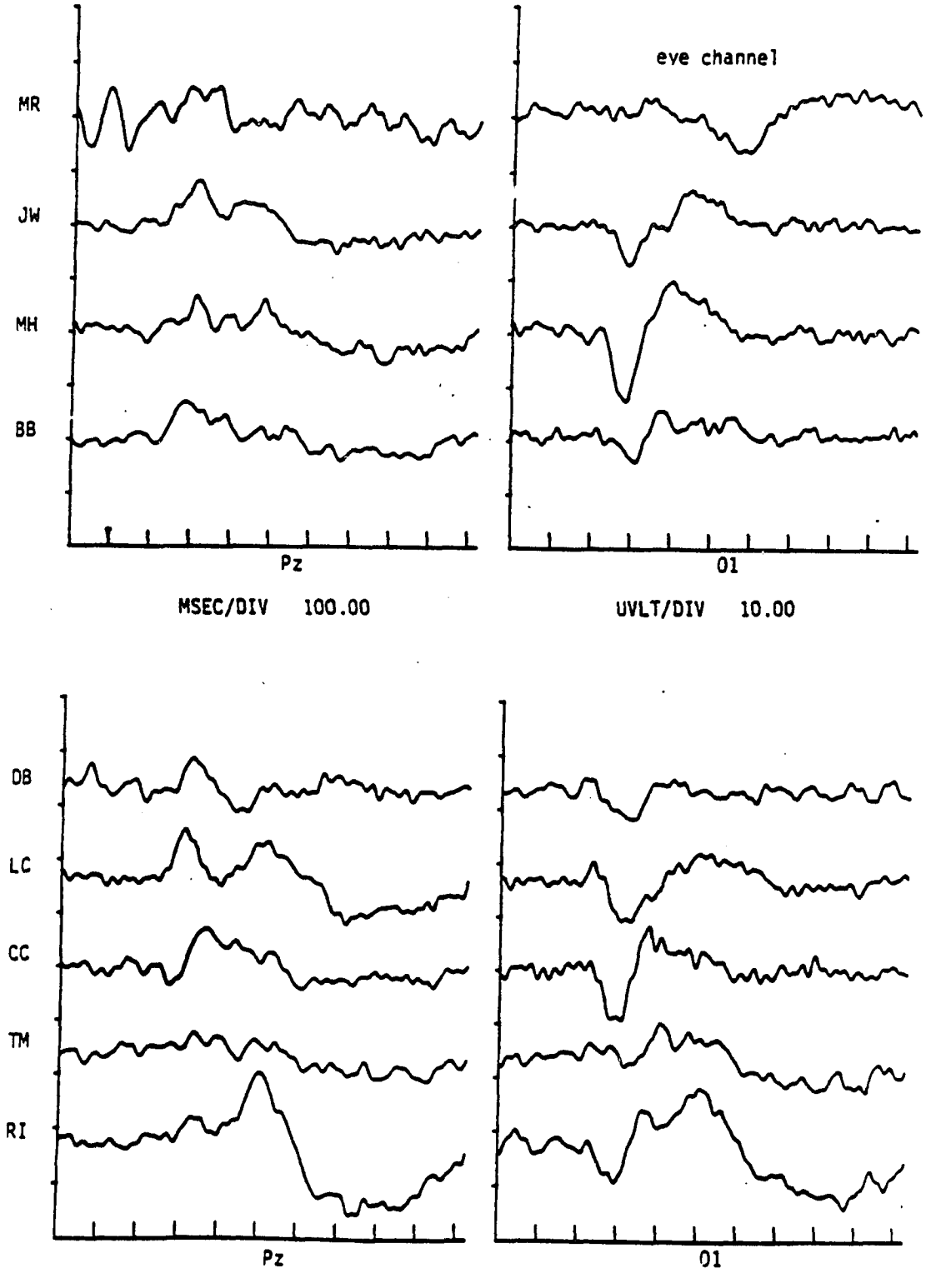
Mecol Control Program for Nicolet Pathfinder II

```
INPUT "DATA DISK MOUNTED AND SUBJECT READY?"TO DUMMY END
ART "B"=OFF
SET SYS;REM\SET AMP"1";LBP=.5;HBP=6000;SNS=100;NCH=1
SET AMP"2";LBP=.5;HBP=6000;SNS=100;NCH=1
TME"B"=1000\SWP"B"=1\CHN"B"=2\SET STIM"0";TRG=2;EXT=2
ZAP A1 B1 A2 B2 A3 B3 A4 B4
DSP A1 B1 A2 B2 A3 B3 A4 B4
AVE A1 B1
AVE A2 B2
AVE A3 B3
AVE A4 B4
LOG R001&
ZAP A5 B5 A6 B6 A7 B7 A8 B8
DSP A5 B5 A6 B6 A7 B7 A8 B8
AVE A5 B5
AVE A6 B6
AVE A7 B7
AVE A8 B8
LOG R002&
ZAP A1 B1 A2 B2 A3 B3 A4 B4
DSP A1 B1 A2 B2 A3 B3 A4 B4
AVE A1 B1
AVE A2 B2
AVE A3 B3
AVE A4 B4
LOG R003&
ZAP A5 B5 A6 B6 A7 B7 A8 B8
DSP A5 B5 A6 B6 A7 B7 A8 B8
AVE A5 B5
AVE A6 B6
AVE A7 B7
AVE A8 B8
LOG R004&
ZAP A1 B1 A2 B2 A3 B3 A4 B4
DSP A1 B1 A2 B2 A3 B3 A4 B4
AVE A1 B1
AVE A2 B2
AVE A3 B3
AVE A4 B4
LOG R005&
ZAP A5 B5 A6 B6 A7 B7 A8 B8
DSP A5 B5 A6 B6 A7 B7 A8 B8
AVE A5 B5
AVE A6 B6
AVE A7 B7
AVE A8 B8
LOG R006&
INPUT "RERUN PROGRAM AND INSERT NEW DATA DISK"TO DUMMY END
```

