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ABSTRACT

This report describes the experimental studies conducted to examine the role of mental structures in four different areas of research. The first area involves the structural analysis of isolable subsystems involved in visual and auditory pattern recognition. The second area involves the study of the encoding and retrieval of emotional or evaluative information. The study of complex patterns of active and passive production of voluntary movements constitutes the third field of investigation. The fourth area cuts across work in the other three and deals with distinctions between automatic processing and processing which is under active attentional control. Experiments in these areas are designed to examine the relationship between mental structures in general and the brain systems which subserve the functions of consciousness. The final part of the report deals briefly with efforts to make these findings on mental structure available in the form of course materials. (Author)

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Final Report

Project No. 033223
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COMPARATIVE PSYCHOLOGY OF MENTAL STRUCTURES

February 1974

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE

Office of Education

National Center for Educational Research and Development

Author's Abstract

Under this grant we have examined some methods used to make inferences about mental structures. The introduction reports this analysis.

Our experimental studies have concerned the role of mental structures in four different areas of research. Each of these areas constitutes one section of our final report. The first area involves the recognition of linguistic stimuli. We present a structural analysis of isolable subsystems involved in visual and auditory pattern recognition. Experiments have been directed to the question of the role of these isolable structures in the process of dealing with auditory and visual tasks. The second main area has involved study of the encoding and retrieval of emotional or evaluative information. The third field we examined concerns the production of voluntary movements. These include complex patterns of actively and passively executed arm movements and eye movements. The fourth area cuts across work in the other three and deals with distinctions between automatic processing and processing which is under active attentional control. Our experiments have dealt with alertness, selectivity and conscious direction as components of attention. We have been interested in the relationship between mental structures in general and the brain systems which subserve the functions of consciousness.

The final part of the report deals briefly with efforts to make our ideas of mental structure available in the form of course materials. These include a brief outline of a new introductory textbook and efforts to develop a computerized course for teaching experimental psychology.

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Introduction

The idea of mental structures as underlying constructs in the study of psychological questions goes back to the birth of psychology in the late 19th century. Wundt and Brentano argued about the status of such mental structures. Wundt held that mental structures were an appropriate subject of psychology because of their availability to introspection. Brentano argued that introspection could only reveal acts performed on structures and not structures themselves, since they lay outside the field of consciousness. Both Wundt and Brentano agreed that the boundary of psychology lay at the borders of consciousness and questions outside this boundary were properly left for physiology.

The cognitive psychology initiated in the last two decades is based upon a conception of man which has come to be called "the information processing view." This conception is one in which the subject of psychology is the organization and flow of information in the nervous system. Thus, one of the central problems for the information processing approach is to relate those mental operations which give rise to subjective experiences available to introspection with those that do not. In this sense the information processing approach provides a neutral language in which to relate the problems of brain and mind. This conception has given rise to many new questions and findings about mental structures which form the basis for our research.

In our use of the information processing approach, two basic methodologies have dominated. These are measurements of the time required for the performance of a mental operation and the degree of interference between two mental operations which need to be performed at the same time. A brief description of our use of these two methods is outlined below.

Time for mental operations

In 1850 the German physiologist Helmholtz determined the speed of neural conduction, thus overturning an old philosophical theory of the infinite rate of nervous processes. Within ten years others led by the Dutch physiologist Donders had developed methods for measuring the time for such mental operations as discrimination and choice.

In the 1950's the time for mental operations was studied in connection with the amount of information carried by a signal. For example, Hick and Hyman found that the amount of information transmitted by a subject was proportional to his reaction time. Fitts showed that the time for accurate movements depended upon the amount of information which the movement generated. These findings rekindled the idea that time served as a natural metric for the study of mental operations, each mental operation requiring a measurable amount of time.

The study of mental chronometry has been intense in recent years. The orderliness of time relations of mental operations made them a favorite method for the study of the relationship between internal events. Consider the simple task of pressing a key to indicate whether two simultaneous letters or words are the "same" or "different". Suppose the definition of "same" is that two letters are either both vowels or both consonants, or that two words refer to living things or nonliving things. There are different bases upon which such a decision might be made. The letters or words might be visually identical (e.g., AA), they may have the same name but not the identical shape (e.g., Aa), or they may be identical only in that they have a classification such as vowel or animal in common (e.g., AE or deer-salmon). This logical analysis is beautifully reflected in the time between presenting a pair of items and the response to it (reaction time), despite the fact that subjects never know which kind of pair will occur on a given trial. Figure 1 shows reaction time to various types of pairs.

