75-13,639

LEWIS, Selma, 1924-

IMPLICIT AND EXPLICIT LEARNING OF ARTIFICIAL LANGUAGES: LEARNING PROCESSES IN RULE APPREHENSION OF COMPLEX, STRUCTURED, PATTERN SEQUENCES.

The City University of New York, Ph.D., 1975
Psychology, experimental

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by

SELMA LEWIS

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.

1975

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.

January 13, 1975
date

Chairman of Examining Committee

January 13, 1975
date

Executive Officer

Arthur S. Reber

Eric Heinemann

Matthew Erdelyi

Supervisory Committee

The City University of New York

Abstract

IMPLICIT AND EXPLICIT LEARNING OF ARTIFICIAL LANGUAGES: LEARNING PROCESSES IN RULE APPREHENSION OF COMPLEX, STRUCTURED, PATTERN SEQUENCES

by

SELMA LEWIS

Adviser: Professor Arthur S. Reber

Interest in complex human learning, or more specifically, the learning process involved in rule apprehension of structured pattern sequences has been greatly stimulated in recent years by developments in linguistics and psycholinguistics, stemming from the work of Chomsky and Miller. A number of studies have examined the acquisition of artificial languages in attempting to explore the underlying cognitive processes used in learning complex rule systems.

A theory of implicit learning has been proposed by Reber to account for the fact that Ss can learn to respond appropriately to complex, highly structured stimulus environments without being explicitly aware of the rule system they are using. Utilizing finite state grammars as the experimental tool, the results of several studies have shown that Ss do develop at least a partial representation of the underlying abstract structure even though they may not be able to explicitly verbalize the rules of formation. However, the level of performance achieved by the Ss did not seem to accurately reflect the levels attained in non-laboratory

situations such as acquisition of language, learning complex games, social interactions in structured situations, etc.

The question of how Ss would learn the underlying structure of an artificial language most efficiently was the focus of this study. Heretofore implicit learning experiments had been carefully designed and controlled so as to minimize the opportunity for Ss to use explicit acquisition strategies such as hypothesis testing. That is, Ss were given neutral instructions and grammatical subsets of a particular synthetic language were then presented as the learning stimuli. It is important to note that the abstract structure of the type of finite state grammars used is too complex to be fully apprehended by Ss through implicit representation alone.

In the present experiment, explicit information about the grammar was provided during the training period to explore the resulting interaction between explicit and implicit processes in the apprehension of the rule system. Subjects in the three experimental groups were given explicit information regarding the structural relationship between the symbols of the language (syntax) either before, during or after the presentation of a set of grammatical exemplars. Two control groups were used, one which received only the explicit explanation and the other only the opportunity to observe the subsets of grammatical strings. Knowledge of the rule system was tested by requiring Ss to determine the grammaticality of

a set of novel symbol strings, one half of which violated the rules of the grammar.

The results showed that for this type of synthetic language acquisition, the best blend of implicit and explicit processes was achieved by the group given the explicit explanation of the grammar before the presentation of the grammatical exemplars. The introduction of the explanation of the actual grammar after Ss had been exposed to the full set of exemplars had a significant disruptive effect. Finally, the disruptive effect was somewhat less if the explanation was introduced in the middle of the learning phase. Note, however, that all three experimental groups performed significantly better than either control group, indicating that a blend of implicit and explicit processes is a more effective technique than either one alone.

Response latencies showed that Ss using an implicit response mode had shorter response times, implying an overall scanning of the total pattern whereas Ss in an explicit response mode showed longer latencies, implying an attempt to reconstruct explicit grammatical rules before responding. Response latencies, thus, were a reasonably sensitive measure of response mode although they did not correlate with Ss' accuracy: the implicit-only group with the poorest rate of assessing grammaticality also showed the shortest response times.

The findings from the study suggest modifications in the developing theory of implicit learning. Specifically, given the complexity of the structures used, it appears as if efficient abstraction of the underlying rule system can be maximized if the rules which define the system are made salient during stimulus presentation. Possible procedures may include reinstating a criterion during the learning phase, supplying Ss with feedback or arranging the stimulus array according to grammatical type. Even more importantly, the problem in such complex learning clearly appears to be one of engaging both implicit and explicit processes. In general, the mode of stimulus presentation is pertinent to the Ss' engaging the implicit processes, while the instructional set variable, whereby Ss are informed about the nature of the stimulus array, is pertinent to the engaging of explicit processes. Thus, both seem to be key factors in providing the boundaries for active engagement of these learning processes. A formal presentation of implicit learning theory should further clarify the nature and direction of future research in this area.

Acknowledgments

I should like to express my appreciation to the members of my Committee for their support and assistance. Also, for the intellectually stimulating, demanding, humorous, understanding way he guided this thesis, I should like to especially thank Professor Arthur S. Reber.

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INTRODUCTION

Interest in complex human learning has been greatly stimulated in recent years by developments in linguistics and psycholinguistics, stemming from the work of Chomsky and Miller (Chomsky, 1957, 1965; Miller and Chomsky, 1963, Miller, 1967). The development of a transformational, generative model of grammar has served to refocus attention on the implicit aspects of language acquisition. That is, the recognition and production of grammatical sentences is apparently learned without explicit awareness, at least initially, of the system of rules or underlying grammatical structure of a particular language. Other instances of an implicit component in complex rule learning have been noted by several investigators (Gibson and Gibson, 1955; Miller, 1958; Reber, 1967, 1969; Foss, 1968; Smith and Braine, in press).

The question of how humans deal with complex systems such as languages, while new in America with Noam Chomsky, is not a new approach (Blumenthal, 1970). One of the traditions in linguistics during the nineteenth century, particularly among German philosophers such as Humboldt, encompassed a more holistic approach, including such mentalistic concepts as intuition, innate properties and *a priori* mental principles. Wundt's contributions in this area represented the culmination of work in this tradition.

While his goal was "to give explicit characterization of the principles that govern the functioning of cognition in humans", he felt that the study of language would offer the best means to achieve such understanding.

For Wundt, language acquisition was seen as a progressive differentiation of a primitive whole. He used the concept of apperception in a manner somewhat akin to the current use of "perceptual", describing "the selecting and structuring of internally directed experience". For him, as with others, the sentence was considered to be the basic unit of sequentially ordered speech and representative of more general cognitive processes.

However, by the early 1900's behaviorism had become dominant in America and interest in classical cognitive psychology declined. It was not until the early 1950's that attention was again directed toward a more holistic concept of human cognitive processes through the advances in linguistic theory and a more sophisticated cognitive psychology began to emerge. Psychologists concerned with language, particularly George Miller, began experimental investigations of the psychological implications of linquistic theory. For both Miller and Chomsky, as for Wundt, language was governed by abstract cognitive structures. They chose syntactic structure as the variable to explore; Miller felt that studies in this area would be an important contribution to psychology.

More recently, a theory of implicit learning has been proposed by Reber to account for the fact that Ss can learn to respond appropriately to complex, highly structured stimuli in the environment without being explicitly aware of the exact nature of the rules system that they are using. No direct analogue to language acquisition is assumed. Rather, the emphasis is on the learning process whereby an underlying abstract structure is acquired even though the rules of formulation cannot be explicitly verbalized by the user. Questions such as "what is learned" and "how it is learned" are some of the current issues that have been raised.

The present study is concerned with the learning processes involved in rule apprehension of structured pattern sequences in an investigation of artificial language acquisition. An artificial language may offer both a syntactic and symbolic component that can be manipulated. The syntactic aspect offers an abstract structure that provides a well-defined set of rules for symbol manipulation. The symbolic aspect offers a well-defined set of symbols that are assigned to a particular syntax, giving it explicit representation. Thus it provides a flexible yet rigorous experimental tool containing both syntactic and symbolic structure.

Artificial Language Studies

A number of studies have examined the acquisition of artificial languages in attempting to explore the underlying cognitive processes used by humans in complex rule apprehension (Miller, 1958, Shipstone, 1960; Braine, 1963; Reber, 1967, 1969; Foss, 1968). Much of the recent research has been oriented around what Foss (1968a, 1968b) and others (Smith and Gough, 1969, Smith and Braine, 1970) have called "miniature languages". Interestingly, there was some earlier work done by Esper in 1925 which has a particularly modern approach in that Esper was interested in complex rule systems rather than in associative systems.

There appear to be two primary approaches to the study of artificial languages. One is specifically to explore the presumed cognitive processes underlying actual language acquisition. Such investigations would utilize artificial stimulus materials that have analogues in natural languages. For example, Smith and Braine (1970) summarize their work as follows:

> "...we have tried to use the experiments to uncover general human learning tendencies and sought to understand how such tendencies might operate in the more complex (language) learning situation that is the child's. This is the way data on artificial languages should be used to throw light on natural language learning."

There are, of course, problems with this approach, particularly in the construction of workable analogues in that the linguistic models themselves may be inappropriate.

Since only syntactic models have been used, the rule apprehension systems uncovered in the laboratory may be unrelatable to natural language acquisition systems which must include a semantic component.

The second approach to the study of artificial languages is based on the assumption that such investigations of highly structured stimulus sequences will provide new insights into how humans deal with complex, rule defined systems. No direct linguistic parallel is assumed and the use of complex synthetic languages has been motivated chiefly by the considerable experimental flexibility permitted in the study of general cognitive information processing. Implicit learning theory, as proposed by Reber, including the focus of the present study, is included in this latter group.

In the first of such studies of artificial language acquisition, Miller (1958) used a finite state grammar to demonstrate that rule learning of the underlying abstract structure was the basis for acquisition of grammatical items, even when Ss were not informed of the rules of formation. A finite state grammar is composed of a definite number of different internal states, where a transition from one state to another is marked by emission of a symbol. Symbol strings would therefore be produced by permissible shifts from state to state, depending on the state system of the particular grammar (See Figure 1). Thus, in any

given finite state grammar, the actual symbols would comprise the vocabulary, the symbol strings the "sentences", and the underlying permissible transition rules, the syntax.

