Encoding, Representation, and Application of Logico-Conceptual Skills

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A. Title and Summary

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Summary

This document summarizes progress in research on the encoding, representation, and use of natural and logical concepts by adult human beings. The program focuses on three general forms of conceptual processes: (a) the identification of stimulus features which are critical to some unknown concept, (b) the formulation of abstract rules for combining stimulus features, and (c) the retrieval of concepts from memory and their use for purposes of reasoning, speeded inference, mental comparisons, reading, and other cognitive operations. In these studies conducted during the past 12 months, we have evaluated a variety of traditional models of memory processes in feature identification and have made some progress on an alternative theory which emphasizes the emergence of feature contingencies. We have continued to study stimulus-rule interactions in conceptual problems with the intention of developing a sufficient data base to support a new theoretical account of rule learning. We have evaluated the effectiveness of prototype and category name as primes for within category instance comparisons and have determined that the category name is a more effective prime. We have undertaken a new line of investigation into the possibility that natural concepts with a complex internal structure may be acquired by subjects in part automatically while consciously

processing other material. We have confirmed earlier findings that picture-word differences in memory disappear at the category level. We have shown how memory and inference operations are carried out at different cognitive levels, perceptual through semantic, and how these levels of analysis and their corresponding mental operations affect performance on subsequent memory tests. A study of same-difference comparisons for perceptual objects and their names showed that the semantic structure representing relationships among those objects enters into comparisons and affects reaction time only when the name (and not the objects) are to be compared. We have begun to extend our program of research into the domain of reading and report some preliminary results of that effort.

Statement of Progress

During the 12 months covered by this report work has progressed on 13 separate studies, several of which remain to be completed. Most of the work has been guided by theory of cognitive operations describing the inferential and memory processes utilized by human beings as they attempt to comprehend and solve conceptual problems. The principal investigator, one post doctoral associate (L. McCabe) and eleven research assistants (M. Camazine, T. Cocklin, R. Kellogg, D. Ketchum, L. Liebelt, M. Masson, L. Mauney, M. McDaniel, S. Reznick, D. Robbins and L. Sala) have taken varying degrees of responsibility for the individual studies. A separate section of the following report is devoted to each independent experiment or series of experiments, initiated or completed during the year.

1. Experiments

i. The effect of semantic distance on same-different RTs (Robbins)

Previous research which we have undertaken has demonstrated that a difference exists between the effects of stimulus similarity in a perceptual task vs. a conceptual task. Specifically, if subjects are presented pairs of geometric stimuli which vary along several dimensions, reaction time to state whether the two stimuli are identical on a given dimension is a function of the number of irrelevant dimensions on which they share a common value. The more similar the stimuli, the faster the reaction time (RT) for same judgments, and the slower the RT for different judgments. Contrarily, when subjects are forced to learn nonsense syllable labels for these same stimuli, and presented only the labels and required to perform the same task as above, the RT function, while similar for 'same' judgments, has the opposite slope for different judgments as that obtained for the perceptual task (for more information see progress report No. 23). Since the two tasks are essentially identical in what is required of the subject, with the exception of the memory retrieval component necessary for the conceptual (syllable label) task, we claim that the retrieval function for the nonsense syllable labels accounts for this difference by postulating that in some sense labels standing for similar figures are stored more closely together, and thus are retrieved for comparison more rapidly.

In order to test this hypothesis, a further study was run, using a control group in which subjects were allowed to retrieve the representations of the conceptual stimuli from memory prior to the comparison and decision stages of the task, through the use of a priming technique. In this experiment, subjects were required to first learn the corresponding nonsense syllable label. Subjects then performed, in random order, blocks of each of the four possible conditions. Condition 1 (primed-geometric) involved presenting the subject with a slide stating which dimension was relevant, followed, after a short delay (1000 msec), by a pair of geometric stimuli to which the subject responded, "Yes" or "No," as to whether the two stimuli were identical with respect to the relevant dimension. Condition 2 (reverse primed-geometric) involved the same task, except this time the slide stating which dimension was relevant was presented after the two stimulus slides. Conditions 3 and 4 (primed-syllable and reverse primed-syllable respectively) were the corresponding conditions using pairs of syllable labels in place of the geometric stimuli. Within blocks of each type of condition, trials were randomized with respect to which of the three possible stimulus dimensions was the relevant one. In addition, this experiment was run over 3 days, with subjects performing one block of trials of each of the four types on each day.

The design was a 2x2x3x3x2x2x3 mixed design. The single between subjects factor was Response hand (dominant, non-dominant). The within subjects factors were Stimulus type (geometric, syllable), Prime (primed, reverse primed), Relevant dimension (size, color, shape), Days (one, two, three), Response (Same, different), and Number of irrelevant dimensions changing value (Irrelevancies) (0,1,2). The procedure was as follows. Thirty-six subjects were run individually on three successive days. On the first day, subjects were given general instructions and allowed 25 minutes to familiarize themselves with the stimulus materials and to learn the association between each of the 8 geometric stimuli and its corresponding nonsense syllable label. Subjects were then tested on this material by being shown one type of slide to which they were required to respond by naming the associated stimulus of the other type. Once the subject had demonstrated competence at this task according to strict criterion he was allowed to go on to the second part of the experiment. The second phase of the experiment was completed by each subject on each of the three days. In this phase, subjects were presented with blocks of trials, with each block made up of 78 repetitions of one of the four trial types. The Stimulus Type manipulation yields blocks of trials in which either geometric stimuli are shown, or syllable stimuli are shown. On geometric trials, subjects make the "same-different" judgment based upon the physically present features of the stimuli, while on Syllable trials, the judgment is based upon a comparison to the geometric figures repersented by the two syllables presented. The first six trials in each block were considered practice trials and were not included in the scoring. Of the remaining 72 trials, 1/2 were positive or "same" trials, and 1/2 were negative or "different" trials. Within each block there was an equal number of trials in which there were zero, one, and two irrelevant dimensions which changed value between the two members of the stimulus pair. Both response latencies and errors were recorded and analyzed in this study.

The results in general replicated our earlier work with one minor difference. In the syllable trials we had previously found that with increasing similarity RT decreased for same judgment trials. However, in our current study, on Day 1, RT actually increased with increased similarity for "same" trials, on day two, RT for this condition was essentially constant, and on Day 3, RT decreased with increased similarity, as in the previous study. Since the current study involved a slightly more difficult task, in which the dimension which was relevant was randomized rather than blocked as in the previous study, we have hypothesized that it is this increased task difficulty which causes the subject more difficulty, or confusion on early trials. If this is the case, there should be a similar effect for the earlier trials in our earlier experiment. We are currently re-analyzing those data to see if the first few trials for each subject exhibit this effect.

The crucial comparison for this experiment involved contrasting the syllable-primed and syllable-reverse primed conditions. The task performed by the subject in these two conditions can be seen to be identical with the exception of the fact that, in the reverse primed condition, the subject is given enough of a head start on the retrieval of the stimuli associated with the given labels that the RT necessary for retrieval should not show up in the subjects recorded reaction times. Thus, we feel that any differences in the RT functions for increasing similarity between the primed and reverse primed conditions can accurately be attributed to a memory retrieval function reflecting the way in which more vs. less similar items of this type may be stored in memory. It is our further hypothesis that this difference should become more pronounced over days as the subject's memory for the stimulus associations and the corresponding retrieval strategy for the various stimuli and their labels becomes more stabilized.

At this point, the data for this study appear to suggest some small, but consistent differences between these two conditions. These differences appear to be rather pronounced for certain subjects and less pronounced, or non-existent for others. It appears that perhaps there were two types of subjects in the sample, or perhaps two different strategies used in performance of this task, such that subjects who were faster at the two tasks appear to also show a difference in the RT functions for these two conditions. However, further analyses still need to be performed before a conclusion of the significance of these differences can be reached.

ii. Priming in Semantic Memory (Sala)

Over the past decade, the internal representation of conceptual knowledge has played an increasingly important role in theories of human cognition. Two general issues have been the target of intensive research. The first of these concerns what is represented in memory and the second concerns how it is represented. As described in the previous progress report, a line of research was begun last year which was designed to address these two issues. In particular, the primary objective of this research was to determine the adequacy of two broad classes of theories about the internal representation of concepts. To review briefly, models of concept representation may be classified as extensional or intensional. Extensional models contend that only specific codes for individual category members are stored in memory, while intensional models hold that a generic code for the meaning of the category as a whole is stored in addition to, or instead of, these specific codes.