The time to match a pair of letters which agree only in name is about 80 msec longer than for a pair which is also idential visually. Suppose you were given two simultaneous strings of ~~letters~~ consisting of one to four vertical pairs. Each pair is either physically identical (e.g., $\begin{matrix}\text{ABFR}\\ \text{ABFR}\end{matrix}$), or one pair is identical in name only ($\begin{matrix}\text{ABFR}\\ \text{ABfR}\end{matrix}$) or all pairs are identical in name only ($\begin{matrix}\text{ABFR}\\ \text{abfr}\end{matrix}$). The same pairs are mixed with an equal number of trials containing a nonidentical pair. The time to make a "same" response increases by 60 msec for each physically identical pair. If the list contains one name identity pair, a parallel line about 80 msec above is obtained. If the list contains all name pairs, a new function is obtained with the slope increased by 80 msec (see Figure 2).

These kinds of results have encouraged the development of mental chronometry as a basic way of measuring mental operations.

Competition between operations

A second way of measuring mental operations depends upon an observation first made by the biologist Jacques Loeb. Loeb proposed to measure mental operations by the amount of interference between some standard task and the mental operation to be measured. For him the question was not the time mental operations required, but rather how much of man's limited capacity attentional system they demanded. In the first volume of the American Journal of Physiology Jeanette Welsh (1898) published a study in which she used maximum hand pressure as a standard task and developed a coefficient of attention for many simple mental operations such as arithmetic, counting and reading. The general idea which stems from Loeb's contribution is that any two tasks which demand access to the same neural processing system will interfere with each other.

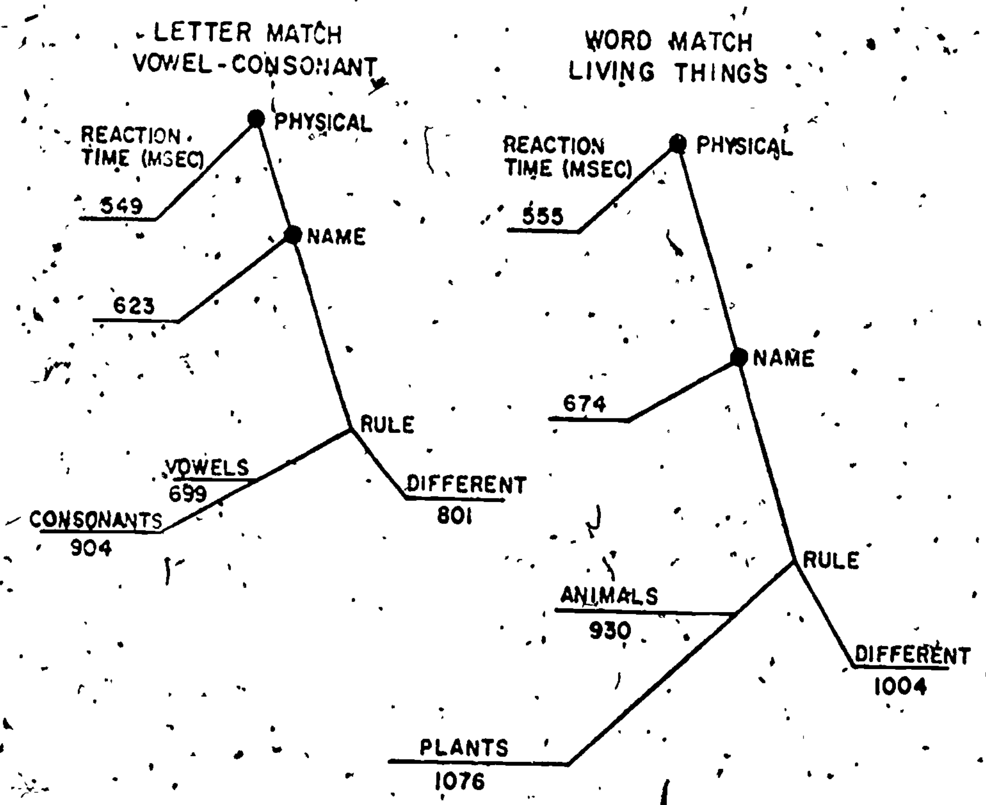

FIGURE 1.

RTs for letter pairs and word pairs that are physically identical, have the same name or obey the same rule.