Miller (1958) found that Ss required to memorize subsets of symbol strings showed greater ability for free recall than Ss instructed to memorize randomly formed strings. It appeared that simple exposure to grammatical items was sufficient for Ss to learn something about the systematic features of the stimuli. He proposed that the experimental Ss organized their recall in terms of various systems of encoding related clusters. However, in his later explorations of the process, Miller (1967) changed his focus and began evaluations of the strategies and hypotheses utilized by Ss.

Shipstone (1960) used a variety of finite state grammars, requiring Ss to sort cards containing sets of stimulus items into whatever they considered "appropriate" categories; the S was permitted to define his model without any restrictions on possible classification schemes. The grammar was considered to be learned if an S's classification scheme matched the underlying strings of the grammar.[1] She thus explored the strategies Ss might be using in abstracting the grammatical rules. Some sorting patterns did emerge, and they were

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[1]For an example of how the underlying strings of a finite state grammar are determined, see Page 27.

not unexpected, including length of sentences, anchor letters, simple alphabetic cues, etc. However, Shipstone found many idiosyncratic systems employed by her Ss and few generalizations could be drawn.

As shown in other research (Reber, in press) such a classification method would tend to elicit specific learning strategies such as in the concept formation experiments of Bruner et al (1956). In such cases, categorization by attributes coincided with conscious learning strategies utilized by Ss rather than any implicit awareness of abstract structure. Shipstone's study, then, although nominally using a synthetic language for acquisition, was, because of the instructional set, really a study in inductive concept attainment rather than a study of implicit learning.

Miller later summarized several grammar learning experiments (Miller, 1967, Chapter 7). In one, Ss were first presented with two lists of symbols, one made up of grammatical items and one of nongrammatical items. After studying both lists, they were then transferred to new lists, but it was found that only very simple grammars could be learned in this fashion and the models Ss built were often overly complex and incorrect. In another set of experiments Ss were given the vocabulary of a synthetic language and instructed to produce symbol strings until they had mastered the grammatical rules. After each item,

they were informed if their responses were right or wrong in accordance with the grammatical structure.

While these studies yielded much data, interpretation was difficult. Miller concluded that in complex rule apprehension, a purely inductive method of learning with insufficient feedback was inefficient. Since complex grammars could not be broken down into simpler parts, Ss related to the systematic aspects when testing rules and required some type of richer feedback to match the system's complexity. Interestingly, Miller ultimately ceased his explorations of the acquisition of artificial languages on the grounds that "...they were far too difficult for an afternoon in the laboratory" (p. 144).

Indeed, such a system cannot be learned in "an afternoon in the laboratory" if the criterion of learning is the S's ability to formalize the rules system of the finite state grammar. In previous implicit learning research (Reber, 1967, 1969), as well as in the present study, the focus has been on Ss' ability to relate to the underlying abstract structure by developing at least a partial representation of the grammar, or rule system. Neither perfect performance nor explicit formulation of the rules was expected; the emphasis was rather on the implicit processes involved.

Jones (1973, 1974) has argued that there are certain conceptual commonalities between the problems posed by the

acquisition of artificial languages and those posed by the problem of serial pattern learning. Included in the latter are pattern perception and probability learning. The theories of rule formation she reviewed were generally based on evidence from less complex sequential event pattern learning, although their relevance for grammatical rule structure was considered. Restle (1967), for example, proposed that lower order rules, such as runs in a cycle, are learned first, then higher order regularities. His theory is basically a hierarchical approach and can be likened to phrase structure grammar. Simon (1972) suggested that Ss induce relations through periodicities in a cycle but has provided highly "specialized" data to support his interpretations. Garner and Gottwald (1967, 1968), on the other hand, emphasize rule-based expectancies such as alternations, depending on the starting point of a cycle. However, they proposed a two-process approach: for a fast rate of presentation Ss respond in a relatively passive way to the total pattern, while at slower rates of presentation they more actively encode features of the pattern.

Jones pointed out that the artificial language experiments using finite state grammars differ from those on serial pattern learning in that they use stimuli which are non-cyclic and non-hierarchical (e.g. Miller, 1958; Shipstone, 1960; Reber, 1969; Kantowitz, 1971). Specifically Reber and Kantowitz proposed that Ss abstract structural relations

from an array of subsets which can then be transferred to new learning. The learning process would proceed from the perception of overall higher order regularities to the discovery of the particular forms of redundancies.

In an effort to further explore the conceptualizations of serial acquisition (e.g. Restle, 1967), and abstract implicit learning (e.g. Reber, 1969), Jones (1971) investigated the manner in which higher order regularities could affect mandatory rule learning in a sequential run-stem acquisition experiment. Lower order rules were held constant, while she varied higher order rules. Jones found that Ss respond to both early in learning and suggested that higher and lower order learning of a pattern proceeded simultaneously and interacted, although the nature of the interaction was not clear. Within the limits of her experiment she found neither Restle's nor Reber's interpretation unequivocally supported. However, she noted that the difficulty level may have been inadequate for a true test of Reber's theory.

Implicit Learning

Reber (1967, 1969, in press) has proposed a theory of implicit learning to account for the process of rule apprehension where the rules are too complex to be overtly mastered by Ss. Data based on several studies of artificial language acquisition show that upon repeated exposure to subsets of symbol strings, Ss will become sensitive to the

inherent abstract structure in the stimulus array and will develop (implicitly) a perceptual model that reflects to some degree the syntactic structure. They are then able to transfer this knowledge to new inputs. Thus, Reber emphasizes the holistic aspects of pattern processing of complex material.

A perceptual learning approach has also been used by Gibson and Gibson (1955). The central mechanism in their theory is a differentiation process which involves the discrimination of distinctive and invariant features in a stimulus array without enriching the array with additional information. The structures learned are assumed to be in the physical array; given subsets of stimuli containing the properties of a total set of structured stimuli, Ss will, by attending to redundancies and invariant combinations, eventually construct an implicit representation of the total model.

In a further development of perceptual learning theory, Gibson (1972) expanded the notion of distinctive features to include their relational structure or varying levels of complexity. She suggested a process of abstraction at a perceptual level to encompass learning rule systems for larger patterns through active effort on the part of the S to reduce uncertainty. Such perceptions, she suggested, could be through superordination or subordination, depending upon the complexity of the structure. It may well be the case that

in a more complex model, perception of a total pattern, or superordination, would be antecedent to explicit awareness of specific subordinate parts. This disposition is supported by the results of the experiments designed to test implicit learning, where Ss were unable to verbalize the rules they were evidencing in their behavioral repertoire.

Other investigators have also emphasized the implicit aspects of artificial language learning. In a study using young children as Ss, Braine (1963) suggested an implicit model to account for such learning. After exposure to sentences from a simple artificial language, Ss then had to complete new sentences. Braine proposed that grammatical structure is acquired by Ss learning the position of a unit in a sequence through a process of contextual generalization. He likened the learning of location to perceptual learning in the sense that Ss become familiar with sounds of units in the temporal position in which they occur.

Smith and Braine (in press) bring together the work with miniature languages treating it as an analogue to natural language acquisition. They suggested that the artificial languages they and others have used could be represented by phrase structure grammar, while finite state grammars could not. They still hold with a position cue view in that what is learned are positional regularities. However, since Braine's Ss were also able to learn inversions, it would appear that their model may be closer to transformational

grammar than originally thought (see Jones, 1973). While the relevancy of miniature languages for natural language acquisition may be tenuous, their exploration of rule apprehension processes in complex learning situations has provided useful data.

In a similar type of study, Foss (1968) found a positive transfer effect to a new subset of items after the original acqusition of a "miniature linguistic system". Based on Esper's earlier work, Foss used form and color as stimuli. Nonsense words, paired with either form or color, were the response items to be learned. In his analysis of the data, Foss concluded that Ss discover systematicity, not necessarily consciously, and extend it to new inputs.

Thus, the results of a number of studies of artificial language acquisition suggest a process of abstraction of structural relations or rule apprehension in complex learning situations.

Implicit Learning Studies

The results of studies designed specifically to investigate implicit learning indicate that what an S learns in an artificial language experiment is an implicit, partial representation of the grammar which underlies the symbol strings or "sentences" to which he has been exposed. In the first of several experiments, Reber (1967) has shown that while Ss were not informed that they were learning rule-

governed stimuli, they did become sensitive to the grammatical constraints of the stimulus array. Knowledge of the rules was evaluated on a discrimination task following the original learning phase; Ss could accurately designate novel symbol strings as grammatical or nongrammatical without being able to verbalize the explicit rules they were using.

A further study by Reber (1969) evaluated Ss' abilities to transfer their knowledge of grammatical structure. The study consisted of an unexpected switch in languages halfway through the experiment. Ss who were switched to a new synthetic language which used new symbols but kept the same underlying syntax transferred better than Ss who were switched to a language with the same symbols but a new syntax. That is, whenever the syntax was kept, positive transfer occurred; whenever the syntax was altered, negative transfer occurred, regardless of any changes in the actual symbols used. It was concluded that the basis for artificial language learning was the development of an overall abstract representation of the grammar, independent of the symbols.

Examination of the results of two further studies lends additional support to the notion of implicit learning of complex, patterned stimuli. In one (Reber, in press), an instructional variable was introduced: one group received neutral instructions as in previous experiments, while the

other group was given explicit instructions to seek out the regularities or rules in the stimulus display. Results showed that the implementation of conscious learning strategies interfered with learning and lowered the ability to discriminate correct from incorrect instances.