The view developed by Rosch (e.g., JEP: G, 1975) may be identified as a model of the extensional type. Rosch suggests that categories are internally structured around a prototype which is represented in memory by the best example(s) of the category. That is, Rosch describes a prototype not as a generic code but as a specific code (the code corresponding to the best example of the category), at least for superordinate categories whose members are visually diverse and cannot be represented by an analog of the category as a whole. Thus, Rosch's prototype model should be distinguished from other prototype models in which the prototype corresponds to an intensional code describing the category as a whole. Furthermore, Rosch argues that, in natural categories, not all category members are equally good exemplars, but vary in the degree to which they exemplify the meaning of a concept or category. Consequently, the prototype is conceived to be surrounded by other less prototypical category members, decreasing in typicality with their "distance" from the prototype (e.g., the category bird is thought to be represented in memory by the most prototypical bird--robin--surrounded by other less typical birds--hummingbird, pigeon, owl, penguin).

Rosch's views of internal category representation may be contrasted with those of theorists who posit that a generic, or intensional, code (which defines the category as a whole) is represented in memory. A preponderance of intensional models (e.g., Bourne, in Theories in cognitive psychology, 1974) have suggested that a concept or category is represented in memory by a rule-form relationship among a set of relevant features or attributes. Thus, for these models, a bird is an animal with wings and feathers, whereas for extensional models, a bird is a robin-like thing. Also included as intensional models are those that describe a category prototype that defines the category as a whole. In these models, features typical of the category members are abstracted and stored in a generic code. That is, the prototype is an abstraction, not a particular category member as in Rosch's view.

In the initial study of this research program, a priming paradigm was used. Subjects performed a matching task in which they were to decide whether or not two simultaneously presented items belonged to the same superordinate category. The pairs of items were presented either in picture form or in word form and varied in typicality. The two items in a pair were either both high typical, both medium typical, or both low typical items. On half the trials a prime preceded the target pair. It was of one of three types-- Prototype Picture, a Prototype Name, or a Category Name. In addition, the interval between the prime (which was exposed for 250 msec) and the target pair was manipulated. It assumed one of four values--250 msec, 500 msec, 750 msec, or 1000 msec.

It was hypothesized that if the meaning of a category is represented in memory by a generic code which is separate from the specific codes which represent category members (including the prototype), then priming with a Category Name should differ from priming with a Prototype Picture or Name. In particular, to the degree that activation of internal codes (by priming) leads to the formation of expectations about upcoming input, verification of category membership should be faciliated more by top-down expectations that can be generically confirmed for many category members than by expectations which match only specific category members, even prototypical ones. Thus, activation of the generic code should facilitate responding more than activation of the specific code for the prototype.

The results showed, among other things, that Category Name primes facilitated responses significantly more than did Prototype Picture or Prototype Name primes, supporting the hypothesis that the intension of a concept is indeed represented in memory as well as its extension.

Prototype Picture primes led to 22 msec of facilitation, Prototype Name primes led to 33 msec of facilitation, and Category Name primes led to 63 msec of facilitation. These data suggested that the representation of a category is a network consisting of two components, an intensional tree and an extensional tree. The intensional tree of a category representation defines the meaning of the concept or category. The extensional tree of a category representation defines the meaning of the concept or category. The extensional tree of a category representation consists of the specific codes for the members of the category. When a prime is presented, it is assumed to activate a certain portion of this representation, depending on the type of prime. If it is a Prototype Picture or Name prime, it will presumably activate one of the specific codes of the extensional tree (e.g., for the category animal, a prime of lion would activate the specific code for lion, rather than the generic code). The activated information could then be used in a top-down way to facilitate the encoding of the target pair. Thus, to the extent that the generic code is more similar to all members of the category, it will produce larger priming effects by virtue of establishing expectations for the few most important features of the stimuli. These features could be verified or rejected more rapidly than if the target pair were encoded in a bottom-up way. However, the prototype code, which is conceptualized here as a specific code, may bear a great deal of similarity to only some of the category items. Moreover, the features which are expected on the basis of the prototype code may differ from those which are expected on the basis of the generic code (e.g., for a prime of lion, the top-down expectations may be for the features of has mane and is animal). Verification of the features expected on the basis of priming with the prototype would appear to take longer than would those expected on the basis of the generic code. In fact, the generic code may have to be accessed indirectly from the specific code in order to speed up responding.

A second study reported in the previous progress report attempted to replicate these findings by changing the Prime Type variable from a between to a within subject variable. In this second study, each Prime Type was presented on a different day, with the order of Prime Type presentation being counterbalanced via a Latin square. When the prime types were blocked in this way, the different types of primes led to different amounts of facilitation on the first day (Prototype Picture primes led to 20 msec of facilitation, Prototype Name primes led to 39 msec of facilitation, and Category Name primes led to 58 msec of facilitation), although the Prime Type X Prime Condition interaction did not reach significance as it did in the first study. However, across days these differences between the primes disappeared, with all three primes leading to statistically equivalent amounts of facilitation (48 msec for Protype Picture primes, 42 msec for Prototype Name primes, and 47 msec for Category Name primes). That there was a difference between prime types on Day 1 which disappeared across days, suggests that with practice all three prime types came to access the generic code. Thus, the memory structure may itself have changed slightly, with all three prime types leading to the activation of the generic code.

Of some concern in these first two studies was the fact that although the Prototype Name prime resulted in less facilitation than the Category Name prime, responses were approximately 50 msec faster for Prototype Name primes, irrespective of priming. This may indicate that the different amounts of facilitation were due to different processing strategies. It is important to know whether Category Name primes are simply more effective in speeding up responses, or whether the different prime types result in different processing strategies, or both. Therefore, a third study was conducted in which Prime Type was manipulated within subjects as in Experiment 2, but prime types were randomized instead of blocked. Since, on any given trial, a subject could not know what kind of prime to expect, strategy-switching would be next to impossible under these conditions. Thus, the purpose of the third study was to determine whether the different prime types would prove to be differentially effective and whether Prototype Name responses would prove to be faster overall.

Although the data are not yet completely analyzed, a preliminary analysis of Same Category pairs for one counterbalance condition yielded rather surprising results. Prime types were differentially effective, with Prototype Picture primes yielding 178 msec of facilitation, Prototype Name primes yielding only 91 msec of facilitation, and Category Name primes resulting in 140 msec of facilitation. Thus, Prototype Picture primes were actually more effective than Category Name primes, with Prototype Name primes being least effective. Moreover, unprimed responses to Prototype Name primes were approximately 61 msec faster than unprimed responses to Prototype Picture or Category Name primes. Since this cannot be attributed to strategy-switching during processing, it is a result that is difficult to understand. Since only one counterbalance has been analyzed at this point, it could be due to stimulus-specific effects.

However, it is also difficult to understand why the Prototype Picture primes proved most effective in this subset of the data, but this also may not prove to be a reliable result when a complete analysis of the data is performed. Interestingly, reaction times were nearly 100 to 300 msec longer when prime types were randomized rather than blocked, so this procedural variation may have had some effect on task performance in and of itself.