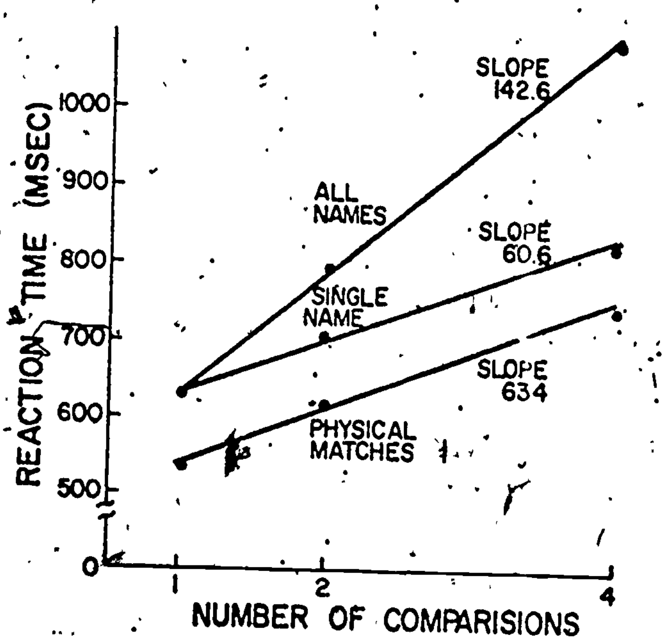

FIGURE 2.

The time to respond to two strings of letters as a function of the number of pairs in the string.

In Loeb's original conception the interference was between entire tasks. This basic conception was represented in the 1950's by the idea that man could be conceived as a single information processing channel. While one signal was being processed, this channel was refractory to the handling of other signals. Thus, the brain was conceived as a single unified channel, and any mental operations took a portion of that overall channel capacity.

However, as long ago as the 1800's the French psychologist Binet and Bliss in this country, among others, had proposed that some voluntary actions were automated in the sense of not requiring any of the limited attentional capacity of the human. Fitts recognized that highly skilled tasks might become automated in this sense. In the last dozen years or so there has become increasing evidence to suggest that the interference between tasks is a function of the degree to which they involve the same neural system. For example, tasks which involve spatial imagery tend to interfere with visual processing, while tasks which require verbal imagery interfere with auditory input. Requiring the subject to hold letter names in store interferes quite strongly with processing other names, but relatively little with visual information processing. These demonstrations, that the degree of similarity in a psychological and a neurological sense between the tasks has a great influence on the degree to which they can be time-shared, suggest that the interference between tasks depends upon the degree to which they use the same neural system.

On the other hand, there may be neural systems of such great generality that nearly any psychological task places a load upon them. Thus, we seek distinction between interference effects which depend upon the similarity between tasks and those which are relatively free of similarity effects. By this technique it is possible to determine the use of mechanisms responsible for the highest level of integration within the nervous system. These mechanisms will tend to show widespread interference effects. More specialized mechanisms will show interference effects only with things that are quite similar to them.

Our general contention is that all mental operations can be measured in terms of the time that they require. Moreover, all mental operations will have specific facilitory and inhibitory effects upon other operations quite similar to them. However, only a subset of mental operations will demand use of the highest integrative mechanisms and thus produce such widespread interference that mental operations of many different types will be inhibited. The study of interference between signals is used to distinguish between automatic kinds of information processing, and those which may be used to create new mental structures.

These techniques can be applied to many different psychological problems, they are methodological points rather than substantive ones, ways of finding out rather than results. In the sections which follow we apply these techniques to a number of different problems in hopes of further elucidating the mental structures and cognitive operations involved in pattern recognition, emotion, movement control and attention.

Pattern Recognition of Linguistic Stimuli

Isolable structures

In previous work we have reviewed the component structures involved in visual and auditory pattern recognition of linguistic stimuli (Posner, Lewis and Conrad, 1972). Although the physiological pathways of input of auditory and visual information are quite separate, there are many common properties among these systems. For both visual and auditory pattern recognition it is possible to view the recognition process in terms of component structures which may be isolated in particular behavioral tasks.

Liberman (1970) divides the recognition of speech into an accoustic (physical) and phonetic level. The idea is that the accoustic input string activates pattern recognizers at the phonetic level, which give rise to categorical interpretation of the input information. Figure 3 also shows a similar analysis for visual recognition of letters which arises from our own work on letter matching. In both cases a physical representation of the input signal overlaps an unconscious recognition process which provides a categorical output.