The second study (Reber, et al., in prep.) attempted to investigate the implicit conceptualizations Ss might be using in developing a representational model of the grammatical structure. Ss were presented with a set of randomly arranged cards, each card containing one letter of a novel, grammatical string from the synthetic language used in the training period. They were instructed to solve the anagram by arranging the letters into a permissible order according to the rules used to form the learning items. On 75% of the trials Ss were given a first, last, or middle letter cue, while no cue was given on the remaining 25% of the trials. Ss were then further tested by the traditional task of discriminating grammatical from nongrammatical items.

While the data were complex, both the pattern of Ss' solutions and post-experimental reports showed a greater awareness of certain features than had been reported in earlier experiments. The results showed that certain invariant features such as anchor letters, some redundancies, and middle chunking were recognized, and that learning continued to take place over the four anagram trials. Here again, however, Ss' verbalizations still included inaccur-

ately stated rules, including those that they themselves were using in solving the anagrams.

More recently, an observation technique was introduced during the learning phase. In previous studies a recall technique had been used during the training period whereby Ss had to submit one correct reproduction of a set of three symbol strings in order to achieve the criterion of learning. The observation technique consists of a rapid presentation of the subsets of grammatical strings, with no opportunity for response or feedback. This provides a more uniform learning situation for all Ss and minimizes the possibility of any explicit rule learning on the part of Ss. This technique had been used successfully in probability learning studies (Reber and Millward, 1968) where no difference in obtaining asymptotes had been found between Ss trained by traditional probability learning techniques and those simply observing the stimulus array without receiving signal lights or making prediction responses.

The results of an experiment designed to compare the performance of groups trained by the recall and observation techniques generally supported Reber and Millward's findings (Waldmann, 1972). The groups did not differ significantly from each other on the discrimination task to test transfer of learning. However, the overall variance was greater for the recall group, suggesting that the recall group was afforded a great opportunity for idiosyncratic

behavior.

Thus the results of all of the studies of implicit learning have clearly indicated that learning of structure did take place, including those using different training techniques and testing for transfer of learning under varying conditions. However, since the average level of performance for over a dozen groups of Ss has ranged from 65% to 80% accuracy, obviously only a partial representation of the grammatical model was being formed. While these figures are considerably above chance, the level of performance did not seem to accurately reflect the levels attained in non-laboratory situations such as acquisition of language, learning complex games, social interactions in structured settings, etc. Therefore, one must conclude (as did Miller) that a completely inductive approach, at least in a laboratory setting, did not seem to result in sufficient learning.

With a view toward further development of our understanding of implicit learning, the following study was undertaken in order to engage the question of how Ss would learn the underlying structure of an artificial language most efficiently. Heretofore the experiments had been carefully designed and controlled so as to minimize the possibility of any explicit rule learning on the part of Ss. However, since the abstract structure of a finite state grammar is clearly too complex a rule system to be

adequately apprehended by Ss through implicit representation alone, explicit information was provided during the training period in order to facilitate further learning. It seemed likely that the resulting interaction between explicit and implicit processes would tend to maximize learning, depending on when it would occur.

Explicit information regarding the structural relationships, or syntax, was introduced before, during and after the presentation of the learning strings. Since it was expected that total exposure time would still be too brief for rote memory to play any significant role, Ss would still have to develop some kind of model based on the abstract structure.

For example, if given the structure first, as in a more deductive approach, the S can then enhance his learning in a more explicit fashion by the presentation of specific examples of grammatical strings. If knowledge of the rules is introduced after the S has inductively constructed his own implicit model in a neutral setting, it may serve an enhancing or clarifying function, or the change in instructional set may prove to be disruptive. Interestingly, there are no a priori reasons for predicting the directionality of this effect. Finally, efficient learning may best be served by a combination of the two methods, with the explicit structure provided in the middle of the presentation of exemplars. In any event, the various approaches

were expected to have differential effects on performance.

Further, while earlier studies have emphasized the implicit aspects of the learning paradigm, an explanation of the rules would permit a more explicit mode to be introduced. Ss exposed to subsets of grammatical items had seemed to initially perceive the larger pattern, with a later separation out of invariant features, possible combinations, etc. However, it appeared likely that in utilizing their knowledge to discriminate new inputs, a more explicit structuring of the rules would be required. An exploration of the relationships between these processes would have import for the continuing development of a theory of implicit learning.

The hypotheses regarding the outcome of the study were as follows:

1) Depending on where in the learning phase the explanation of the rules system is introduced, differences will emerge among the three experimental groups in latency, accuracy and error patterns. However, the direction of these differences cannot be predicted a priori.

2) The expected differences among experimental groups will depend on the response mode used. Ss using an implicit mode developed before the explanation of the grammar would be expected to have shorter latency times, reflecting an overall scanning in a more gross perceptual manner. Ss using an explicit mode would be expected to have longer latencies as they attempt to reproduce the actual grammar.

3) Two control groups will be used in which the mode of response is fixed. Intergroup comparisons should enhance the reliability of the above expectations. That is, the longest latencies are expected from the explicit only group, while the implicit only group should demonstrate the least overall accuracy and shorter latencies.

4) When an implicit response mode is used, length of symbol strings should have little effect on the results.

5) Idiosyncratic error patterns are expected under the explicit response mode, but not the implicit.

METHOD AND PROCEDURE

Overall Design

There were five groups, three classified as experimental and two as control. Each experimental group is defined by the pattern of implicit and explicit training procedures used; the control groups were run with one or the other procedure exclusively. Note that the differences here are entirely with the training procedures, all groups were run identically during the testing phase.

Learning Phase. The learning phase was designed to provide each group with a different mode of acquisition of the grammar.

Stimulus Materials

The materials for this phase were constructed using a finite state grammar (Chomsky and Miller, 1958) with the letters P, S, T, V and X as the vocabulary and a set of rules of sentence construction as the grammar. The language is given in schematic form in Figure 1.

A finite state grammar such as this may be characterized as a Markovian process in which a transition from any State S_i to any State S_j produces a symbol. A string of symbols, or "sentence" is produced by entering the array at S_0, proceeding according to the permissible transitions as defined by the arrows, and exiting at State

S_0'.

Twenty-one strings were chosen from the grammar as representative of the five possible sentence types, each composed of from three to eight symbols (see Appendix I). The complete grammar may also be notated by the following sentence types, with each loop ("S", "T", "VPX") appearing parenthetically:

Type I:	T(S)XS
Type II:	T(S)XX(T)(VPX)VV
Type III:	T(S)XX(T)(VPX)VPS
Type IV:	P(T)(VPX)VV
Type V:	P(T)(VPX)VPS

Training Procedure

The five groups were run as follows:

Control Group E (Explicit). These Ss were presented with the schematic diagram of the grammar, as shown in Figure 1, and given an explanation of the finite state model. In addition, five examples of symbol strings were followed through step by step in order to insure that the rules for forming "sentences" were understood. The S was then asked to generate his own "sentences", one each of four, six and eight symbols. This procedure took approximately ten minutes and the diagram remained in front of the S during the entire period.

Control Group I (Implicit). The Ss in Group I were initially given neutral instructions; that is, they were told at the outset only that they were participating in a simple memory experiment. They were requested to pay careful attention to the stimuli since they would be asked questions on them later. The Ss were then shown the 21 strings from the grammar placed in a fixed order of presentation. The full list was shown three times, resulting in 63 observations of grammatical exemplars with a total observation time of just over seven minutes. There was no criterion of learning established and no responses were made.

Experimental Group I-E (Implicit-Explicit). These Ss were initially given the same neutral instructions as Group I and shown the 63 grammatical exemplars. At the end of this period they were presented with the explicit information about the grammar as outlined for Group E.

Experimental Group E-I (Explicit-Implicit). The Ss in this group were initially presented with the explanation of the grammar as in Group E and then observed the list of grammatical symbol strings, as in Group I.

Experimental Group I-E-I (Implicit-Explicit-Implicit). These Ss were initially given Group I instructions and shown the list of 21 grammatical exemplars twice, then they were given Group E training, and then viewed the list of exemplars a third time.

Testing Phase. Upon completion of the learning phase, each S was evaluated on his apprehension of the grammatical rules by being required to discriminate grammatical from nongrammatical items. It was at this point that Group I was informed of the structured nature of the stimuli, but no explanation of the actual grammatical rules was given.

Stimulus Materials. The test stimuli consisted of 50 items, 25 grammatical and 25 nongrammatical. The 25 grammatical items were strings of letters drawn from the same grammar used during the training period. The 25 nongrammatical items all contained some violation of the grammar. Some items were formed randomly and contained multiple violations; all others had only one, classified as a first letter, last letter, second-to-last letter, or internal letter violation (see Appendix II). Each symbol string contained from three to eight letters.

Testing Procedure

All groups were run under the same procedure. The test items were shown one item at a time and the S was required to make a decision as to whether or not the item conformed to the rules of the grammar. Subjects pressed a button marked "yes" for grammatical items or "no" for nongrammatical items. No feedback was given about the correctness of their choice and the next item was then presented.

The full list of 50 test items was shown twice (designated below as Trial 1 and Trial 2), with a three minute break in between the two trials. All Ss were informed of the equal proportions of grammatical and nongrammatical items.

Besides accuracy, measures of response latency and confidence level were obtained in order to ascertain the relevance of different effects and response modes used by the Ss. No time constraints were placed on the Ss and they were not informed that response latencies were being recorded. Response latencies were considered to offer a sensitive measure of discriminating between Ss who were going through the explicitly encoded rules from those who responded by scanning the total pattern.

After their "yes" or "no" response was made, Ss were requested to give their level of confidence in their answer on a five point scale, with a five indicating maximum confidence in the correctness of their choice.