Figure P

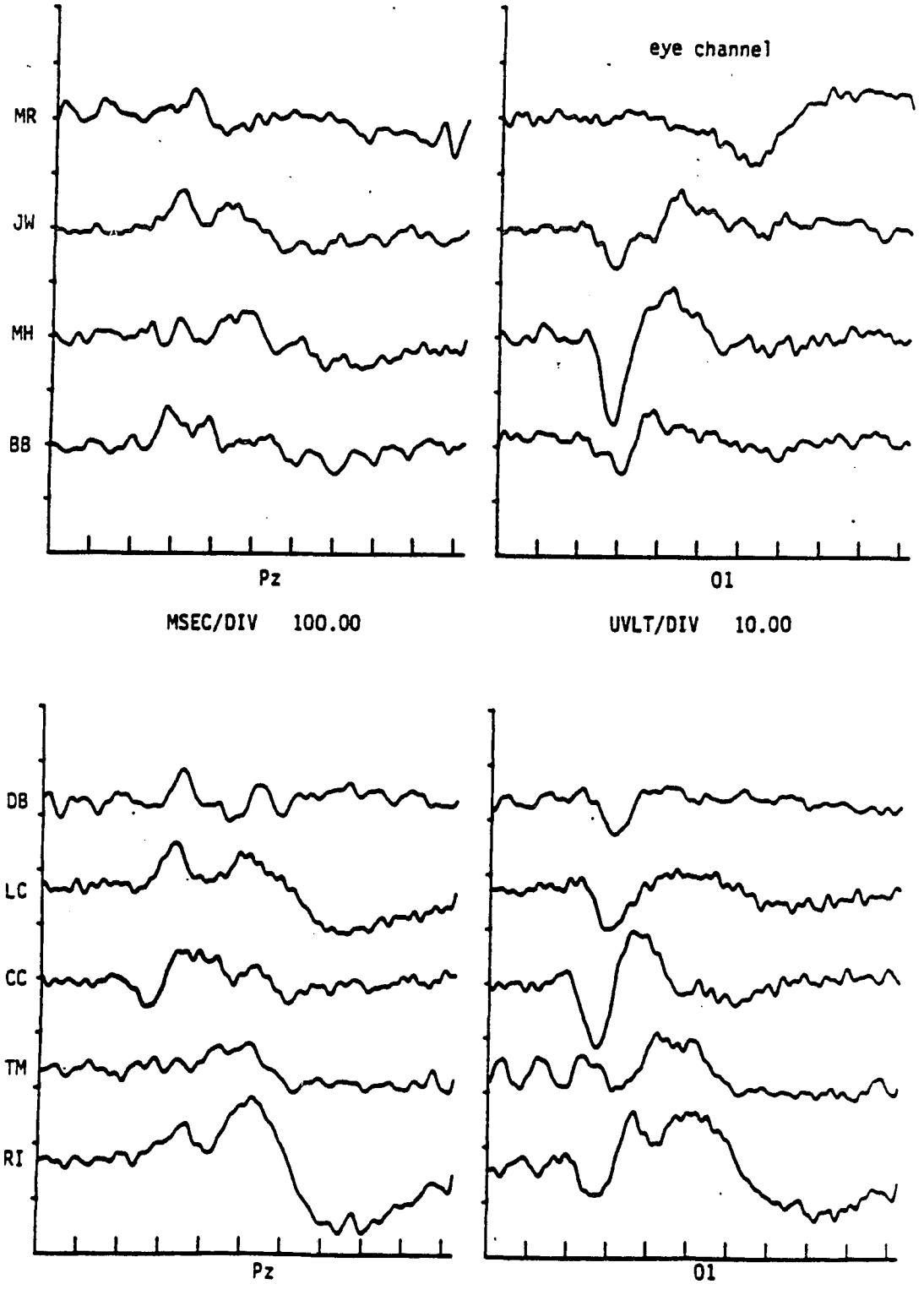
Evoked Potential Measures for Individual Subjects