This categorical output at the phonetic level for speech appears to involve an analysis which is indifferent to the physical feature of the input item. Thus, items which differ along accoustic dimensions are classified into the same phonetic category. A very similar process classifies different types of print as instances of the same letter in the visual system. It had been thought that the auditory and visual systems differed in the ability to use information from the stimulus level in behavioral judgments. A recent result shows that these differences appear to be more quantitative than qualitative. For example, it is possible to show that two physically different (e.g., Aa) visual stimuli which have the same name take longer to classify as "same" than two physically identical visual stimuli, and that it takes longer to classify two accoustically different tokens of the same phonetic category as "same" than it does when the two tokens are identical (Pisoni, 1974).

Perhaps because of our habitual processing modes, or perhaps because of the inborn character of auditory to phonetic distinctions (Eimas, 1971), the ability of subjects to be aware of distinctions between accoustic realizations of the same phonetic category appears to be much less than the ability of subjects to do so with visual distinctions. But in general one must be impressed with the degree of similarity in the basic workings of the pattern recognition systems for auditory and visual stimuli.

Hierarchical organization

What appears as the hierarchical nature of the organization of the isolable systems shown in Figure 3 is misleading. Recent results

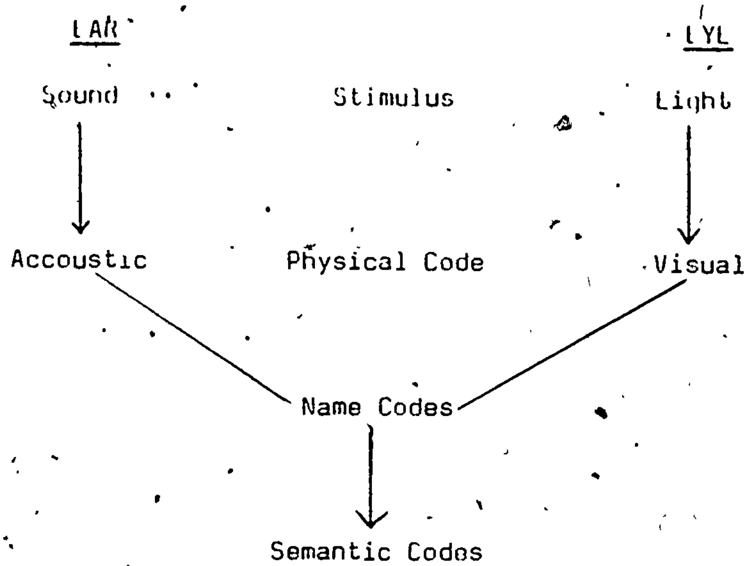

Figure 3.

Levels of processing for auditory and visual input.

at both the physiological and at the behavioral level indicate that both visual and auditory pattern recognition levels tend to operate in parallel and not in a serial fashion. I have made this point in several published articles (Posner, 1969; Posner, Conrad and Lewis, 1972).

The physiological evidence reviewed by Stone (1972) suggests that the structural hierarchy obtained by Hubel and Wiesel in their study of visual pattern recognition in monkeys, in which simple, complex and hypercomplex cells seem to form a hierarchical generalization on the stimulus input, breaks down when one looks at a temporal analysis of the functions of these levels. Indeed, it appears that simple and hypercomplex cells are more rapidly activated from lower levels of stimulation than are the complex cells.

In much the same way there appears to be no simple hierarchy in the behavioral task either. For example, it is possible to have tasks which require the manipulation of the physical stimulus (Shepard and Metzler, 1971) which go on for much longer times than the time to name or classify the input. Thus, persistence in the processing at the more peripheral levels allows them to overlap in time with deeper levels of processing. This same result has been reported in recent work by Wood (1974) in the auditory system. Thus, the notion of isolable subsystems which handle different aspects or levels of signals does not suggest that they form a strict hierarchy, either at the physiological or at the behavioral level. Because of this lack of hierarchical organization, it is necessary to study the coordination of these isolable subsystems in different tasks. A number of our experiments have been directed to this question.

Coordination of codes

Under this grant we undertook a study of the coordination of codes in a number of different experimental situations. These include visual search, search of active memory and rehearsal and translation processes. This paper has been published under the title "Coordination of Internal Codes" in Chase, W. G., ed., Visual Information Processing.
Let me summarize the results of these studies and add to them those which have been obtained since the time of the publication of that paper. In these studies we found that many tasks which involve the lookup of information from memory depend upon more than one isolable code. For example, in the visual search task both the physical feature of the visual form and its name combine to influence the time for the subject to do the task. It is impossible, or at least very difficult, for the subjects to avoid the influence of both of the codes. More interesting, it was found that even when information comes by separate modalities such as simultaneous auditory and visual information, the search processes occur in very much the same way as if all the items were in the same code. The results of one extensive study are shown in Figure 4.