We may conclude two things from this line of research. First, Prototype Picture and Name primes are not cognitively synonymous with Category Name primes, a result which is clearly contrary to extensional models. Thus, these data suggest that a generic code is indeed stored in memory in addition to specific codes for category members. Second, in whatever way concepts are internally represented in memory, their structure is by no means fixed, but is susceptible to change with repeated encounters with category members. Internal memorial structures are apparently rather easily modified by experience. Subsequent studies in this program of research should allow us to pinpoint differences between the prime types (a fourth study is now underway to determine if the retrieval dynamics of the prime types are different) and will hopefully elucidate the structure of the memory representation.

iii Conceptual Random Access Memory Probe (Robbins & Kellogg)

Previous studies using a conceptual random access memory probe (CRAMP) have shown that for an affirmative feature identification task, subjects tend to make a significant number of errors when asked for information about the occurrence of events on the immediately preceding trial. In our original study, subjects were asked to solve a series of simple feature identification problems in which the task was to discover which one of eight possible letter stimuli was the critical value. To do this, the subject was presented a series of trials, on each of which four stimuli were presented, and was required to classify each stimulus set as positive or negative. Feedback was then given, to assist the subject in identifying the single critical stimulus value. In addition, on 50% of the trials, subjects were asked to state their current hypothesis as to which stimulus letter was the critical one. After the end of the trial, 50% of the time subjects were requested to give some specific type of information about the events of the preceding trial. The information requested consisted of four types: what feedback was received, what their response had been, what hypothesis they had given, or which particular stimuli they had seen. The results of this study showed that, in a binary forced choice recognition task, correct recognition scores for feedback, response, hypothesis, and stimulus questions were: .96, .84, .79, and .74 respectively. The results were unexpected from a hypothesis theory point of view.

In a subsequent study one group of subjects was instructed to perform the feature identification task as rapidly as possible, and not pay much attention to the memory probes while a second group was instructed to pay particular attention to the probes, and to solve as many problems as they could, while being particularly careful to answer the memory probes correctly. There was no significant difference between the two groups, essentially replicating the previous study and ruling out an attentional interpretation of the data.

A third study is presently in the planning stage. The rationale for this experiment is twofold. First, we want to set up conditions which will force subjects to pay more (or less) attention to the memory probe questions, hypothesizing that simple instructional differences between the two groups of the previous experiment may not have been sufficient to produce such a difference in strategies. Second, the previously obtained results are somewhat contradictory of much of the previous hypothesis testing theory research, and instead tend to support a feature frequency model of performance for the specific task we have employed. It appears obvious from the literature in the field that there are a variety of tasks which subjects have been asked to perform, which conform nicely to a hypothesis testing model. There also appears to be mounting evidence for a feature frequency model of performance being appropriate for other sorts of tasks. It seems reasonable to suspect that at least some subjects have both types of problem solving capacities available and may use whichever is most appropriate for a given task. Since our previous results, which demonstrate marked failure to remember stated hypotheses under specific conditions, have been replicated in pilot work, as well as in two published experiments, it appears we have demonstrated a task in which subjects clearly do not remember hypotheses, presumably do not use them, and hence, since they do solve the problems, most likely use some sort of feature frequency information as a basis of solution. We now feel it would be of great interest to attempt to determine the boundary conditions of hypothesis forgetting, and this then is the second rationale for the current study.

In this study we have altered the frequency of both asking subjects to state their hypotheses and of giving memory probes (both 50% in previous studies). There are now two levels of percent of hypothesis information requests (25% and 75%), and two levels of memory probe frequency (25% and 75%). These two variables yield a 2x2 factorial design, producing 4 groups. We plan to have 10 subjects per group for a total of 40 subjects.

It appears likely that, if hypothesis and memory probe information are requested on each trial, subjects will alter their problem solving behavior, and remember this information most of the time, probably at the expense of performance on the main task. Additionally, our previous results have shown that at moderate levels of hypothesis/memory probe information requests, such memory is fairly poor. It would be of great interest if we could demonstrate a function relating frequency of memory question to recall performance of this information, thus clearly demonstrating that subjects, if left to their own devices, do not generate hypotheses or consciously remember specific stimuli of a previous trial, but can do so if it is to their advantage to do so.

The current experiment is being run on a new, improved version of the CRAMP program which in addition to allowing for variable rates of hypothesis selection and memory probe requests, greatly simplifies the selection of hypotheses and memory probe responses, and in general makes the experiment much simpler for the subject from a mechanical/technical point of view. Due to the difficulty in reprogramming CRAMP, and unavoidable delays in its implementation, we are just beginning to run subjects in this experiment at the current time.

We anticipate further studies involving such manipulations as problem difficulty and type of stimuli used to further determine the specific conditions under which subjects will prefer to solve problems using some method which does not require the ability to formulate, use, and retrieve overt hypotheses.

iv. Picture-word differences in a conceptual task (Liebelt)

A variety of paradigms has been employed to investigate picture-word differences. Studies using recognition memory, frequency judgment, discrimination and paired-associate tasks have generally demonstrated an advantage for pictures. However, when the task involves treating the stimuli as members of a category, rather than as unique items, this pictorial superiority disappears. For example, subjects who judge the frequency with which a picture or word item occurred in a list are more accurate when pictures are used. But when their task is to estimate the number of picture or word items from the list within a given category, no significant difference between pictures and words is obtained.

One explanation which has been advanced for these findings is that perceptual information is more readily available from pictures, giving them an advantage when the task stresses the encoding of the perceptual features of the stimuli. When attention to the more abstract, conceptual features of the stimuli is required, as in categorization tasks, the importance of perceptual information diminishes, and with it the pictorial advantage. Furthermore, the abstract nature of the conceptual features suggests that words might yield substantially better performance than pictures on this type of task.

In support of this line of reasoning, most investigations of picture-word differences using the traditional concept learning paradigms have failed to show a picture superiority. An illustrative example is Katz and Paivio's (JVLVB, 1975) attempt to demonstrate imagery effects in concept identification. They used a Hullian paired-associate task in which concept imageability and stimulus type (pictures/words) were varied. Their primary finding was that high-imageability concepts such as vehicle were significantly easier to identify than low-imageability ones, such as types of fuel. While no main effect of stimulus type was observed, this variable did interact significantly with the 6 different concepts they used. To quote Katz and Paivio, "pictorial presentation was superior for some concepts and inferior for others. The differences are small and do not fit any obvious pattern."

What kinds of concepts might be more easily identified from pictures than from words? Eleanor Rosch's research concerning the structure of natural categories provides an interesting hypothesis. Rosch contends that superordinate concepts such as vehicle are comprised of basic-level categories such as truck, car, boat, etc. These basic-level concepts are in turn composed of subordinate level instances such as pickup truck, dump truck, tank truck, etc. One way of describing the difference between superordinate and basic-level concepts is that superordinate categories share conceptual features in common, whereas basic-level concepts are more perceptually based. Vehicles all share the conceptual feature of transportability, while trucks also have perceptual features such as wheels and engines in common.

The perceptual/conceptual distinction made earlier with respect to picture-word differences may map onto Rosch's basic-superordinate hierarchy.

Since identifying a basic-level concept requires attention to perceptual similarities, one might predict that pictures would serve as better instances than words in such a task. Conversely, when conceptual features must be abstracted to identify a superordinate concept, words would be expected to show an advantage. The present experiment was designed to test these hypotheses.

The paradigm used in this experiment was adapted from Katz and Denny's (JVLVB, 1977) study of abstract versus concrete concept attainment. Although they did not include pictures vs. words as a variable, the task seemed well-suited for that manipulation. The subject's task was to figure out what concept was represented by an instance (picture or word) on each and every line of a 15-line set. Half of the subjects had pictures of objects on each line, while the other half had 2-word labels of objects to choose from. Cardboard covers were used to vary the amount of information the subjects had in view as they progressed from line to line; half of the subjects had access to all of their previous choices while working on any subsequent line, and the other half could only see the line they were working on, requiring them to remember what had occurred on previous lines. This manipulation was included in order to assess whether the advantage usually enjoyed by pictures in memory tasks would surface in this paradigm. The level of the solution category was either basic or superordinate. Instances from 5 other categories were used as distractors and the level of these distractor categories was also varied. This factor was included so that distractor context effects could be examined.

Thus, 4 variables were included in this experiment: stimulus type, solution category level, memory load, and distractor category level. All factors were manipulated between-subjects, yielding a 2 x 2 x 2 x 2 factorial design. A total of 80 subjects participated in the experiment, 5 in each of the 16 groups.