Graphic Task



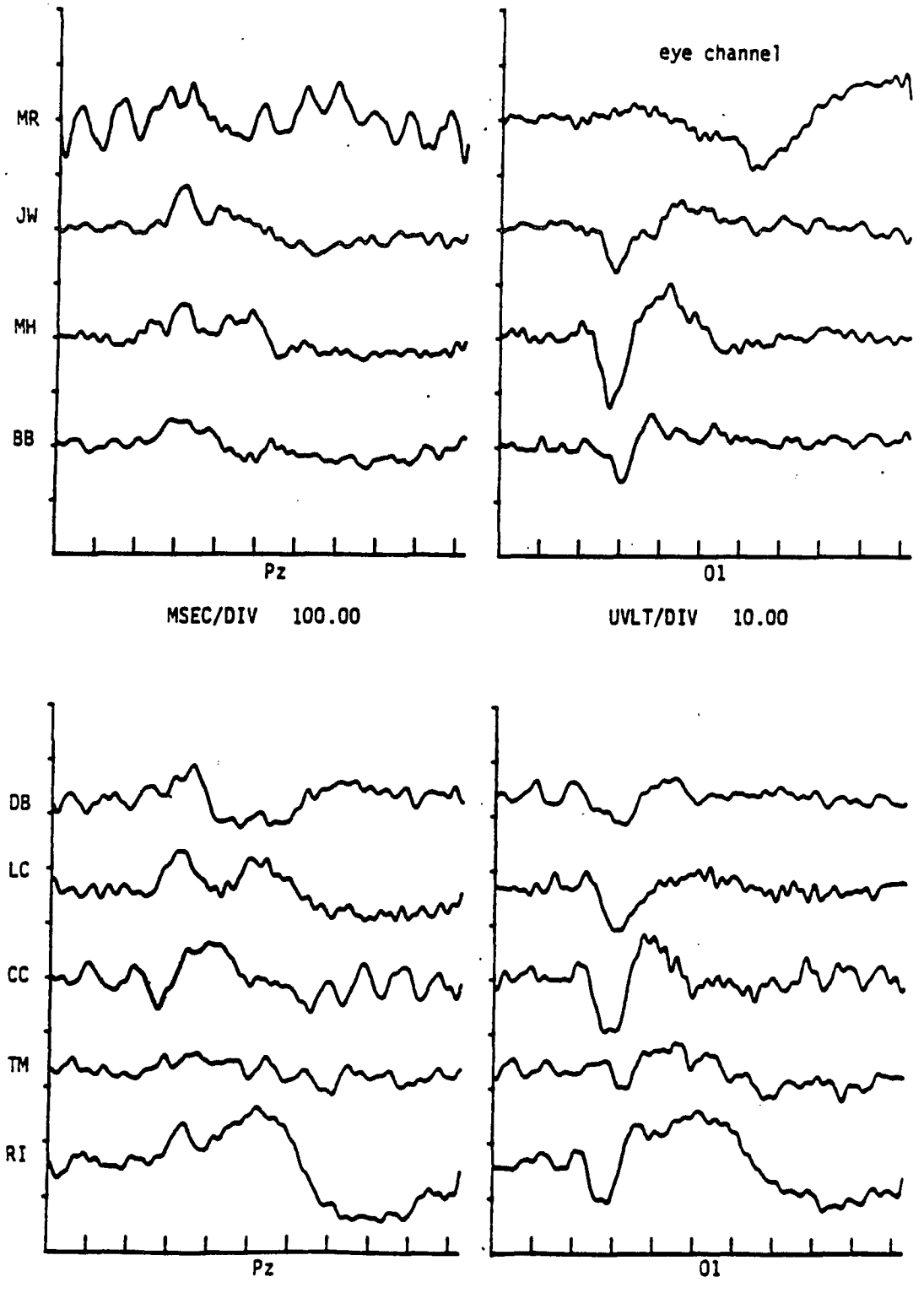
Evoked Potential Measures for Individual Subjects