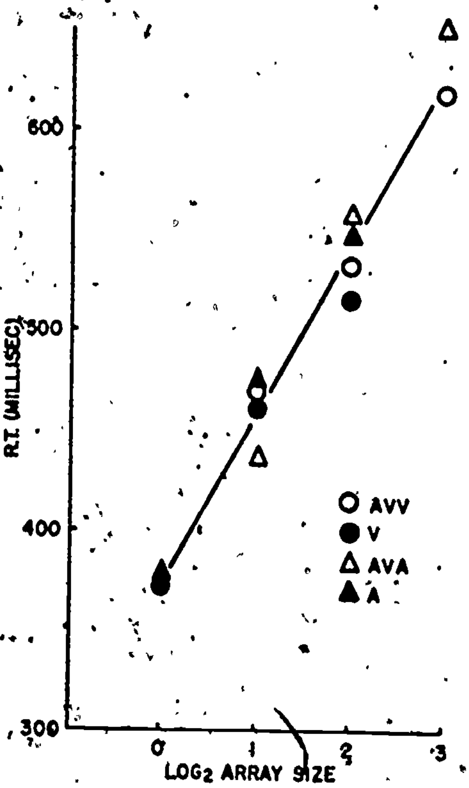

Fig. 4. RTs as a function of the log of the array size, collapsed over all type of arrays.

The search time is exactly the same as though all the material had been presented either aurally or visually. This result suggests to me that although the input of pattern recognition processes are quite separate, the organization of such items in the nervous system involves tight connections between the different input modalities. This means that as far as search processes are concerned, the origin of the item is unimportant. This result might be less surprising if it were not coupled with another result which in a sense contradicts it. If the subject is able to process the information consciously, that is, if he is able to concentrate upon the code of a particular item, then we find that the representation of that item is code-specific. Thus, the representation of items in active and long term memory does not seem to be much affected by the code of input, but when the subject goes to think about a particular item, the code in which he conceives the item has a vast effect upon its processing. These results are pointed out in the "Coordination of internal codes" paper.

Range of activation

There may be two different reasons that search of memory is not much affected by the input modality of the items. One possibility may be that an input item tends to activate codes which represent different isolable subsystems automatically. Thus, the presentation of a given item irrespective of input modality would provide activation of all codes of that item associated with it. This would mean that if a letter was presented aurally, its visual code would be active as though it had been presented visually. Another possible explanation is that the coding of input items is translated into an abstract representation which no longer deals with the information in the individual input codes. Many recent theories (Anderson and Bower, 1973) have favored a more abstract level of representation for items. On the other hand, much of our work has indicated the possibility of a multiple code interpretation. For example, Warren has shown that a given input word will activate a variety of associates even without the subject's intention. Moreover, Rogers (1972, 1974) has shown some evidence for the activation of the visual representation of an auditory stimulus even without active effort by the subject. Thus, it is possible that the input item activates a multiplicity of codes, and this is the reason that search tasks do not show a difference depending on the input modality.

Individual differences

If, as our data seem to indicate, an input item activates a wide range of codes in the nervous system of which the person is aware of only a subset, there is interest in what determines that subset. This appears to be a good place to look for differences among individuals in the code to which they habitually attend. In the "Coordination of codes" paper we presented some evidence by Snyder (197?) that subjects who report themselves as high in visual imagery tend to perform well on tasks involving the rotation of complex forms and also on certain aspects of letter perception which emphasizes the physical code of the letter.

A more extensive analysis of individual differences in auditory processing has been reported by Day (1973). She distinguishes between two groups of subjects. One she calls language bound. They seem to deal primarily with the linguistic interpretation of input. The other group she calls stimulus bound and they appear to be free to access the physical code as well as the higher level analysis. We used our high and low imagery subjects on a task which Day had explored. This task required subjects to find a set of target letters in each of a list of words or nonsense strings. Day showed that language bound subjects had trouble in doing the task when the items in which the targets were located were words. Our data were not too clear cut, but they led us to hypothesize that high imagery subjects (stimulus bound in Day's terminology) tended to perform the task in a visual code, while low imagery subjects appeared to recode the items into letter names. Further tests need to be made of this idea.