Subjects were told that their task was to identify the category that was represented on each line of the set. They were then shown an example of what constituted a correct solution to an analogous problem. Subjects were instructed that on each line they were to place a check mark over the instance they thought was from the solution category and to write the category name on the line provided. Subjects were told that they would have 20 seconds in which to work on each line. Those subjects in the high-memory load conditions were also informed that since they would only be able to see one line at a time, they should try to remember as much as possible about previous lines.

The major dependent variable was trials to solution. A 4-way analysis of variance showed that basic-level categories were identified significantly faster than superordinate concepts. This results supplied another line of converging evidence that basic-level categories are primary cognitive classes in the world of objects. A second finding was that low memory load subjects required significantly fewer trials to solve the problem than did their high memory load counterparts, demonstrating the validity of the memory load manipulation. When the solution or target category is on the superordinate level, words are substantially better than pictures. When the solution is on the basic level, pictures show a slight superiority. This marginally significant trend is in accordance with the major conceptual/perceptual predictions. Although the memory load x stimulus type interaction failed to attain statistical significance, it is clear that increasing the memory load has a considerably larger deleterious effect on pictures. This memory finding suggests that subjects were attending to conceptual rather than perceptual features of the pictorial stimuli. The apparent improvement in word-based performance when memory load is increased is the result of one deviant cell.

Although the main effect of stimulus type did not reach statistical significance, it is interesting to note that the overall means shown an advantage for words. Almost all of the previous concept experiments showing the disappearance of the picture superiority effect have still produced an advantage for pictures. The trend toward word superiority in this study lends support to the notion that verbal stimuli produce better performance in tasks requiring the abstraction of conceptual features. In addition, the trend toward a stimulus type x solution category level interaction suggests that the conceptual/perceptual task distinction can also be successfully applied within the Rosch hierarchy of categories.

A replication of this experiment is currently being contemplated using a larger sample size in order to reduce the often excessive within-cell variability.

v. Variations in Conjoint Feature Frequencies in a Feature Identification Task (Liebelt)

This experiment is designed to shed some light on the distinction between a propositionally-based representations of concepts in memory and any prototype model which claims an analogic representation. The experiment hinges on what we read to be one of the assumptions of most prototype models, namely that the prototypical instance contains all defining characteristics of the concept in question. In other words, the prototype is a conjunction of defining features. In such a theory, there is no room for what might be equivalent to a non-occurrence marker, that is, a tag or marker in memory to indicate that, under certain circumstances, feature $\underline{x}_{\underline{m}}$ cannot occur in an exemplar. Suppose the concept to be learned is characterized by a set of features, some of which show a low or nonexistent conjoint frequency. In other words, features x and y are among the several which show a high probability, contingent relationship with the concept. If, however, a given positive instance has feature x, it is unlikely to have feature y. Alternatively, if it has feature y, it is unlikely to have feature x.

Conjoint probabilities are as straightforward to manipulate as are the probabilities of individual features. Where the conjoint probability of two defining features is 0, their relationship can be described in terms of an exclusive disjunctive rule: "Members of the category must have (or are likely to have) feature x or feature y but not both." The probability of joint occurrence, of course, can be manipulated from 0 through 1.0, the latter being the inclusive disjunction: "Members of the category must have both feature x and feature y." The question at issue is, what will the subject designate as the prototypical stimulus and how will he judge degree of category membership in the case of low conjoint frequencies, or as conjoints change from 0 to 1.0. If our reading of prototype theory is correct, even in the case of 0 conjoint frequency (an exclusive disjunctive rule), the subject should choose as "best instance" that stimulus which contains both defining features, all other things being equal. And he should rank other stimuli accordingly on category membership. In contrast, a theory based on propositional representations, such as the one we propose, would predict no clear prototype and the evaluation of instances with feature _x_ or feature _y_ alone as equally representative, other things being equal. There may be some functional relationship to be discovered with this manipulation and, in this experiment, we plan to vary systematically the conjoint probability of two critical features, 0 through 1.0. Tests of category membership and typicality based on ranking, reaction time, and paired comparisons will be administered subsequent to a study-test acquisition phase. Preparations for this experiment are currently underway but no data have, as yet, been collected.

vi. Rules, Features, and Concept Verification (Ketchum)

The difficulty of learning a conceptual rule has been shown to depend upon the stimulus attributes that the rule conjoins. For what appear to be separable attributes, the disjunctive rule is easier than the conjunctive. In contrast, for what appear to be integral attributes, the conjunctive rule is easier. Our interpretation of this phenomenon rests on the distinction between perceptual and logical analysis. When two attributes are locally integrable, they are perceived as a "blob" or single unit and responded to accordingly. Perception leads directly to conjunctive sorting. When the rule is disjunctive, logic and perception conflict and the subject must override his perceptual tendency with a more complex logical analysis. When two attributes are locally separable, they are perceived and responded to independently, which is consistent with a disjunctive relationship. If the rule is conjunctive, perception and logic conflict and the subject must override perception with a more difficult logical analysis in order to sort stimuli in accord with the conjunctive rule.

Such an interpretation of the rule learning data is ad hoc in the sense that we have no independent assessment of the subjects perceptual tendency in regard to stimuli used in rule learning experiments. Therefore, we undertook a series of six experiments to examine the perceptual characteristics of stimuli and the relationship of these characteristics to rule utilization in a concept verification task which emphasizes speed of reaction to stimuli based on some known concept. We expected that any pair of features which has been shown to be conjunctively biased in a rule learning task would, because of the way it is perceived by subjects, facilitate the verification of a conjunctive concept relative to a disjunctive concept. As a corollary, any pair of features shown to conduce to disjunctive sorting would, because of its perceptual characteristics, facilitate the verification of a disjunctive rule.

Over the six experiments, the pattern of reaction times was inconsistent with this hypothesis. Verification times were always faster for conjunctive concepts, although more so for stimuli which lacked both relevant characteristics (FF) than for any other class (TT, TF, and FT). Feature salience rather than feature integrality appeared to be the main determiner of performance in the verification task. The series of studies, while interesting and informative in their own right, leave the proper interpretation of feature-rule interactions in a rule learning task still in doubt.

vii. Conscious processing of conceptually related faces (Kellogg and Cocklin)

In a previous series of four experiments (Progress Report No. 23), an attempt was made to define operationally the distinction between conscious and subconscious encoding processes. Three criteria were proposed: (a) simultaneous conscious pocesses interfere with one another whereas subconscious processes may operate in parallel without interference, (b) intention to perform is important for conscious processes but not for involuntary subconscious operations, and (c) the awareness accompanying conscious operations permits introspection, however, subconscious processes are not available for introspection. To examine these criteria, subjects were presented with a series of IDENTIKIT faces, which shared a number of features in common. In the conscious encoding condition, subjects were instructed to attend fully to each face. In the subconscious condition, subjects were required to calculate mental multiplication (e.g., 468 X 7) while looking at each face. After the study phase, a surprise recognition test was given. The test included old faces, related faces, and new faces, which contained a novel feature not shared by the others.

The results showed that viewing the faces did not interfere with accuracy of multiplication--the subconscious condition performed as well as a control group, which calculated the arithmetic in isolation. Moreover, subconscious encoding was not affected by intention to perform. Subjects instructed to ignore the faces were able to reject new faces just as well as subjects told to split their attention between the faces and the arithmetic. Finally, when subjects in the subconscious conditions were asked to rate how much they haed consciously thought about the faces during the study phase, their ratings were unrelated to their ability to reject new faces. In contrast, these ratings were positively correlated with recognition for the conscious condition. The more subjects claimed to have attended, the better they were able to reject new faces. Thus, subjects in the conscious condition were able to introspect with some validity about encoding the faces but, in the subconscious condition, failed the correlational test of introspection.