Phonetic Task



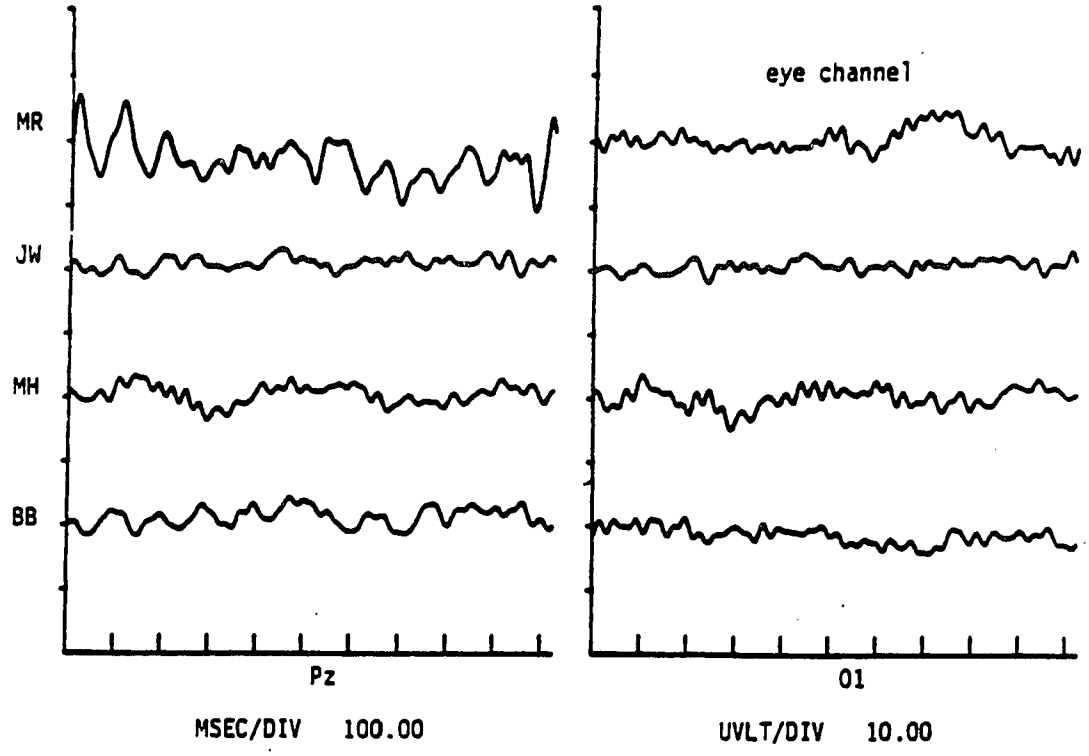
Evoked Potential Measures for Individual Subjects