In another study Snyder found that high imagery subjects were less influenced than low imagery subjects by the common name of physically different letters (e.g., Aa) when required to classify them as physically different. This finding may relate to one reported by Hunt, Lunneborg and Frost (1973) in which they found that high verbal scorers on the SAT (perhaps language bound in the Day terminology) also seemed to show a smaller difference between physical and name matches than low verbal scorers. Presumably this was because the name code could be accessed more easily by the high verbals.

These experiments indicate a number of ties between ways of classifying subjects that are used in different laboratories. If they can be tied more firmly to pattern recognition levels we may have important new techniques for dealing with differences between individuals.

Adaptation of linguistic detectors

Recently Eimas and Corbin (1973) have presented some evidence that feature detectors in the auditory system can be adapted by repeated stimulation. Their evidence is equivocal, since the shift they find in the boundary of the identification functions could be predicted either by adaptation or by repeated stimuli better defining an auditory target. Our experiments designed to adapt detectors for visual letters using an increase in reaction time or signal detection as a criterion were unsuccessful.

At present we are attempting to replicate the Eimas effect using an increase in reaction time to the adapted stimulus as a criterion. The results obtained so far provide substantial support for the adaptation explanation. If this continues to occur, we will be anxious to determine whether this represents a genuine difference between the modes of pattern recognition, or whether the differences are due to methodological distinctions.

Summary

Our work in pattern recognition suggests the cogency of an analysis based upon levels of processing in both visual and auditory pattern recognition. It also indicates the range of codes activated by a given input item. Because there is widespread automatic activation of codes, it becomes important to determine how limited capacity conscious mechanisms are contacted by these codes. Our results suggest that conscious processing is quite specific and that the particular codes used may be a matter of individual differences or of training.

Emotion

The study of emotion has been broad and diffuse. We shall take as a working definition of emotion that provided by Magda Arnold (1970). She defines emotion as "the felt tendency toward something appraised as good (and liked) or away from something appraised as bad (and disliked)." Although our general definition will agree with Arnold's, our work is somewhat broader than this definition in that we will be concerned with the antecedents of the "felt tendency." These antecedents may not themselves be felt, that is, may not be conscious processes but rather may be unavailable to introspection.

Views of emotion

Neuropsychological accounts of emotion have enjoyed historical prominence in psychology. William James (1884) held the view that our experience of emotion lay in the feedback from autonomic responses. His formulation emphasized the relationship between autonomic responses and subjective experience and was a reaction to what he took to be the traditional view of emotion in which a conscious cognition of the input mediated between the stimulus and the feeling of emotion. This traditional view is shown in a flow diagram in the upper panel of Figure 5. James' view emphasized the cognition or conscious content as arising out of the emotional autonomic responses, as shown in the middle panel of Figure 5. Cannon (1927) suggested instead that the autonomic responses and the subjective experience were both the result of classifications of input by the central nervous system. Cannon's view is widely accepted; however, most research has concerned how hypothalamic activity controlled the autonomic system and not the question of why a stimulus input produces hypothalamic activation in the first place. Figure 5 shows that none of the views of emotion deal with the memorial representation of information that allows the stimulus input to be classified in a way which would produce emotional responses at either the conscious or the autonomic level. This lack of concern with the memory representation of emotion is surprising in light of the current wide interest in mental operations and their representation. But it should be pointed out that prior to Bruner's 1957 paper which began the trend to see perception as a process of classification, most psychological views of perception focussed on the conscious content, not on the problem of how an input would be classified.

Recently Schacter (1962) has shown that the cognitive labelling and interpretation of autonomic states has very important effects upon the behavior of subjects in emotion-arousing situations. Schachter simply does not deal with an explicit enough processing model to tell us at what level this cognitive component is aroused.

Only Herbert Simon (1967), among recent theorists of cognitive psychology, has specifically discussed the role of affect in an information processing system. He argues that it has two purposes.

TRADITIONAL VIEW

Input ⟶ Conscious Percept ⟶ Autonomic Activation ⟶ Behavior

JAMES - LANGE VIEW

Input ⟶ Autonomic Activation ⟶ Conscious Percept ⟶ Behavior

CANNON - BARD VIEW

Input ⟶ Thalamic Activity ⟶ Conscious Percept ⟶ Behavior
Thalamic Activity ⟶ Autonomic Activation ⟶ Behavior

Figure 5.

Various views concerning the processing of emotion.

One is to serve as a means of determining when a particular problem solution is satisfactory. The second is as an interruption mechanism. In this role affect allows a "serial processor" to respond to urgent needs in real time.