Although it was expected that only subjects in the conscious condition would show veridical introspection, a methodological criticism can be raised against the correlational tests. Because subjects were asked to introspect about the study phase after the recognition test had been administered, one might argue that attention ratings reflected how well subjects felt they had done on the recognition test. That is, subjects who thought they correctly recognized many old faces may have given a high attention rating. Veridical introspection about encoding the faces during study may not have taken place in either experimental condition. To counter this argument, an additional experiment was needed.

Instead of collecting the attention ratings at the end of the testing session, subjects in the followup study were asked to introspect immediately after the study phase. Only the conscious condition was tested ($n = 24$) and the instructions, materials, and general procedure were identical to those employed in previous experiments.

The recognition data showed that subjects were able to reject new faces with about the same degree of accuracy as those assigned to conscious conditions in previous work. More importantly, the correlation between attention ratings and recognition was again significantly positive ($r = .42$, p .05). The fact that this correlation did not drop to zero in the present experiment indicates that veridical introspection concerning encoding processes was not an artifact of the experimental procedure.
In conclusion, when attention ratings are collected either before or after the recognition test, there is evidence of valid introspection for the conscious condition.

viii Attention and Memory: A Levels of Processing Perspective (Kellogg)

Levels of processing theory represents an increasingly popular approach to the study of human memory. Previous formulations of this theory have postulated only sensory-semantic depth as a dimension of processing. But it would seem to be important to include modality and levels of consciousness, as well as levels of sensory-semantic depth, as relevant dimensions for describing the nature of mental processes. The main concern of the present work was to explore further a new method of operationally defining the distinction between conscious and subconscious processes in the context of memory experiments. In previous work, the author has developed a method for studying subconscious encoding processes--the key assumption is that presenting a word before subjects' eyes while they are engaged in mental calculation of a difficult math problem (e.g., 468 x 7) depletes limited conscious capacity, leaving only subconscious resources available for word encoding. The operational basis of this claim rests on three converging criteria: interference, intention, and introspection.

Because conscious capacity is small, words that are encoded consciously should produce a decrease in arithmetic performance by dual task subjects relative to a control condition, which performs the arithmetic in isolation. If word encoding is subconscous, then no interference should occur. If subjects instructed to ignore the words display inferior recognition memory for the words compared to subjects told to split attention between the words and arithmetic, then conscious encoding is indicated. But intention to act should have no effect for subconsciously encoded words. Finally, when subjects are asked to rate how much attention they paid to the words, and these ratings are correlated with recognition ability, a significant positive correlation indicates conscious encoding. Conscious processing permits veridical introspection, but these variables should be uncorrelated if encoding is subconscious and takes place without awareness.

Levels of consciousness was manipulated in a paradigm that tested recognition memory for words (e.g., TRAIN) presented in conjunction with orienting statements, which primed either phonemic (e.g., It rhymes with brain) or semantic features (e.g., It is a form of transportation). Two empirical questions were asked. In this situation, do depth and consciousness exert independent effects on recognition performance? Second, does reactivating subconscious encoding processes by having subjects perform difficult arithmetic during recognition produce substantial memory for unattended words? Many studies have shown that subconsciously processed words are poorly remembered. But the lack of memory may be due to either the unavailability or the inaccessibility of traces. According to the encoding specificity principle assumed by the version of levels of processing theory adopted in the present research, successful retrieval of subconsciously formed traces may depend on reactivating the original subconscious encoding operations.

Three experiments focused on the above two questions in addition to validating the proposed operational definitions of consciousness. A total of 15 experimental conditions ($\underline{n}$ = 12) were tested. The conditions included single task control and a variety of dual task conditions, which varied in the requirements placed on subjects concerning the secondary words. The arithmetic task was primary for all dual task subjects.

The results demonstrated both conscious and subconscious encoding with the former yielding superior memory ability. Although the depth effect was apparent for conscious encoding conditions, the effect for subconscious conditions depended on the retrieval environment. Phonemic and semantic orienting statements produced equivalent recognition performance if a standard test was used. But if subjects were assigned to conditions that reactivated subconscious encoding processes, then semantic statements resulted in superior retention. In fact, the magnitude of the depth effect for the reactivated subconscious encoding condition was equivalent to that shown by conscious conditions. It was concluded that depth and consciousness exert independent effects on retention, however, one must be careful to access subconsciously formed memory traces in a manner consistent with the encoding specificity principle.

ix. Representation of Visual Information in Memory (Mauney and Camazine)

Considerable debate exists over the representational mode of visual information in memory. Anderson (Psych. Rev., 1978) argues that visual information is stored in an abstract propositional network of features. His "fan effect" has previously been documented in experiments using verbal materials (Anderson & Bower, HAM, 1973; Anderson, Language, memory, and thought, 1976). The fan effect is interpreted within the context of an associative network theory; it assumes that each concept is represented by a node in memory and that each concept is connected to the propositions involving it by associative links. A memory probe is activated by perceptual processes creating a spread of activation from a concept node throughout its propositional context. The more propositions involving a concept, the greater the fan out of the node.

Anderson (Cog. Psych, 1978) presented subjects with a series of study faces comprised of features occurring in varying frequency throughout the 18 faces. In the test phase of his experiment, the 18 study faces were mixed with 18 new faces constructed from the same original features using the same frequency format. In a reaction time experiment, he found that high-frequency study faces and foils took longer for subjects to identify or reject than low-frequency study faces and foils. Anderson judged this difference in reaction time to reflect the relative difference in size of the activation field of each item. The greater the propositional context of each concept, the more time required to identify or reject it.

Criticism of this position comes from sources who argue for two distinct modes of information representation--one visual and one verbal (e.g., Paivio, Imagery and verbal processes, 1971; Paivio, Images, perception and knowledge, 1976). Studies of mental rotations (e.g., Cooper & Shepard, Cog. Psychol., 1973), perceptual comparisons based on long-term memory information (e.g., Mayer, Perception and Psychophysics, 1973), and effects of image size (Kosslyn, Cog. Psych, 1975) demand re-evaluation of Anderson's theory of a propositional representation for visual materials. Anderson and Bower concede that even if a propositional model is appropriate for long-term memory, it is possible that an imagery representation could prove useful for some cognitive phenomena. Anderson further comments that to construct a dual model of memory representation would be a step away from parsimony and especially inelegant if one model can account for both bodies of phenomena.

The impetus for the experiments in progress grew out of the feasibility of an imagery representation in memory and the conditions under which visual information might enter a propositional memory network. Some researchers, Anderson among them, suggest that visual information stored as Gestalt units would not be subject to interfering effects defined on subparts. Anderson proposed that presence of a fan effect for faces would be evidence against a Gestalt representation in memory. Proceeding on the assumption that an imagery representation does exist which stores information in Gestalt units, a number of predictions may be made in regard to Anderson's paradigm: (1) An imagery mode would not fare well on the identification task. Subjects would be less attuned to the feature context of the faces and more influenced by the configuration of the whole; thus, they would be less successful at detecting subtle feature differences in the foils and be error prone. Anderson must be criticized for the high degree of recognition involved in his rigorously learned faces. In addition, the feedback phase of the reaction time task constitutes a learning situation which continually modifies the representations of the stimulus materials and further suppresses the configurational properties of the faces. (2) A reversal or general flattening of the reaction time phenomena on error trials. The configurational properties of the faces would be more misleading with highly familiar foils than with faces composed of low frequency features. An imagery mode of representation would be quick to accept a foil according to the strength of its configurational similarity to a study face or set of faces. Faces which are less familiar would be subject to greater scrutiny before a decision could be made. While Anderson used RT data from correct response trials only, a reversal of the trend for error trials, if it occurred, could not be explained under his model. There is no reason to assume that, because subjects arrived at an erroneous conclusion, erroneous cognitive processes were at work. A significant reversal of the reaction time trend in an error group of trials would be evidence of a mode of representation in which the configurational properties of the stimuli are paramount. (3) An imagery mode of representation or primary reliance on such a mode can be predicted by perceptual measures. We would expect the high error group to constitute a certain perceptual group within the pool of subjects. Primary dependence on the configurational properties of the visual field is a global perceptual quality; persons who are more attuned to the detail of a given visual field are more analytic in their perceptions. (4) The structure of the stimuli will to some extent determine the mode of representation. As foils approach a prototypical quality, that is, as the number of high-frequency features per face increases, primary reliance on a propositional mode of representation (as evidenced by correct responses) decreases. Furthermore, and in accordance with our second prediction, reaction times would show a general reversal at each level of typicality.