Category Task



Evoked Potential Measures for Individual Subjects

Syntactic Task



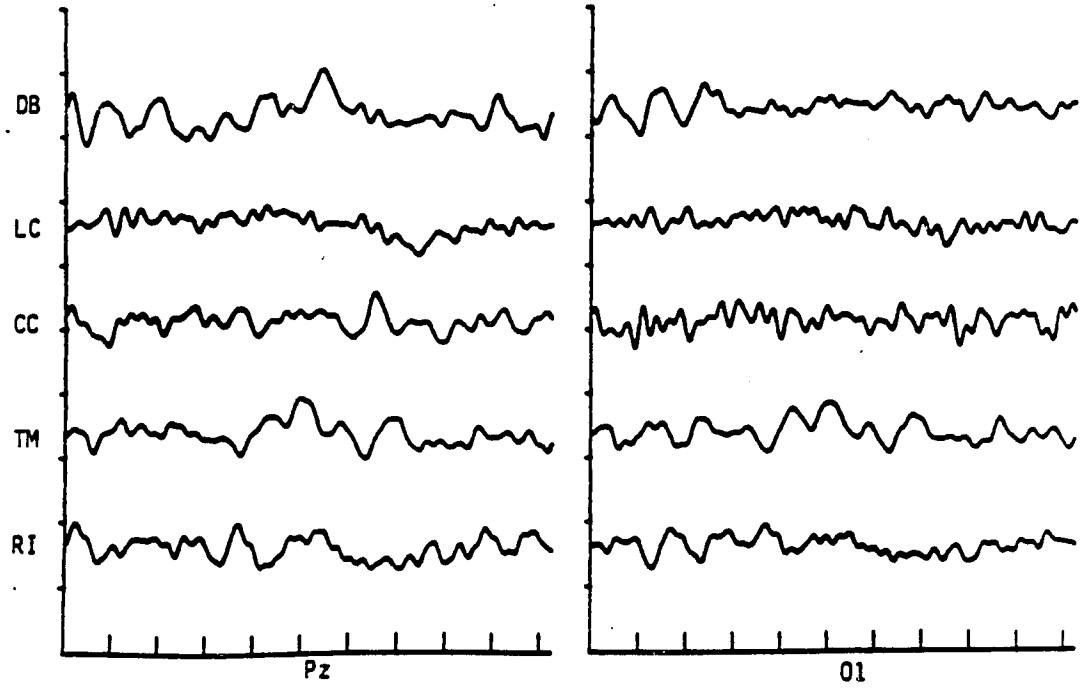


Table H.

Evoked Potential Measures for Individual Subjects

Amplitudes and Latencies at Electrode Pz

Graphic Task

G-P-C GROUP

SUBJECT	P2	P3	LATE NEGATIVITY
MR	222msec. 2.87uvlt.	340msec. -0.57uvlt.	684msec. 0.85uvlt.
JW	212msec. 8.09uvlt.	326msec. 4.24uvlt.	684msec. -2.69uvlt.
MH	212msec. 6.69uvlt.	382msec. 6.12uvlt.	684msec. -5.92uvlt.
BB	186msec. 6.94uvlt.	376msec. 2.11uvlt.	684msec. -3.01uvlt.
	208msec. 6.14uvlt.	356msec. 2.97uvlt.	684msec -2.69