Unfortunately, Simon had an implicit view of human information processing which rises primarily out of verbal accounts of subjects in the process of problem solving. He conceived of the human as primarily a serial processor of information. For this reason, emotion, which appears to arise outside of the serial process and to intrude itself upon the serial processor, seemed to be a very special type of information processing activity. This view of the uniqueness of emotion as a dimension of information processing is one that is rather widely held either explicitly or implicitly.

There is a moderate amount of empirical literature which supports the view of emotion as intruding upon conscious activity. Some of these data arise from studies of subception (Lazarus and McCleary, 1951). These studies showed that the threshold necessary to evoke an emotional response (GSR) to a stimulus was lower than that required for a verbal response. One implication of studies of this type was to suggest that emotional responding to a stimulus could be obtained prior to the conscious awareness which leads to the verbal report of stimulus identity. Unfortunately, these important studies of subception were flawed by the difficult problem of relating the continuous GSR thresholds to the discontinuous verbal identification thresholds. A similar difficulty has plagued more recent efforts (Wickens, 1972) to establish that emotional dimensions are encoded prior to those involved in semantic interpretation.

Perhaps the most impressive evidence favoring the availability of emotional reactions outside of the serial processor are recent studies by Corteen and Wood (1972) and von Wright (1974). In these studies subjects are required to shadow a message presented to one ear by speaking back the words as quickly as possible. At varying points in their task, words on the other ear which have been paired with shock previously are exposed to the subjects. There is clear evidence of the emission of GSR responses at rates of shadowing which normally exclude the subject's ability to report semantic information coming from the unattended ear. Moreover, in the work of von Wright, it was shown that the size of the GSR response on the unattended ear was as great as on the attended ear.

At first, these findings with regard to emotions seem to confirm the special role which Simon has suggested for it. However the general analysis of semantic processing has also been changing rapidly. It now appears that most of the habitual processing involved in the extraction of meaning from auditory or visual words does not require a conscious search process. Rather, the perceptual input can be seen as contacting its representation in memory in an automatic and parallel fashion (Keele, 1973; Shiffrin, 1974; and LaBerge, 1974). The limited capacity conscious processing system often enters the picture only late in the process of comprehension (Conrad, 1974; Posner and Snyder, 1974). For example, it has been shown that an ambiguous word will activate representations in the memory system corresponding to both of its meanings, even under cases where context clearly produces conscious awareness of only one of the two meanings. Moreover, words presented on the unattended ear may have the effect of contacting semantic units in memory (Lewis, 1970) and of disambiguating information presented to the attended ear (McKay, 1973).

The new views of language perception are hierarchical in that a word will successfully contact its phonological, phonetic and semantic representations. This process may go on entirely outside of the subject's conscious awareness. Thus, the evidence that emotion can be released without awareness of the input item which caused it cannot be used to establish a difference between evaluative and other semantic dimensions.

Despite our better understanding of the relationship of conscious attention and memory, we are left with no clear answer to the question about whether emotions differ in their representation in memory from other semantic dimensions, and if they do, how they differ.

Evaluative meaning of words

There has been a substantial empirical literature studying the acquisition and utilization of the evaluative meaning of words and objects. For example, it is known that a classical conditioning procedure may be used to transfer an emotional response from either an unconditioned stimulus or one which has already been conditioned to a presently neutral stimulus (Statts and Statts, 1957).

The bulk of recent investigations of emotion and its memorial representation have involved the emotional connotation of trait descriptive adjectives. Asch (1946) investigated the impressions which people formed of others based on a series of adjective traits describing a given person. This has led to a long series of experimental investigations (Anderson, 1972) in which people have attempted to form deliberate impressions of others from listening to a set of trait descriptive adjectives. It is clear from these studies that people can form such impressions. Moreover, Anderson and Hubert (1965) have argued that the storage of such information is separate from the specific set of adjectives by which this information is conveyed. The basis for Anderson's view is that if asked to recall the adjectives in a given list, the subject shows a relatively strong recency effect, but if asked to rate his overall emotional response to the person, the primacy effect is stronger. This evidence for a difference in storage systems is relatively weak for two reasons. First, the experiment forces a subject to concentrate his attention upon the development of an impression. Yet, as we have seen above, the more interesting cases of emotion are those in which emotion seems to intrude upon a person rather than being constructed deliberately by him. Second, the data from free recall certainly argue that the exact serial position obtained from a list of items will depend not only upon the memory system used but also upon the length of time between the presentation and recall and the exact form of the recall process. Thus, the difference in serial position curves between impression formation and free recall really provide relatively little evidence on the nature of the storage systems by which the emotional information is stored.