After completion of the discrimination task, there was a post-experimental de-briefing and interview in which Ss were questioned about knowledge of the grammatical rules, awareness of their own rule-governed behavior, response mode used, etc.

Apparatus. The stimulus items were arranged in a programmed sequence and projected onto a screen by means of an automated, Kodak Carousel Model No. 800. The cycle was

set at eight seconds, resulting in approximately seven seconds of exposure time and a one second inter-item interval.

During the test phase, the stimuli were presented manually one at a time and remained on the screen until a response was made. Response latencies were recorded automatically as soon as the response button was pressed by the S.

Subjects. Subjects were seventy-five (75) undergraduates selected from psychology courses and randomly assigned to one of the experimental or control groups, yielding fifteen (15) subjects in each group.

RESULTS

In this section the overall effects will be analyzed first, with a "fine-grained" analysis to follow:

Accuracy

Table 1 lists the group means for the probability of a correct response ($P_{(C)}$) for all 100 discrimination test items and the breakdown of the two trials of 50 items. An analysis of variance (Table 2) showed one significant effect: groups, $F(4,70) = 5.23$, $p < .01$. Trials, $F(1,70) = 2.67$, and groups x trials interaction, $F(4,70) = 1.4$ did not reach significance.

An analysis of the group means revealed that the differences among the three experimental groups were not highly significant. Group E-1(.76) was better than either Groups I-E (.70) or I-E-I (.71) but only the difference between Groups E-I and I-E was significant, $t(28) = 3.7$, $p < .001$. Thus, the explicit information given before examples of the grammatical subsets were shown resulted in greater learning than when it was given during or after. The effect on these latter groups appeared to result in a disruption in learning that was somewhat stronger when Ss had already built up their own implicit model and were then given the actual grammatical model without being exposed to additional exemplars (Groups I-E and I-E-I).

This point will be developed in more detail in the discussion section.

Latency

The group means are shown in Table 3. An analysis of variance (Table 4) showed two significant effects: groups, $F(4,70) = 5.95$, $p < .01$, and trials, $F(1,70) = 26.92$, $p < .001$. There was no significant group x trial interaction, $F(4,70) = 1.3$.

Here, as predicted, the two control groups differed from each other significantly, $t(28) = 4.32$, $p < .001$. The implicit group achieved the shortest latencies, suggesting that the Ss' response mode was one of scanning across the total pattern; the latencies of the explicit group were the longest of all since they could only test the encoded rules of the grammar in an explicit fashion. Thus, the response mode used by the experimental groups could be inferred from their latency scores.

There were no significant differences in response latency among the experimental groups. However, as with the accuracy measure, the trend was the same; Group E-I achieved the shortest latencies, with Groups I-E-I and I-E following. The inference from these data is that Group E-I, which also differed significantly from Group E, $t(28) = 3.72$, $p < .001$, was operating in a more implicit response mode, Group I-E in an explicit response mode and Group I-E-I presented a mixed

picture.

The only other significant effect was trials and this result was not entirely unexpected. Although a large majority of Ss reported that they were not aware that the same list was shown twice, a practice effect is not unlikely. However, while the response latencies for all of the groups decreased from Trial 1 to Trial 2, there were no differences large enough between the means of any one group to reach significance.

In addition, the distributions of latencies for a variety of conditions were compared with each other in order to determine whether Ss displayed differential response times for different conditions. The following comparisons yielded significant differences in the latency distributions (all tests were Kolmogorov-Smirnov tests).

All of the groups except Group I-E-I had significantly shorter latencies on the items they responded to correctly; that is, G|G and NG|NG produced faster response times than G|NG and NG|G (all p's $< .05$). These tests were carried out in order to further refine any overall findings on the correlational analysis between latency and accuracy. These results would tend to support one of the assumptions of the simple detection model discussed below wherein it is assumed that Ss either "know" the grammaticalness of a given item or they guess. It is a reasonable extension to assume that such guesses would produce longer latencies. While

this main effect was not found to be statistically significant for Group I-E-I, the results were strongly suggestive of the same trend.

The only other significant finding was that Groups I-E and E both showed shorter response times when erroneously responding "grammatical", i.e., G|NG, than when erroneously responding "nongrammatical", i.e., NG|G. Group I-E-I was also unusual in that all "grammatical" responses were significantly faster than "nongrammatical", regardless of correctness ($p < .05$).

Confidence Level

There were no differences among any of the groups on the level of confidence measure. While individual styles seemed to vary within each group, the average result for all groups was approximately 3.5 on a 5 point scale.

Correlations

A correlation matrix was done for each group using all response measures: accuracy, latency and level of confidence (Table 5). Only two significant correlations were found. The first was a negative correlation ($r = -.48$, $p < .05$) between accuracy and confidence level in Group I-E, where the Ss with the highest levels of $P_{(c)}$ reported the lowest confidence levels. The shift in response mode from implicit to explicit may account for this result.

Other correlations between accuracy and confidence level, while only approaching significance, did indicate a more expected tend. Experimental groups E-I and I-E-I showed a positive correlation between accuracy and confidence level, which was in keeping with the results usually found in studies of this type. As will be enlarged upon in the Intragroup Analysis below, the results of a simple signal detection chi-square analysis show no indication that Ss in the experimental groups were using other than a partial representational model of the grammar to some degree.

The second significant correlation was a negative correlation ($r = -.46$, $p < .05$) between latency and accuracy in Group I, suggesting that the implicit mode, where effective, produces a tendency for rapid apprehension of total patterns. However, in general, few significant correlations emerged.

Grammatical (G) and Nongrammatical (NG) Responses

Table 6 gives a breakdown of the test-trial data according to responses to the G and NG items. These data give a more fine-grained analysis of the accuracy results described above. The most salient features here are the similarity between the total number of G and NG responses for the three experimental groups and control Group I, showing lack of response biases, and the highly significant NG response bias in control Group E ($p < .001$).

Error Analysis

The above analyses, of course, only treat part of the data. Also of interest are the error patterns exhibited by the Ss. The following analyses break down Ss' incorrect assignments to grammatical and nongrammatical items.

Grammatical Items

The proportion correct responses to each of the five sentence types (see Page 30) generated by the grammar were examined. Note that at least superficially it would seem that Type I items ought to be detectable as grammatical more easily than the other four since they contain a maximum of one loop, whereas the others contain up th three. Interestingly, this effect was not evident. Among the experimental groups and control Group I there were no significant differences in detection of grammaticality by item type. The only effect found here was in control Group E where Type III items were significantly less frequently detected than other types, $t\ (14) = 2.74$, $p < .01$.

In general, it seems clear that Ss' coding systems are not based upon these specific "sentence" types. This result is in keeping with earlier findings (Reber, 1967) and argues against Miller's (1958) notion that the acquisition of synthetic grammars is based upon a chunking according to sentence types.

Nongrammatical Items

As mentioned above, the nongrammatical items were constructed by introducing specific violations of the syntax. The primary interest here was in the position where the violations occurred; that is, first letter, last letter, next to last letter and internal letter violations. There were also a few items which were formed randomly and therefore contained multiple violations.

Not surprisingly, these latter items were easier to detect as nongrammatical than the single-violation items. Moreover, of the others, there tended to be fewer errors on last letter violations. The greatest difficulty was experienced in the detection of the items with a violation in an internal position, including the next to last letter position. That is, a kind of serial position effect pertains here. These results are similar to those found in earlier studies with the exception of the next-to-last letter violation which had been more detectable than internal violations.

Table 7 shows these effects in full detail by comparing the detectability of each of these five types of nongrammaticality with each other. It may be noted that Group I shows the least effect of item types which is not surprising given their overall poorer performance.

These results, although complex, agree with the findings of Reber et al (in preparation). In that study, where

Ss were required to solve anagrams based upon the grammar, the more invariant features such as the anchor letters were positioned correctly more frequently than the internal letters.

Item Length

Again, superficially, one might expect that the length of an item ought to be a significant variable. However, the data do not reveal any such effect. Item length was not a significant factor in accurate responding on the discrimination task. As is argued below, the lack of an effect here can be interpreted as evidence of a holistic process of pattern apprehension.

There was one significant effect here: two groups (E-I and E) showed significantly higher error rates on four letter items than on other item lengths $t(14) = 2.23$, $p < .05$ and $(14) = 2.74$, $p < .01$. This result is presumed to be an anomaly and there is no obvious interpretation.

Intragroup Analysis of Response Probabilities

An item by item analysis of the two presentations of each item was carried out in order to investigate the appropriateness of the coding system used by the Ss in the various groups. Consider the following assumptions: (1) an S knows the grammaticalness of the i^{th} item with probability $k_{(i)}$ and does not know it with probability $1-k_{(i)}$; (2) when

he does not know, he guesses correctly with probability g and incorrectly with probability 1-g. Since each item was presented twice and there was no feedback, there are four possible outcomes for each item: (a) correct on both presentations, (b) correct on the first, an error on the second (c) an error on the first, correct on the second, and (d) error on both. The following equations describe these four possibilities:

$$P(CC) = k + (1-k)g^2$$

$$P(CE) = P(EC) = (1-k)g(1-g)$$

$$P(EE) = (1-k)(1-g)^2$$

where k is the average of all k_i's and g = .5. These equations describe what is probably the simplest detection model possible. On each trial the S either knows the grammaticalness of the item or he does not, and when he does not, he guesses. The actual value of any one of the equations can be read from the data and used to estimate k. The values listed in Table 8 were obtained by using the empirical values of P(CC) to predict the values of P(CE), P(EC), and P(EE).

For the experimental groups the fit is fairly good; in each case χ^2 fell short of significance. With N = 1500 the power of the test is quite high and the lack of clear statistical significance lends support to the model. However, for both of the control groups the effect was significant beyond the $p < .001$ level, suggesting the use of non-representational strategies by the Ss in these groups.