Experiment 1 constitutes a total replication of Anderson's (1978) procedure except in one instance. Anderson's foils were constructed in accordance with the frequency format of the study faces. Each of the 18 foils contained two features of the null (9-fan) value. Six of the 18 had the remaining two features chosen from the 3-fan feature pool; six had one 3-fan feature and one 1-fan feature; and the remaining six foils had two 1-fan features in addition to the null features. Eighteen of our foils were constructed in this manner; however, four additional foils were added to each block of trials. These were prototypes which were constructed from the 9-fan dimension of each feature.

Of primary interest in this first experiment is whether a general reversal of Anderson's (1978) reaction time trend may be obtained for error trial data. This would be predicted in accordance with our first two hypotheses and would be impresive evidence of an imagery mode of representation--at least within some subjects. We will also be interested in the possible emergence of high-error and low-error groups of subjects within the random pool.

Subsequent experiments will test predictions 3 and 4. A battery of perceptual tests will be administered to subjects prior to the reaction time experiment in order to determine their perceptual orientation. We would expect subjects to differentiate into high and low error groups in accordance to their perceptual pre-disposition. Prediction 4 will be put to the test by presenting a novel group of foils whose overall frequency-values approach the prototypical value, e.g., 9-9-9-1 and 9-9-9-3 faces. We would expect the reliance on a propositional mode of representation to asymptote at these stimulus levels for successive groups of subjects according to their relative position on the global-analytic perceptual continuum.

Perceptual style is of prime interest in this study. If it can be demonstrated that the nature of the visual field affects the representation in memory of visual material, contrary to the position of the propositionalists, then the theoretical presence of an imagery mode of representation will gain credence.

Anderson (1978) must be criticized for failure to provide stimulus materials which are not readily succeptable to semantic encoding. Also, his method of memorization for the study faces (associating the face with a profession name) invites a plurality of linguistic associations during encoding. This effect is bolstered during the feedback phase of testing. However, given its methodological imprecisions, Anderson's study constitutes a commendable effort to bring clarity to this issue. It remains for future researchers to devise stimuli which are devoid of linguistic components in order to examine the representational mode of visual information.

x. Speeded Inference and Levels of Information (McDaniel)

The levels of processing approach, proposed by Craik and Lockhart (JVLVB, 1972), has been the impetus for much research demonstrating that memory for an item is a function of the type of processing performed on that item. Deep levels of processing (semantic processing) are shown to produce better performance on memory tests than more shallow levels of processing (phonemic and orthographic processing). Very recently, however, several studies have suggested that the approach outlined above is too simplistic. Our laboratory (McDaniel, Friedman, & Bourne, M&C, 1978), among others (Morris, Bransford, and Franks, JVLVB, 1978), has shown that the effectiveness of certain types of processing depends on the type of information needed for the memory test. That is, it appears that different types of processing result in the storage of different kinds of information about a stimulus. Whether or not a particular type of processing results in good memory performance depends on whether one tests for the particular information stored. A brief review of our previous work will nicely illustrate this point and, more importantly, serve as an introduction and partial description of our current work.

We had subjects perform an incidental processing task, which was followed by a set of memory tests designed to measure different aspects of memory for the stimuli. The incidental task was a set of speeded inference problems. These problems entailed viewing sequentially two words which shared some common value. The subject's task was to name as quickly and accurately as possible the common value. Each subject solved two different types of problems, each type of problem requiring a different level of processing. One type of problem, termed "conceptual," required identifying whether the two words were either animals, weapons, large objects, or small objects. The other kind of problem, termed "perceptual," required identifying whether both words were typed in either upper case letters, lower case letters, Italic type font, or Gothic type font. Each stimulus item had a value for every perceptual and conceptual dimension so that it was possible to counterbalance words and problems.

After completing the speeded inference problems subjects were given three tests of their memory for the instances, always in the same order. First, subjects were asked to write down as many of the instances as they could remember. Second, they received a verbally presented recognition test (auditory recognition) consisting of the 31 nouns the subjects had seen and 31 distractors conceptually similar to the target items. These two tests were intended to measure the amount of conceptual or name code information that the subjects had retained. Finally, subjects were given a 4-alternative forced choice visual recognition test, consisting of only the 32 nouns actually seen during the problems, printed in all four possible styles (e.g., HIPPO, hippo, <u>HIPPO</u>, <u>hippo</u>). This test was designed to measure how much subjects remembered about the physical characteristics of the words, when they had been given the name codes.

The results of a series of these experiments showed a consistent interaction between processing type and test type such that conceptually processed items were remembered better on the recall and auditory recognition tests and perceptually processed items remembered better on the visual recognition test. It should also be mentioned that performance on the visual recognition test was low, suggesting that (as Craik & Lockhart maintain) perceptual information as a whole is not very memorable.

The current experiment was designed to further investigate this encoding--test interaction. The paradigm was the same as that outlined above with two modifications. First, the subject did not know the type of problem (conceptual or perceptual) until after the first slide was presented. This was achieved utilizing a cue light whose onset was between the presentation of the first and second word. The idea was to induce the subject to extract both kinds of information from the first sitmulus item (the first word) but only one type of information from the second stimulus item. In this way we would be able to compare memory for a word processed on all dimensions versus memory for a word processed on only one dimension. Second, two time intervals were varied. These were the time interval between offset of the first word and onset of the problem type cue and the interval between onset of the problem type cue and onset of the second word. There were two values associated with the intervals, .7 seconds and 3 seconds. This manipulation was designed to investigate how various types of information might fare under different amounts of rehearsal and/or elaboration. Subjects were presented with 32 of these problems after a training period consisting of 12 similar problems with visual material. After completion of the problems, subjects were given the three memory tests described above.

The results showed that for the recall and auditory recognition tests, words processed conceptually were remembered better than words processed perceptually, replicating our earlier results for these tests. However for the visual recognition test, there was no effect of problem type. In addition, overall performance on this test was very near chance levels of responding. Thus it appears as if floor effects may be responsible for our failure to find an advantage of perceptual processing on the visual recognition test.

The effect of word order was significant for all tests, with words presented first remembered better than words presented second. This effect held regardless of whether the word presented second was processed semantically or perceptually. This result is consistent with Craik and Tulving's (JEP: General, 1975) notion that elaboration of an item is important for memoribility of that item, and also extends that notion by showing that perceptual as well as semantic elaboration can be beneficial. In addition, memory of perceptual information seems to benefit from semantic elaboration. There were some time interval effects which were generally the result of manipulating the interval between first word offset and cue onset. For the purposes of this discussion they may be summarized by saying that the short (.7 second) interval resulted in better performance regardless of problem type, especially for memory of the first word. Thus the short interval between word one and cue was not only sufficient for extracting various levels of information about the word, but in fact seemed to produce more effective processing (in terms of memory performance) than the long interval.

In summary, the experiment described here offers support for an "elaboration" view of encoding. It also suggests further investigation is needed to answer questions about memory of perceptual information, e.g., under what test conditions and processing conditions can one expect to find memory for perceptual information? In addition the temporal dynamics of information extraction and elaboration needs to be more thoroughly investigated. The present results suggest that, within the present paradigm, the critical processing interval is that between Word 1 termination and cue onset. Further experimentation might profit by focusing more systematically on this time interval instead of the interval between the time when the subject knows what type of problem to solve (cue onset) and second word onset.

xi. Picture-text interactions in reading comprehension (McCabe)

Preliminary to an investigation of the effects of picture-text interaction on text decoding and comprehension, structural equivalence of pictures and text versions of several stories was established for college student subjects utilizing methods described by Baggett in her dissertation (University of Colorado, 1977). The next step was to demonstrate a match of a picture and a portion of the text for each of these elements in each story. This procedure involved the presentation of picture stories to half of our 40 subjects. These subjects were asked to match randomly ordered portions of text to each picture. The other half of our subjects were given story texts and had to match randomly ordered pictures to each portion of text. Portions of text were modified in order to conform to our subjects' general consensus when differences arose between our match of picture and text and that made by the majority of our subjects.