G-C-P GROUP

SUBJECT	P2	P3	LATE NEGATIVITY
DB	226msec. 5.47uvlt.	430msec. 0.65uvlt.	628msec. 1.52uvlt.
LC	210msec. 8.96uvlt.	400msec. 5.85uvlt.	628msec. -5.21uvlt.
CC	262msec. 7.23uvlt.	422msec. 2.63uvlt.	628msec. -3.37uvlt.
TM	236msec. 4.38uvlt.	388msec. 3.10uvlt.	628msec. -3.44uvlt.
RI	232msec. 5.35uvlt.	402msec. 13.61uvlt.	628msec. -12.21uvlt.
	233msec. 6.27uvlt.	408msec. 5.16uvlt.	628msec. -4.54uvlt.

Evoked Potential Measures for Individual Subjects

Amplitudes and Latencies at Electrode Pz

Phonetic Task

G-P-C GROUP

SUBJECT	P2	P3	LATE NEGATIVITY
MR	240msec. 5.26uvlt.	358msec. -0.93uvlt.	666msec. -3.74uvlt.
JW	216msec. 7.04uvlt.	324msec. 4.65uvlt.	666msec. -1.88uvlt.
MH	212msec. 3.47uvlt.	370msec. 4.85uvlt.	666msec. -5.68uvlt.
BB	184msec. 7.19uvlt.	372msec. 0.63uvlt.	666msec. -1.20uvlt.
	213msec. 5.74uvlt.	356msec. 2.30uvlt.	666msec. -3.12uvlt.

G-C-P GROUP

SUBJECT	P2	P3	LATE NEGATIVITY
DB	244msec. 5.32uvlt.	434msec. 2.56uvlt.	700msec. 1.49uvlt.
LC	226msec. 8.42uvlt.	400msec. 5.90uvlt.	700msec. -7.15uvlt.
CC	246msec. 4.94uvlt.	428msec. 2.66uvlt.	700msec. -1.50uvlt.
TM	238msec. 2.13uvlt.	414msec. 5.16uvlt.	700msec. -3.52uvlt.
RI	260msec. 7.21uvlt.	420msec. 11.93uvlt.	700msec. -12.54uvlt.
	242msec. 5.60uvlt.	419msec. 5.64uvlt.	700msec. -4.64uvlt.

Evoked Potential Measures for Individual Subjects

Amplitudes and Latencies at Electrode Pz

Category Task

G-P-C GROUP

SUBJECT	P2	P3	LATE NEGATIVITY
MR	232msec. 6.40uvlt.	414msec. 2.58uvlt.	664sec. -0.43uvlt.
JW	218msec. 7.64uvlt.	302msec. 3.78uvlt.	664msec. -2.67uvlt.
MH	214msec. 6.07uvlt.	388msec. 4.79uvlt.	664msec. -4.20uvlt.
BB	186msec. 4.91uvlt.	386msec. -1.45uvlt.	664msec. -2.48uvlt.
	212msec. 6.25uvlt.	373msec. 2.42uvlt.	664msec. -2.44uvlt.

G-C-P GROUP

SUBJECTS	P2	P3	LATE NEGATIVITY
DB	250msec. 5.82vlt.	416msec. -2.78uvlt.	726msec. 1.46uvlt.
LC	216msec. 6.71uvlt.	420msec. 3.97uvlt.	726msec. -4.48uvlt.
CC	292msec. 6.47uvlt.	412msec. 6.31uvlt.	726msec. -3.29uvlt.
TM	262msec. 3.11uvlt.	436msec. 2.38uvlt.	726msec. -0.98uvlt.
RI	232msec. 6.98uvlt.	414msec. 9.87uvlt.	726msec. -10.87uvlt.
	250msec. 5.81uvlt.	420msec. 3.95uvlt.	726msec. -3.63uvlt.

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