In order to clarify these results, two other implications of the model must be considered: (a) an S never incorrectly thinks he knows the grammaticalness of an item and (b) an S knows the grammaticalness of the i^{th} item with a probability constant across all i, regardless of the characteristics of the item and regardless of whether or not he has seen the item before. The first of these implications is related to the prediction that the proportions of items with two errors should be equal to the proportions of items with only one error. It is of interest because it logically precludes the use of any strategy which was not isomorphic with the grammar, since any such strategy would force items into the (EE) category and inflate it beyond (CE) and (EC). The model, then derives further support as a characterization of the three experimental groups from the fact the P(EE) is not significantly greater than either P(CE) or P(EC) in these cases.

Thus, although significant positive correlations between the accuracy and confidence level measures were not obtained, it seems safe to assume that the Ss in the experimental groups were using strategies representative of the actual grammar. However, the inappropriateness of the model for the implicit control group was not in keeping with the results of previous studies. The strong implication is that the use of the observation technique for initial learning

will have to be reconsidered.[2]

Summary of Major Results

1. Group E-I Ss showed the best apprehension of the grammar. They were significantly better at evaluating grammaticalness than those of Group I-E, as well as both control groups. There was, however, no reliable difference between Groups I-E-I and I-E.

2. Group E-I also displayed the shortest response latencies among the three experimental groups although the differences between them did not reach statistical significance. Group E-I did differ significantly from Group E, the explicit control group. Group I, the implicit control, also differed significantly from Group E, suggesting a basic similarity between Groups E-I and I in the pattern of latencies they exhibited. This result further suggests, although weakly, that the two groups were using a similar response mode which is characterized as a scanning of the total pattern. This interpretation does receive support from Ss' introspective self-reports after the conclusion of the experiment.

3. The parallel implication (also weak) is that the other three groups, I-E, I-E-I, and E, were using a more

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[2]Beins (also in prep.) found this uncharacterically high P(EE) with Ss who learned initially using the observation technique.

explicit response mode, which would leave them to deal with the stimuli by making efforts to analyze their grammaticality by "filtering" them through more explicit rule systems. Once again, post-experimental interviews tend to support this generalization although it should be recognized that it is an inference that is suggested with caution and the data do not unambiguously support such an interpretation.

4. The performance of the control groups was as predicted. Group E had the longest latencies with relatively poor accuracy, while Group I had the shortest latencies along with relatively poor accuracy. The $P_{(c)}$ result for Group I was lower than expected, however, and raises the question of the effectiveness of the observation method as a training technique with such complex learning. This point is pursued in more detail in a later section.

5. In the analyses of Ss' error patterns, the findings were that (a) with the exception of Group E, $P_{(c)}$ was not different across the five types of items; (b) with the exception of the four-letter strings for two groups, item length was not a significant factor, and (c) $P_{(c)}$ was highest on randomly formed items and items with last letter violations, while internal violations showed the lowest $P_{(c)}$.

6. There were no differences among groups in confidence level and no highly significant correlations among accuracy, response latency and confidence level

measures. However, Groups E-I and I-E-I show a trend toward a positive accuracy-confidence level correlation and this was further substantiated by the fact that the simple detection model gave a good fit to all of the experimental groups. Further, with regard to the latency measure, all groups showed significantly shorter response times (except for Group I-E-I which barely failed to reach significance) on correct assignments of grammaticality, indicating that latency measures are related to accuracy.

7. As stated above, both of the control groups showed evidence of more idiosyncratic error patterns, indicating the greater use of individual strategies. The clear implication is that the training procedures for these groups were not sufficient for a rich enough apprehension of grammatical structure. Note that this finding for Group I was not anticipated.

DISCUSSION

There were several important features of these results, although the differences among the experimental groups did not always reach statistical significance. It was quite clear that the most efficient learning of the complex structure was through a more deductive method, i.e., Group E-I. In interpreting this result certain points are important. Initially, it should be recognized that the explicit explanation of grammatical structure provided to the Ss in each of the experimental groups was too cursory and too brief to allow for complete memorization of the structure. This is obvious insofar as none of the Ss achieved a perfect performance on the discrimination task, which would have occurred had the Ss accomplished a complete representation of the underlying structure. Further, it is important to note that none of the Ss had had previous experience with these rather "alien" synthetic languages with which they were required to operate. As a result, it seems reasonable to infer that the viewing of grammatical exemplars for this deductive group (E-I) actually served a dual function.

In the first place, the presentation of the exemplars provided a clarifiable manifestation of the syntactic structure to which they had been exposed. Second, the opportunity to scan grammatical exemplars can be inter-

preted as a period of rehearsal whereby the Ss could implement the model that had already been presented.

Thus the E-I order apparently served to focus the implicit processes in the direction of the underlying abstractions so that the apprehension was more representative of the actual grammar than in other groups. Further, this procedure seemed to result in a scanning of the total pattern when confronted with the test items, as evidenced by shorter latency responses. Thus, along with some prior knowledge of the underlying structure, the role of exemplars in complex learning appears to be a critical one.

On the other hand, the explanation of the grammar after the exemplars had been observed (specifically here Group I-E) appeared in general to have a disruptive effect on learning. These Ss were initially given neutral instructions and asked to try to remember as much as they could about the stimuli as they were presented. The strong suggestion is that the use of neutral instructions at the outset of learning invites individual subjects to evolve idiosyncratic abstractions of the underlying structure. Such abstractions are not necessarily, but indeed, would almost universally be "inappropriate" representational systems insofar as a grammar of the kind displayed in Figure 1 is concerned. The import, then, of the introduction of the explicit phase in the training program would be to act in a disruptive and interfering fashion.

It appears that rather than using the explicit information they had received to bolster their existing models, most Ss discarded their own model and related only to the model they were shown. This threw their response set into the explicit mode as they attempted to recreate the exact model on the transfer task. Thus, Ss in Group I-E, where the disruptive effect would be maximized, displayed the longest response latencies of the experimental groups.

This disruptive effect was further validated in that this Group I-E, along with the explicit control Group E, showed the greatest trial effects on the discrimination task. Since the control group had been given only the explicit explanation, an increment in correct responses on Trial 2 would have to reflect some learning. The suggestion is that these Ss were trying to use the test items on Trial 1 as exemplars. Again, the Ss' self-reports were indicative of this interpretation.

It is interesting to note, however, that with several Ss in Group I-E, the explicit training did serve an enhancing function. With these Ss it appeared that their own model was either more firmly established or was more representative of the actual grammar. Thus, having developed a more implicit model, the introduction of the actual rules resulted in a blending of the underlying rule system and the underlying abstractions of the individual S.

Why this effect did not occur with more Ss in this group may have been a function of response set as engendered by the instructions or the inefficiency of the observation technique which did not allow for sufficient model building in all Ss.

In a more recent study of implicit learning (Reber and Kassin, in prep.), this role of response set was explored. The observation technique was also modified so that rather than simply observing the stimuli in serial presentation, the stimulus array was laid out in front of the Ss. The experiment manipulated two variables: (1) structural salience of the stimulus array, i.e., the array of 21 letter strings was arranged either randomly or according to grammatical type such that all exemplars of Type I were in Column 1, all of those of Type II in Column 2, etc.; (2) instructional set, i.e., Ss were either instructed to look for structure or given neutral instructions. Of the resulting four groups, the one which showed markedly superior performance over the other three was the group which had both explicit instructions to search for structure and the stimulus array which made the structural features of the grammar highly salient.

The implication of these results is that explicit instructions to search for structure may be an even more complex variable than previously supposed. The critical issue seems to be an interaction between instructions to

search for structure and the amenability of the stimulus array to be cogently analyzed for such structure. The difficulty with the experiment upon which this dissertation is based, as well as other work (Reber, in prep.), is that stimulus materials have been presented in a random serial order such that the salient features of the grammar are distinctly less than obvious. Under such conditions instructions to search for rules is clearly detrimental; however, such is not the case in the study by Reber and Kassin.

The Ss in Group I-E-I, where the explicit information was introduced in the middle of the learning phase, also responded with slightly greater accuracy and shorter latencies than Group I-E. In this case, the Ss had observed the list of 21 grammatical exemplars twice and then after the explanation of the rules, saw the entire list another time. This procedure presumably allowed for more active participation in the process of seeking structure when restudying the symbol strings. The problem, however, is that the level of performance of Group I-E-I was not greater than that of the other experimental groups as was initially expected, and indeed, showed a tendency to be somewhat below that of Group E-I. Once more, the interpretation that suggests itself is that as with Group I-E, the introduction of the explicit information served in a generally disruptive fashion in that it interfered with the abstractions that the S had begun to develop during the

first two presentations of the list of 21 grammatical exemplars.

In other respects, Group I-E-I behaved in similar fashion to Group E, the explicit control group. There was some tendency for learning from Trial 1 to Trial 2 although less than observed in Group I-E. However, Group I-E-I, like Group E, showed a tendency toward nongrammatical responses on the transfer task, although to a lesser extent. The reason for this bias is not clear except as insofar as it may be simply another characteristic of the explicit response mode.

Group E had the longest response latencies, the second lowest average $P_{(c)}$ and a strong nongrammatical response bias. These data suggest the obvious: the explicit group, whose only training consisted of the presentation and description of the schematic diagram in Figure 1, had no other recourse during the test phase than to try to "fit" each test item into their memory of the diagram. Since the training phase was too short to allow for the schematic to become "fixed" and since there was no observation period during which implicit abstractions could be formed, the result was that each S was left with a degenerate schema which necessarily would inflate the tendency to make nongrammatical responses. It should be noted that there is nothing particularly profound about this interpretation; indeed, the group was run merely as a control to

allow the assessment of the impact of the strict explicit training mode.