We then asked 30 college students to answer comprehension questions about our stories after being presented with a story in one of five formats. These five formats were: 1) text only; 2) pictures only; 3) matching pictures and text; 4) pictures from one story paired with the text from another story; and 5) the story was not presented at all (subjects were asked to read the questions and give their best guess). Questions for stories in the first four formats were retained only if 75% or more of the college students answered these questions correctly. Questions for the stories that were not read were eliminated if more than 50% of the college students answered them correctly.

Having established empirically the equivalence of our picture and text stories, and the psychometric acceptability of our comprehension questions, we then presented our materials to 142 children (Grades 2 through 6) in the Denver Public School System. This study was an attempt to clarify Samuels' (J Educational P, 1967) position that young children found pictures to be a distraction while they were attempting to read text. The children were tested individually. Each child was asked to read three stories aloud (text only; text plus matching pictures; and text plus nonmatching pictures). The experimenter recorded the number of oral reading errors and the length of time required to read the story. At the end of each story, the appropriate comprehension questions were presented to the child and his answers recorded. Initial data analyses indicate no grade by story type interaction effects for any of the three dependent measures (number of decoding errors; reading time; number of comprehension errors). However, across all grade levels, pairing matching pictures with text improved performance as compared to the text only story. On the other hand the presence of nonmatching pictures interfered with performance as compared to text only stories. These differences were particularly apparent for story comprehension. Thus, it appears that the critical variable is not the age of the child, but rather degree of overlap in information content between the pictures and the text. When this agreement is high, performance is facilitated. Interference occurs when there is a lack of agreement between the information carried by the text and the pictures.

xii. Reading and the Time Course for Loss of Semantic and Surface Information (Sala & Masson)

Until recently, a preponderance of models characterized reading as a unidirectional process consisting of hierarchically arranged stages. Typically, in these models, reading is said to begin with the registration of visual information in sensory memory and from there the information is successively transformed or recoded, first in terms of features, then letters of phenemic codes, spelling patterns, words, phrases, and finally in terms of sentence meaning. In such models, processing is strictly bottom-up or data driven, in the sense that mental operations at one level may influence operations at other levels only if they are immediately above them in the processing hierarchy. Higher-order operations may not influence, or in any way change, processes lower in the hierarchy. Thus, information flows in one direction only--upward. Furthermore, lower-order analyses (e.g., letter identification) must precede higher-order analyses (e.g., word identification) if a sentence is to be successfully read or understood; higher-order analyses must await the output of lower-order analyses before they can begin execution. In the sense that these models rely wholly on sensory data (and its successive transformations) versus memorial information, they are data driven or stimulus-controlled.

There is now a good deal of empirical evidence which suggests that strictly bottom-up models are inadequate to account for the reading process. This evidence has been reviewed rather comprehensively by Rumelhart (Tech. Rep. CHIP 56, 1976), who points out that virtually all processing levels may be influenced by higher-order processes. For example, ambiguous letter configurations are read in different ways depending upon the word context in which they are embedded (Nash-Weber, in Representation and understanding, 1975), making it appear as if words are identified prior to or simultaneous with letter identification. Similar examples can be cited for processing of words placed in different syntactic and semantic settings, for parsing syntactically ambiguous sentences, and for comprehending meaning in various thematic contexts. These findings argue against the class of models which contend that reading is a sequential, stagewise process, and point to the likelihood of a heterarchical exchange of information by component processes.

Thus, theorists have recently been led to develop models which have a top-down or conceptually driven component in addition to the bottom-up processes. Top-down capabilities exist in a model when higher-order mental operations can influence processes that are lower in the hierarchy (e.g., expectations about the meaning of a sentence may change word identification processes to word verification processes). Oversimplified, top-down processing consists of a sort of hypothesis generation and testing procedure in which certain meanings, surface structures, and, hence, visual configurations are expected. A reader uses his knowledge of the world, of the discourse, and of the language, to generate expectations about the kinds of words and meanings that are likely to occur next in a sentence or paragraph. In other words, as a reader deciphers a written message, information is sent down from memory to lower-order processes, directing and facilitating their execution. These higher-order hypotheses are confirmed or rejected by data sampled from the visual signals.

It is readily apparent why bottom-up and top-down processes must interact--why they must continually communicate with and interrogate each other--for few relevant hypotheses could be generated by a cognitive system unless they were based on information related to the incoming visual signal. Thus, information must initially be processed in a bottom-up way until enough information has been activated in memory to provide a basis for the predictive, conceptually driven activity (Schank, in Computer models of thought and language, 1973). Let us consider an example adapted from Smith (Understanding reading, 1971, p. 193). If we are presented with the sentence, "The prizewinning book was written by the young _______________," our processing would be primarily data driven until world knowledge about "books" and "writing" were activated in memory. That is, prior to activation of this knowledge, we would proceed through the sentence by operating on letters and letter clusters, grouping these into words, and so on. Once relevant semantic information is activated, however, it is used in a conceptually driven way. We are able to predict that the final word of the sentence is likely to be "novelist" or "author" or even "man" or "woman." Part of this predictive activity is based upon our knowledge of our language. We know, for example, that a noun should fill the blank. In addition, however, we know something about what nouns fit the blank appropriately. For example, the blank could not be filled by the word "bear" or "couch." Thus, part of the conceptually driven activity is meaning-based. Once such expectations about to-be-read words are formulated, they can be verified or rejected by data driven processes. That is, we can use these expectations to help us decode the printed symbols. If our data driven processing tells us that the first three letters of the final word are "n-o-v," we can eliminate "author," "man," and "woman" as possibilities.

Such interactive models have been discussed in the literature in various forms (Adams & Collins, Tech. Rep. No. 32, 1977; Levy, JVLVB, 1977; Masson & Sala, Cog. Psych., 1978; Rumelhart, Tech. Rep. CHIP 56, 1976). For all of these models, however, the interactive nature of processing stems not only from the fact that both bottom-up and top-down operations interact with and require each other, but from the fact that processes operating on the many sources of information embodied in the written message and stored in memory also interact. That is, operations are simultaneously carried out on all levels of information--from orthographic, lexical, and syntactic information, to semantic and thematic information. These processes are asynchronous, parallel, and independent in the sense that they operate simultaneously. They are interdependent in the sense that processing at any given level may be influenced by processing at levels both higher and lower in the heterarchy.

The degree to which processes operating on typography, surface structure and meaning interact may have important implications for memory. We might expect that the memory trace resulting from those interactive processes itself contains interdependent components representing typography, surface structure, and meaning. In fact, we should be able to determine empirically the degree to which the memorial representation of the graphemes, surface structure, and meaning of a sentence are interdependent by observing the rate of decay of those components over time. If these components decay at similar rates we would have some evidence that they are interdependent and perhaps produced by the hypothesized interactive processing.

Thus, to provide an empirical test of these ideas, an experiment was performed that was an extension of our earlier work (Masson & Sala, Cog. Psych., 1978). Two between subject factors were manipulated: Processing Task (Read Aloud, Produce a Sentence Continuation) and Delay Between First and Second Reading (No Delay, Two Days, One Week). Three within subject factors were manipulated: Typography on First Reading (Transformed, Normal), Typography on Second Reading (Transformed, Normal), and Test Wording (Verbatim, Paraphrase). Subjects read two sets of sentences (the second set contained all sentences in the first set plus some new ones). One half of the subjects merely read aloud, and one half read aloud and produced a sentence which could logically follow the one that they read. Within each group of subjects, one third read the second set of sentences immediately after having read the first deck, one third read the second set after a delay of two days, and one third read the second set after a delay of one week. Half the sentneces in each deck appeared in transformed typography and half appeared in normal typography. Moreover, the sentences in the original deck appeared in the second deck either as verbatim copies of themselves or as paraphrased versions of themselves. This meant that each subject read one eighth of the sentences in each of the following conditions: normal-normal, verbatim; normal-normal, paraphrase; normal-inverted, verbatim; normal-inverted, paraphrase; inverted-inverted, verbatim; inverted-inverted, paraphrase; inverted-normal, verbatim; inverted-normal, paraphrase. Sentences (and their paraphrases) were fully counterbalanced. After each sentence in the second set, subjects were asked to judge: (1) whether the sentence meant the same as one in the first deck, (2) whether it was a verbatim or paraphrase copy of that sentence, and (3) whether it appeared in the same or different typography. Dependent measures were reading speed in seconds on both readings, time to produce a sentence continuation (for those subjects), and recognition accuracy.

Of primary theoretical importance are the measures of recognition accuracy for typography, surface structure, and meaning. Two predictions may be derived from the theoretical framework described here. First, we expect the decay rate for the three recognition measures to decay more rapidly for sentences read in normal typography than for sentences read in inverted typography. Since we hypothesize that reading of inverted typography requires more consciously controlled interactive processing, we expect more durable memory representations to be established for inverted sentences than for sentences read in normal typography. This result is likely to be especially pronounced for subjects who merely read aloud, for we would expect reading processes to be highly automated under read aloud conditions on normal typography, and automatic processing is hypothesized to read to less durable memory representations (Shiffrin & Schneider, Psych. Rev., 1977). Two hypotheses may be entertained as underlying reasons for this difference in memorability as a function of the resource demands during processing--either or both of them may be true. First, some investigators hold that automatic processing is comprised of fewer and qualitatively different sets of operations than controlled processing of the same material (e.g., Kolers, JEP: HLM, 1975). When a set of procedures becomes automatic, some of the old operations are elimited, and the automatic set may be less retrievable as a result (i.e., there are fewer operations to be recognized or reinstated and, consequently, fewer opportunities for retrieval). Second, it may be that controlled processing results in better memory because attention is devoted to the items that are processed and attention enhances memory storage (Shiffrin & Schneider, Psych. Rev., 1977).

Second, we expect that decay rates for typography, surface structure, and meaning will be similar--or, in other words, we expect to find no interaction between Delay Between First and Second Reading (No Delay, Two Days, One Week) and Recognition Measure (Typography, Surface Structure, Meaning). If there is no such interaction, we will have some tentative evidence for the hypothesis that interactive processing results in a memory trace with interdependent components. That is, there will be some support for the notion that when the wording and syntactic pattern of the sentence are consciously and elaborately processed along with the meaning of the sentence, their representations in memory are interrelated and, hence, decay at similar rates. However, if Delay interacts with Recognition Measure, there are three alternative interpretations that must be considered:

(a) Processing during reading is not interactive; different kinds of information are processed independently of one another, or

(b) Processing is interactive but does not produce a trace whose components are interdependent, or

(c) Processing is interactive but some component processes are automatic while others are consciously controlled, resulting in a memory trace whose components vary in durability and decay rates.

Data analyses are not yet complete, so the outcome of the experiment is unknown at this time. However, these data will further elucidate what we hypothesize to be a highly interactive process and will allow us to focus further research efforts on delineating exactly how such interactive processing affects storage and retrieval of linguistic and semantic information.

xiii. Resource Allocation in Reading (Sala & Masson)

Many current models of attention characterize man as a limited capacity processor (e.g., Shiffrin & Schneider, Psych. Rev., 1977), but LaBerge and Samuels (Cog. Psych., 1974) were among the first to grasp the importance of capacity limitations on processing as they relate to reading. LaBerge and Samuels wrote:

> Among the many skills in the repertoire of the average adult, reading is probably one of the most complex . . . During the execution of a complex skill, it is necessary to coordinate many component processes within a very short period of time. If each component process requires attention, performance of the complex skill will be impossible, because the capacity of attention will be exceeded. But if enough of the components and their coordinations can be processed automatically, then the load on attention will be within tolerable limits and the skill can be successfully performed. (p. 293)

Interactive models, such as the one we have proposed, imply that a great deal of computation is going on in parallel during the decoding of written input to meaning. Clearly, capacity limitations would be exceeded if at least some of the component operations were not automatic. It thus becomes important (1) to ask which operations are automatic; whether only bottom-up processes may be automatic or whether some top-down ones may be too; (2) to ask which operations demand attention, (3) to ask how automatic and attention-demanding procedures interact, and (4) to ask whether the interaction of bottom-up and top-down processes may itself be automatic. In the current experiments we addressed some of these issues at a global level by asking whether we could demonstrate that reading inverted typography actually requires more resources than reading normal typography.

Masson & Sala (Cog. Psych., 1978) have proposed that the interaction of conceptually driven and data driven processing may be either automatic (requiring little or no processing capacity) or controlled (attention-demanding). For someone who is reading normal typography, this interaction is probably largely automatic. This is likely to be especially true if one is merely reading aloud; meaning may be processed only to a small degree.

The interaction of the components may be somewhat less automatic when performing a task requiring good comprehension. Moreover, reading inverted typography is likely to be even less automatic than reading normal typography for good comprehension; it is likely to be controlled. Inverted typography represents a novel set of stimuli with which the data driven reading processes are not practiced. Because of its unfamiliarity, the operation of data driven processes on the inverted typography is slow and elaborate, and efficient decoding relies heavily on the use of conceptually driven processes. Unless the reader can generate meaning-based hypotheses to aid him/her in analyzing the graphemes, successful reading of the text will be very difficult. Thus, reading of inverted type is likely to involve extensive, consciously controlled interactions of conceptually driven and data driven processes.

To test these hypotheses experimentally, we conducted two dual task experiments. As is typically done in a dual task experiment, subjects were instructed to devote as much of their resources to a primary task as necessary for performance to meet a high criterion. Then, with whatever resources were left over, they were to attempt to perform a secondary task. To the degree that performance on the secondary task suffers, the primary task can be concluded to require either more or less resources.

In our experiments, subjects were asked to read sentences for good comprehension as their primary task. They were given a fill-in-the-blank comprehension test to encourage them to devote sufficient resources to the reading process and to assess the quality of comprehension resulting from the performance of the primary task. As the secondary task, subjects were asked in one experiment to listen to standard tones embedded in white noise and detect changes in tone from the standard. The second experiment was just like the first, except that subjects were asked to detect letters embedded in a sequence of digits. Two different secondary tasks were used in order to ensure that at least one of the secondary tasks, when coupled with the primary task, exceeded the capacity limitations of the subjects. Only when limitations are exceeded can the capacity requirements of the primary task be measured by observing the degree to which secondary task performance is depressed over a control condition. Reading rates were also measured.

Each subject participated in five conditions after familiarization with the procedure through practice conditions. In two of these conditions, reading normal typography alone, and reading inverted typography alone, subjects read sentences without performing the secondary task to give us a baseline reading rate and comprehension score for each control condition. These conditions preceded the three critical experimental conditions for half the subjects and followed them for the other half. The three critical experimental conditions were as follows: (1) performing the secondary task alone, (2) reading normal typography and performing the secondary task, and (3P reading inverted typography and performing the secondary task. These three conditions were sequenced using a 3 x 3 Latin square to counterbalance their order. In addition, sentences assigned to be read in each of the five conditions were fully counterbalanced.

The expected outcomes of these two experiments are straightforward. If our hypotheses are correct and reading inverted typography involves extensive, consciously controlled interactions of conceptually driven and data driven processes, while reading of normal typography is more automatic, then secondary task performance should be lower (as compared with the baseline detection rate) for reading inverted sentences than for reading normal sentences.

Signal detection data analyses have only just begun, so the results of the two studies cannot be reported at this time. However, the results of the experiments should tell us something about the source of capacity limitations during the complex skill of reading. Furthermore, they should provide another test of the adequacy of the interactive reading model that we have proposed, indicating in particular the conditions under which the interactive use of information during processing is resource-demanding.

2. Publications resulting from research supported by these grants (since Report 23)

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