The most significant aspects of the results from Group I were the relatively low $P_{(c)}$ level and the short response latencies. In the post-experimental interview, these Ss were also the least able to formulate the rules they had used in making a decision on grammaticality on the transfer task. As with all of the groups, some learning of structure did occur, although less than in previous studies where memorization and reproduction of exemplars was the training technique.

What has become apparent in the more recent implicit learning studies is that the observation technique in its present form is not the most effective mode of presentation for either building or implementing an implicit model. It does not allow for Ss to obtain a robust enough knowledge of structure for maximum transfer or formulation of the rules. While this technique was effective in the probability learning experiments (Reber and Millward, 1968), and may be effective when other simpler structures are being studied, it does not seem to provide for as much learning of complex rule systems as the memory procedure.

Several variables may be operative here. For one, the total training time may be too short to allow for any consolidation of learning acquired. Another feature is the completely passive quality of the observation procedure

where the Ss just observe the stimuli without any feedback. Yet another factor is the random, unstructured order of presentation of the stimulus items which, while deliberate in its inception, is not conducive to implicit model building.

The problems here are complex and the suggestion is that they are quite deep. As was pointed out above, the mode of presentation interacts both with instructional set and saliency of the stimulus array. It is also possible that the relative ineffectiveness of the observation mode in this study is due to the relatively short observation period. If a pure observation procedure is to turn out to be useful in producing implicit acquisition of structure, it may require a more extended exposure to grammatical exemplars than that used in this study. There is some evidence for this interpretation. In Waldmann (1972) the observation Ss were yoked to Ss run under the memorization and recall procedure and many of them observed as many as 100 - 140 exemplars. Further experiments may separate out these factors in order to answer the question of how structure is best learned, rather than whether it can be learned at all.

However, whatever structure was learned by Group I was through implicit processes only and the response mode was gross scanning of the entire pattern. Thus, not only did this group achieve the shortest latencies, but there

was a significant correlation between latency and accuracy. The Ss with the highest $P_{(c)}$ had the shortest latencies; again, this was in agreement with the findings of previous experiments where Ss, having developed an underlying model, tended to respond more quickly.

Review of Stated Hypotheses

Thus, in evaluating the overall results of this investigation of implicit learning through the study of artificial language acquisition, only some of the original hypotheses were confirmed, while others either did not attain statistical significance or did not result in the expected findings:

1) It was predicted that significant differences would emerge among the three experimental groups in latency, accuracy and error patterns, depending on where in the learning process the explanation of the rule system would be introduced. This hypothesis was only partially confirmed in that the differences among the experimental groups did not emerge as clearly as expected. However, there were some implications for the importance of where in the learning phase the explanation of the rule system should be introduced. It became clear that the training conditions did determine the response set of the Ss and the degree of focus of implicit processes toward more coherent structure.

The problem basically was that within the context of the acquisition of a rich and complex structure, the anticipated "blending" of explicit and implicit training procedures did not occur. The implication of this is that Ss' implicit models were not necessarily representative of the underlying grammar. The one condition (Group E-I) where this was controlled, was the condition which showed the greatest degree of learning. Presumably, this procedure gives rise to the "blending" that was initially hypothesized, and it is argued that it occurred because the Ss were given an explanation of structure initially and then used the exemplars to enhance their own implicit model building. Reversing the procedure or interrupting the implicit processes was not adequate under the present training conditions.

Therefore, the models used, as reported by the Ss in the post-experimental interviews, seemed to have been more reflective of individual representations than of a mapping into the actual grammar. As in earlier studies of encoding strategies (Miller, 1958; Shipstone, 1960), no clear patterns among Ss were found. However, most strategies were based on a combining or chunking of symbols within a string. This was in keeping with the findings of the anagram study (Reber, et al., in prep.) where Ss had to generate their own strings from randomly arranged symbols. An analysis of errors revealed more intra-chunk errors than breaking up of invariant combinations. That is,

there was a significant tendency to keep the VPX loop together; errors like VXP or PVX were more common than errors resulting from a breaking up of the chunk.

2) This hypothesis dealt with response latencies expected from the three experimental groups, depending on the response mode used. It was predicted that Ss using an implicit mode would have shorter latency times, while Ss using an explicit response mode would have longer latencies. The response latency data confirmed this hypothesis, implying that Ss did respond more quickly when operating in what has been termed an implicit mode by scanning the total pattern. Thus it appears that it was only in Group E-I that sufficient explicit-implicit interaction occurred for Ss to slip into responding in a more implicit manner, leaving the other two experimental groups in varying degrees of explicit responding, and, therefore, longer latencies.

3) With regard to the control groups, this hypothesis stated that the longest latencies would be expected from the explicit only group, while it was predicted that the implicit only group would demonstrate the least overall accuracy and shorter latencies. The control groups, in which the mode of response is fixed, were expected to enhance the reliability of the experimental group findings.

Since the control groups performed as expected with regard to the latency and accuracy measures, this hypothesis

was upheld. Lacking highly significant differences among the experimental groups, these findings from the control groups were particularly relevant in interpreting the results of the study.

When the latency distributions were compared for differential responding, it was found that all of the groups did tend to respond more quickly on the correct responses as compared to when incorrect responses were made. Other findings appear to indicate that the groups using a more explicit response mode (Groups I-E, I-E-I, and E) responded "grammatical" more quickly, even when in error. While the exact import is not very clear, it would suggest that a higher criterion for calling an item nongrammatical was used by these groups when their own implicit models were not sufficiently robust.

4) The hypothesis that when an implicit response mode is used, the length of the symbol strings should not be a relevant variable was confirmed by the error analysis of Group E-I and I's data. However, it was also generally true for the other groups, although the explicit control group did experience some greater difficulty with the longer items.

A limited length-range was used in the present study, with items consisting of from three to eight symbols. Within this range it appears that even with only a partial, implicit model, the length did not impose too great a

burden, as it did when Ss were operating exclusively in an explicit mode.

5) A more idiosyncratic error pattern was expected from Ss using an explicit response mode. Overall this did not prove to be the case. Rather, the relevant variable here seemed to be the degree of representative structure acquired and idiosyncratic patterns as evidenced by large P(EE) values were found only in the control groups, regardless of response mode used.

Implications for Implicit Learning Theory

In considering the relevance of the findings of this investigation for the development of a theory of implicit learning, it would be useful to begin with a review of the questions raised and dealt with in previous studies. Early studies were focussed on what a subject learns in an artificial language acquisition experiment. Both Miller (1958) and Reber (1967, 1969) found that Ss did relate to the constraints of the grammar and did respond to the underlying abstract structure rather than the actual symbols used in a particular synthetic language. Since the rule system was too complex to be discovered by utilizing individual strategies or testing simple hypotheses, Ss were unable to formulate the rules they were using.

This type of learning has been likened to a more perceptual learning where Ss become aware of the regulari-

ties in a stimulus array and respond accordingly. An instance of this would be natural language learning where a speaker's utterances generally conform to the structure and grammaticality can be recognized and judged, even though the underlying rules cannot be explicitly stated. As formulated by Gibson and Gibson (1955), increasing differentiation occurs through exposure to subsets of stimuli which lead to learning of structure through a process of abstraction or perception of the larger pattern.

This process, whereby Ss come to respond efficiently to the structure inherent in a stimulus display by developing implicitly a perceptual model that to some degree resembles such structure, was termed implicit learning. In order to further test the notion that Ss were not imposing their own idiosyncratic coding schemes onto the structure, a study was carried out using instructions as the experimental variable (Reber, in press). It was found that the Ss given neutral instructions performed better on the transfer task than Ss instructed to try to find the rule system used. Since these results were contrary to the findings of most concept formation studies, it was considered further validation for a theory of implicit learning.

Also, since post-experimental interviews confirmed the fact that Ss were generally not able to verbalize the rules they were using, the next question raised was just how these representative models were being formed. In an

attempt to determine what implicit conceptualizations they might be utilizing, a study was run in which Ss were required to generate their own grammatical "sentences" from a randomly arranged set of symbols (Reber et al., in prep.). While this proved to be a fruitful approach in increasing Ss' ability to verbalize the rules they were using, the data were too complex to provide insights into the acquisition process.

Another attempt was made along these lines by providing Ss with a questionnaire covering specific aspects of the rules such as anchor letters, redundancies, chunking, etc. (Beins, personal communication). The results indicated that Ss do tend to behave in a regular fashion and actually use the rules they could specify, although they could not necessarily specify all the rules they were using.

However, while the data being accumulated to further define the theory of implicit learning did provide some answers to the questions posed, several other issues emerged as relevant and requiring further investigation. The major result requiring attention was that although some structure was being learned, Ss' level of performance on the test items did not approach the learning manifested in non-laboratory situations. Since learning in these situations does not occur in a vacuum, as is often the case in the laboratory, the role of explicit learning now seemed

appropriate for consideration.

As George Miller (1967) suggested, structures like that in Figure 1 are too complex for an "afternoon in the laboratory." Certainly, when only implicit acquisition procedures are used, there is no doubt that his assessment is correct. Thus, for the present study, the shift in emphasis was motivated by the question of how implicit processes can be bolstered so that complex structures can be acquired more efficiently.

One of the tenets of implicit learning theory was that efficient responding was achieved through a rudimentary inductive process of implicit model building. The possible effect of explicit information had been minimized. Yet it seemed likely that a blend or interaction of both implicit and explicit processes would more nearly approximate complex rule apprehension in many instances of implicit learning outside the laboratory.

This overall hypothesis has been confirmed by the results of this study although the main thrust was to investigate the optimal period during training to introduce information about the rule system in order to engage both implicit and explicit processes. Further work in this area might concentrate on just how to maximize the interaction for the most efficient model building. This may be subsumed under mode of presentation of the stimuli.

Besides the role of explicit information, the question of active and possive learning has been shown to have important implications for implicit learning theory. Garner and Gottwald (1968), in their studies of pattern perception, postulated a two-process approach based on rates of presentation. Faster presentation rates led to Ss' passive relating to the total pattern while they more actively encoded features of the pattern at a slower rate of presentation. It now appears that if the structure to be acquired is very complex, active as well as possive learning is necessary. Note, however, that the generality of the Garner and Gottwald position must be tempered by the recognition that the underlying structure they were using was considerably simpler than those used here.

However, while rate of presentation is a factor to be considered, the problem in complex learning appears to be more one of engaging both implicit and explicit processes. The observation technique provides for a relatively fast presentation of the stimulus items which, coupled with neutral instructions, results in a mode of presentation that would engender a passive response set. The S is requested to pay attention to the stimuli but is not necessarily actively engaged in the learning process.[3] It

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[3]The differentiation between active and passive is understood here to reflect a difference between the implicit and explicit formalization of hypotheses and strategies; i.e., "active" is used synonymously with conscious hypothesis testing about rule structure.

may be that some criterion of initial learning should be imposed, either by returning to the previous method of having the Ss correctly reproduce a set of symbol strings or by modifying the observation technique. One method might be to request Ss to generate "sentences" after the initial observations. After some feedback on their responses, they could then be given another opportunity for observation of the grammatical subsets. In this way, the presentation of the explicit information could be integrated with the more passive components of the learning situation.

Although not a central issue in the conceptualization of implicit learning so far developed, the role of feedback could be further explored. In comparing the performance of our Ss with people engaged in implicit learning in non-laboratory situations (e.g., natural languages, acquisition of complex social codes), it seems clear that there is on-going feedback on their behavior which undoubtedly assists the differentiation process. Therefore, criterion learning with feedback may be required to ensure the necessary conditions to enhance S's model building. It would also tend to encourage a model more representative of the actual underlying structure.

For such a method to succeed, it may be important to reexamine the order of stimulus presentation as well. Up to this point, with the exception of the experiment noted

earlier in the discussion (Reber and Kassin, in prep.), the stimulus items have been presented in a random order, without regard to grammatical or "sentence" type. Given the complexity of the structure, it may not be possible for Ss to relate to the underlying rule system in a meaningful way unless the rules which define the system are made more salient. In order to have Ss build a sufficiently robust model, the stimulus array could be arranged according to the grammatical type, with feedback provided after presentation of subsets of each type in order to facilitate learning.

To summarize the foregoing discussion on the mode of presentation of the learning items, it is suggested that in order to ensure the active engagement of the Ss in the implicit learning process, the observation technique be modified. Such modification would include the organization of the grammatical strings by "sentence" type, introduction of some form of criterion learning, and feedback on the correctness of their responses being furnished to the Ss. Redesigning the learning phase in this manner should provide the opportunity for Ss to more actively encode the features of the patterns presented.

Besides the mode of presentation, another key factor in providing the boundaries for active engagement in the learning process is the instructional set. While the manner of presenting the stimulus array is more directed toward the

implicit processes, the instructional set seems to be more related to the explicit processes. Informing the S of the fact that the stimulus items are rule-governed without necessarily giving the explicit information about the specific structure would stimulate an active search for regularities. Taken together, both explicit and implicit processes should be engaged, allowing for maximum integration and, therefore, greater learning to take place.

Given these conditions, the question may again be raised as to where in the learning phase specific information on the rules system should be introduced in order to achieve the best performance on the transfer task. Again, this question is predicated on the assumption that the rule system is too complex for the Ss to discover the actual structure through hypothesis testing and use of individual strategies. This is pivotal in the investigation of implicit learning; that is, while Ss may be directed to look for structure, any model they build will be an implicit mapping into the grammar rather than "cracking the code" as in more explicit concept formation studies.

Perhaps the answer to this question will lie in further defining the aspect of implicit learning under investigation. The main emphasis of this and other recent studies referred to has been on how to set the boundaries to achieve the most efficient learning as measured by performance on a transfer task. In this sense, the

findings would support an approach that would introduce some knowledge of the actual grammatical structure at the beginning of the learning phase, thus allowing Ss to build a sufficiently strong model based on a blending of implicit and explicit processes with adequate opportunity for utilizing the exemplars.

While not in the scope of this study, a careful analysis of the results suggests another broader interpretation of implicit learning which would apply when a more inductive approach is adhered to. Such a focus would be appropriate where subsets of complex behavior are observed in a more implicit fashion over a period of time and the explicit processes engaged when attempting to formulate the underlying common structure. This might occur in some situations where the systematic nature of the stimuli is unknown, such as learning complex games, developing a complex skill or acquiring a language. A formal presentation of implicit learning theory should further clarify the nature and direction of future research in this area.

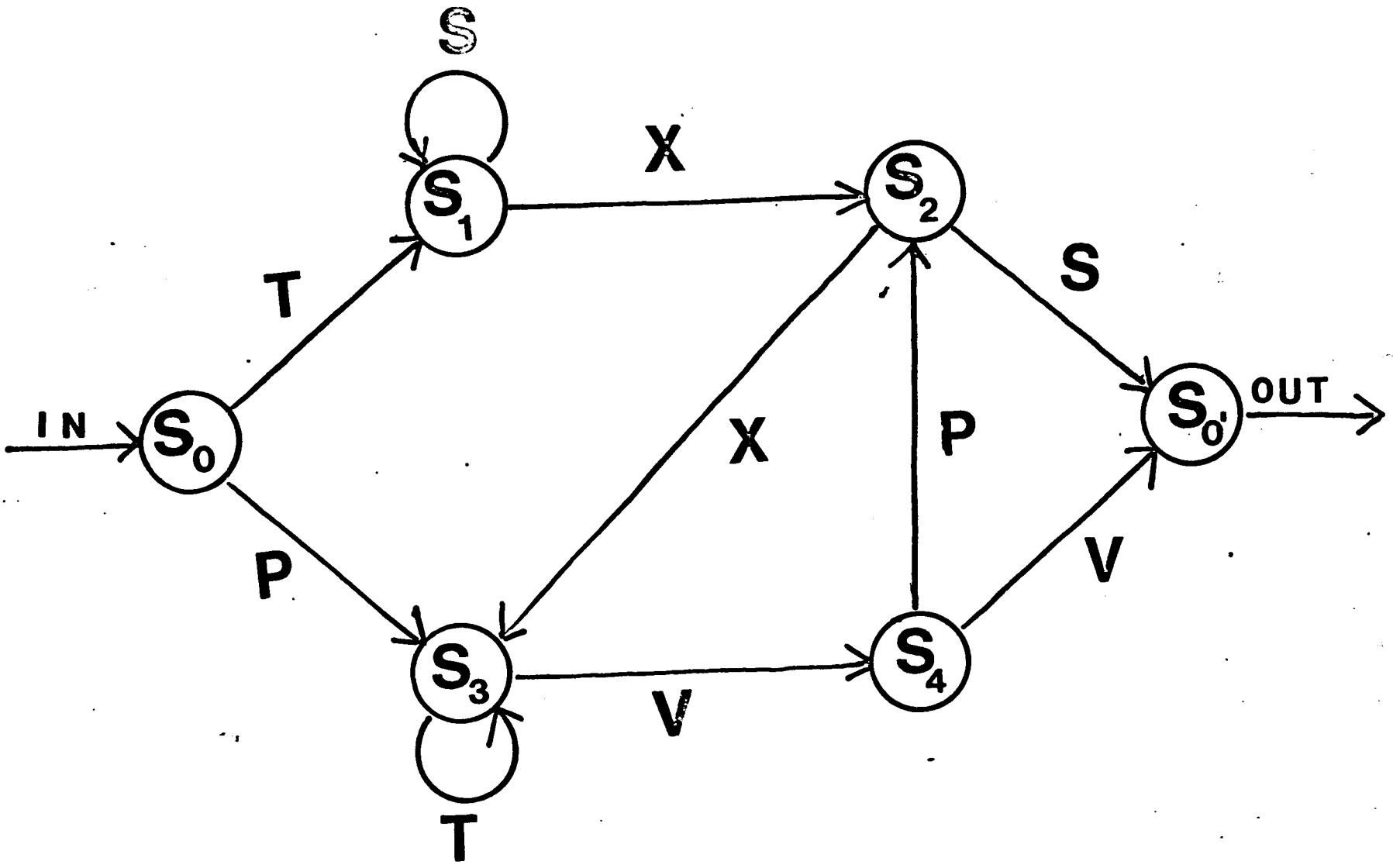

FIGURE 1

TABLE 1

Probability of Correct Responses $P_{(c)}$ for Each Group Broken Down into Trials and Item Type

Group	Trial 1	Trial 2	Total	Grammatical Items	Nongrammatical Items
I-E	.68	.72	.70	.67	.75
E-I	.76	.76	.76	.79	.75
I-E-I	.70	.72	.71	.67	.75
E	.64	.68	.66	.57	.76
I	.63	.62	.62	.64	.61

TABLE 2

Analysis of Variance:
Probability of Correct Responses

Source	SS	df	m.s.	F	p
Groups	3401.87	4	850.47	5.23	.01
Error	11386.01	70	162.66		
Trials	89.71	1	89.71	2.67	n.s.
Groups x Trials	186.81	4	46.70	1.39	n.s.
Error	2351.16	70	33.59		

TABLE 3

Mean Response Latencies
for each Group in Seconds

Group	Trial 1	Trial 2	Total
I-E	7.1	5.7	6.4
E-I	4.9	4.4	4.7
I-E-I	6.4	5.3	5.8
E	9.4	8.2	8.8
I	4.2	3.8	4.0

TABLE 4

Analysis of Variance:
Response Latencies

Source	SS	df	m.s.	F	p
Groups	409.71	4	102.43	5.95	.001
Error	1204.01	70	17.20		
Trials	31.47	1	31.47	26.92	.001
Groups x Trials	6.11	4	1.53	1.31	n.s.
Error	81.82	70	1.17		

TABLE 5

Correlations for Each Group Between Accuracy, Latency and Level of Confidence Measures

	Accuracy	Latency	Confidence Level
Group I-E			
Accuracy	-	-.19	-.48*
Latency	-	-	.01
Confidence Level	-	-	-
Group E-I			
Accuracy	-	.12	.26
Latency	-	-	.07
Confidence Level	-	-	-
Group I-E-I			
Accuracy	-	.27	.29
Latency	-	-	.01
Confidence Level	-	-	-
Group E			
Accuracy	-	.12	.17
Latency	-	-	.10
Confidence Level	-	-	-
Group I			
Accuracy	-	-.46*	.18
Latency	-	-	-.32
Confidence Level	-	-	-

*$p < .05$

TABLE 6

Frequency of Grammatical (G) and Nongrammatical (NG) Responses to Grammatical and Nongrammatical Items for Each Group[a]

Group	Item			
	Response	G	NG	Total
I-E	G	509	206	715
	NG	241	544	785
E-I	G	583	186	769
	NG	167	564	731
I-E-I	G	505	193	698
	NG	245	557	802
E	G	425	179	604
	NG	325	570	896
I	G	477	295	772
	NG	273	455	728

[a]Group differences are highly significant, $p < .001$.

All groups were able to discriminate grammaticality from nongrammaticality at far better than chance levels.

Note also that Group E shows a strong bias toward nongrammatical responses.

TABLE 7

Comparisons between the Detectability of the Various Types of Violations of the Grammar[a]

	Group I-E				
	S[b]	I	F	L	R
S[b]	-	n.s.	.05	.02	.01
I		-	.05	.02	.01
F			-	n.s.	.01
L				-	n.s.
R					-

	Group E-I				
	S	I	F	L	R
S	-	n.s.	.05	.05	.001
I		-	.01	.01	.001
F			-	n.s.	.01
L				-	n.s.
R					-

	Group I-E-I				
	S	I	F	L	R
S	-	n.s.	n.s.	n.s.	.01
I		-	n.s.	.01	.001
F			-	n.s.	.001
L				-	.01
R					-

	Group E				
	S	I	F	L	R
S	-	n.s.	n.s.	.02	.01
I		-	n.s.	.05	.01
F			-	.05	.001
L				-	n.s.
R					-

	Group I				
	S	I	F	L	R
S	-	n.s.	n.s.	n.s.	.02
I		-	n.s.	n.s.	.005
F			-	n.s.	.02
L				-	.01
R					-

[a]The entries give the level of significance of all comparisons between types of violations. For example, in Group I-E, random items (R) were detected as nongrammatical more accurately than were internal-error items (I) and the comparison was significant as $p < .01$.

[b]The five types of violations were classified as follows:

Second from last letter	(S)
Internal letter	(I)
First letter	(F)
Last letter	(L)
Random letters	(R)

TABLE 8

Test of Simple Detection Model for each Group[a]

	Group									
	I-E		E-1		I-E-I		E		I	
	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs
P(CC)	424	424	500	500	433	433	408	408	361	361
P(CE)	109	94	83	80	106	93	114	86	130	111
P(EC)	109	115	83	87	106	104	114	118	130	98
P(EE)	109	117	83	83	106	120	114	138	130	180
	χ^2 = 2.98		χ^2 = .30		χ^2 = 3.44		χ^2 = 12.06*		χ^2 = 29.87*	
Estimate of k	.43		.56		.44		.39		.31	

* $p < .005$
** $p < .001$

[a]The model is rejected for Groups E and I but not for Groups I-E, E-I, and I-E-I.

APPENDIX I

The 21 Grammatical Items Used as Learning Stimuli During the Training Phase

PVV

TSXS

TSSXXVPS

PVPXVPS

TSSSXXVV

PTVPXVV

TXXVPXVV

PTTVV

TSXXTVPS

TXXTVPS

PTVPS

TXS

PVPXTVPS

TXXTTTVV

PTTTVPS

TSSSXS

TSSXXVV

PVPXVV

PTVPXTVV

TXXVPS

TSXXTVV

APPENDIX II

The 50 Test Items, 25 Grammatical and 25 Nongrammatical, each shown twice

*VPXTVV	TXS
TSSXS	*PTVPXVSP
*PXPVXVTT	TSSXXTVV
*TXVPS	PVPXTVPS
PVPS	*XXSVT
PTTTTTVV	*TPTXS
*TXXTVPT	*PVXPVXPX
*PTVPPPS	*TXPV
TSXXVV	TSXXTTVV
*PSXS	PTVV
*VSTXVVX	TXXTTVPS
TXXTTVV	*TSXXPV
*PTVVV	*PTTPS
PTTVPS	TXXTVV
TSSXXVPS	PTTTTVPS
*TXV	TSXXTVPS
*PVTTTVV	*TTVV
TXXVV	PTTVPXVV
PTTTVV	*TSSXXVSS
TSXXVPS	PVPXTTVV
*SXXVPS	*PVTVV
*PTTTVT	*SVPXTVV
PTVPXVPS	*PTTTVPVS
*TXXVS	TSSSSXS
PVPXVV	PVV

*Represents a nongrammatical item.

BIBLIOGRAPHY

Blumenthal, A.L. Language and Psychology: Historical Aspects of Psycholinguistics. New York: Wiley, 1970.

Braine, M.D.S. On learning the grammatical order of words. Psychological Review. 1963, 70, 323-348.

Bruner, J.S., Goodnow, J.J. and Austin, G.A. A Study of Thinking. New York: Wiley, 1963.

Chomsky, N. Syntactic Structure. The Hague: Mouton, 1957.

Chomsky, N. Aspects of the Theory of Syntax. Cambridge: M.I.T. Press, 1965.

Chomsky, N. and Miller, G.A. Finite state languages. Information and Control. 1958, 1, 91-112.

Chomsky, N. and Miller, G.A. Introduction to the formal analysis of natural languages. In R.D. Luce, R.R. Bush and E. Galanter (Eds.) Handbook of Mathematical Psychology. Vol. 2, New York: Wiley, 1963.

Esper, E.A. A Technique for the Experimental Investigation of Associative Interference in Artificial Linguistic Material. Language Monographs. 1925, No. 1.

Foss, D.J. An analysis of learning in a miniature linguistic system. Journal of Experimental Psychology. 1968, 76, 450-459(a).

Foss, D.J. Learning and discovery in the acquisition of structured material: the effects of number of items and their sequence. Journal of Experimental Psychology. 1968, 77, 341-344(b).

Garner, W.R. and Gottwald, R.L. Some perceptual factors in the learning of sequential patterns of binary events. Journal of Verbal Learning and Verbal Behavior. 1967, 6, 582-589.

Garner, W.R. and Gottwald, R.L. The perception and learning of temporal patterns. Quarterly Journal of Experimental Psychology. 1968, 20, 97-109.

Gibson, E. and Gibson, J.J. Perceptual learning: Differentiation or enrichment? Psychological Review. 1955, 62, 32-41.

Gibson, E.J. Reading for some purpose: Keynote address. In J.F. Kavanagh and I.F. Mattingly (Eds.). Language by Ear and by Eye. Cambridge: M.I.T. Press, 1972, pp. 3-19.

Jones, M.R. Effects of context on lower-order rule learning in sequential prediction. Journal of Experimental Psychology. 1971, 91, 103-109.

Jones, M.R. Cognitive representations of serial patterns. In B. Kantowitz (Ed.). Developments in Human Information Processing. (In preparation, 1974).

Kantowitz, B.H. Information versus structure as determinants of pattern conception. Journal of Experimental Psychology. 1971, 89, 282-292.

Miller, G.A. Free recall of redundant strings of letters. Journal of Experimental Psychology. 1958, 56, 485-491.

Miller, G.A. Project Grammarama. In The Psychology of Communication: Seven Essays. New York: Basic Books, 1967, pp. 125-187.

Reber, A.S. Implicit learning of artificial grammars. Journal of Verbal Learning and Verbal Behavior. 1967, 6, 855-863.

Reber, A.S. Transfer of syntactic structures in simple artificial languages. Journal of Experimental Psychology. 1969, 81, 115-119.

Reber, A.S. Implicit learning of synthetic languages: the role of instructions. Cognitive Psychology. in press.

Reber, A.S. and Millward, R.B. Event observation in probability learning. Journal of Experimental Psychology. 1968, 77, 317-327.

Reber, A.S., Hether, C. and Lewis, S. A study of implicit learning of artificial languages: anagram solutions (in preparation).

Restle, F. Grammatical analysis of the prediction of binary events. Journal of Verbal Learning and Verbal Behavior. 1967, 6, 17-25.

Shipstone, E.I. Some variables affecting pattern conception. Psychological Monograph. 1960, 17, (Whole No. 504)

Simon, H.A. Complexity and the representation of patterned sequences of symbols. Psychological Review. 1972, 79, 369-382.

Smith, K.H. and Gough, P.B. Transformation rules in the learning of miniature linguistic systems. Journal of Experimental Psychology. 1969, 79, 276-282.

Smith, K.H. and Braine, M.D.S. Miniature languages and the problem of language acquisition. 1970, mimeographed.

Smith, K.H. and Braine, M.D.S. Miniature languages and the problem of language acquisition. In T.G. Bever and W. Weksel (Eds.), The Hague: Mouton & Co., in press.

Waldmann, D. Application of the observation technique to finite state language acquisition. Unpub. Masters Thesis, Brooklyn College, 1972.