The conscious nature of the impression formation task is evidenced by the work of Diller (1969). In much previous work (Kahneman, 1973) it has been shown that the conscious attention or effort invested in a stimulus will manifest itself in interference with other high priority tasks which the subject may be given. We have argued elsewhere that this interference effect can be used to measure the use of a limited capacity processing system in the solution of the task problem. Thus, if a subject is given a single letter followed after one second by a second letter to which he is to respond "same" or "different", the interference to a secondary task is time locked to but preceeds the presentation of the second letter. The encoding of information from the first letter is time locked to the first letter. Diller (1969) showed how these same principles applied to the process of impression formation as usually studied in the laboratory. He found that when pairs of adjectives were inconsistent in the impression they give, subjects invest a good deal more energy in the process of deriving an overall impression. These results give additional comfort to the efforts to study the process of impression formation within the general rubric of an information processing theory and by methods developed in information processing psychology.

One of the most fruitful paradigms to study the level of representation of information is the short term memory scanning task developed by Sternberg (1966). Sternberg and others have used this task to separate out several processing stages through which a subject goes in arriving at the judgment of whether an item was a member of a just immediately preceeding list. While there has been a good deal of dispute about the details of this model, it seems to be a good place to start in trying to determine what it is about emotion which might affect the ability of subjects to extract factual information. By use of this task, then, we seek an understanding of the level at which emotional information makes its impact upon the decision about a factual matter, namely the presence of a word in a just previously presented list. After testing a number of models in this very short term memory situation, we then ask how emotional information compares with specific item information over time. It might well be expected that the retention characteristics of emotional information would differ from that of specific items.

Retrieval of item and value information

In order to observe the relationship between the emotion and item information, we provided subjects with three kinds of sentences. The sentences always consisted of a single proper name followed by one, two or four adjectives. The adjectives might be all positive in emotional tone, all negative in emotional tone, or a mixture of positive and negative tones. The words were selected from nouns provided by Anderson. Following the sentence subjects were given a single probe word. On half the trials the probe matched one of the adjectives in the sentence, and on the other half it did not. Subjects were to respond as rapidly as possible whether the item in the probe matched an item in the sentence.

The basic results of the experiment are quite simple. For "yes" responses reaction times did not differ for positive, negative, or neutral lists. This evidence seemed to indicate that the emotional tone of the list was having no effect upon the subject's judgment. There was one indication of a difference between the lists. The neutral list showed systematically greater errors as the size of the list became longer, whereas the positive and negative lists did not show such a systematic increase with list size. Presumably something about the consistent tone of the list and the fact that it matched the tone of the probe was helping the subject to avoid making errors.

This effect can be seen more closely by examining the "no" responses. The "no" responses may be broken down into two types, those in which the emotional tone matched the list and those in which it did not. We compared the two different kinds of "no" responses averaged across conditions where the list was positive and where it was negative. This is a particularly sensitive comparison since the probes are the same in both conditions. The results show a small but significantly faster reaction time when the emotional response is opposite to that of the list than when it is identical. This is accompanied by a small but significant reduction in error when the emotional response did not match the list. While the difference in reaction times between matching and mismatching "no" responses does not change as a function of size of the list, the error differences change sharply as a function of size of the list. When the list consists of four items, there is a much higher probability that the subject will make an error where the emotional response matches the list than when it does not match.

What do these results tell us about the relationship of the item information and the emotion? They provide some constraints which can be used to reduce the set of applicable models. But they do not provide by themselves a very clearcut model.

First, consider the fact that the emotional tone has some effect. All previous studies of trait descriptive adjectives have deliberately set the formation of an impression as the subject's task. This experiment did not. Indeed, a match in emotion is not a reliable cue in the neutral condition and would produce only .75 correct responses in the positive and negative conditions. Yet, there are clear effects of the impression on the task. It is clear then that the impression can be learned "incidentally" in the sense that no deliberate instructions need be given. Introspective reports from our subjects say that they are aware of the fact that the names often had a positive or negative connotation. It would be interesting to reduce the cue validity still further.

Given that the emotional response has some effect, one possible model would be to suppose that subjects first tried to base their reaction upon the emotional response and only then if that failed, turn to the item information. Thus, when the emotional tone mismatched they could respond quickly because that is a valid cue to a "no" response. This model clearly will not do. If the subjects first compared the emotional response of the probe with the list, it would be expected that the reaction time to "no" responses which differed in emotion would not depend upon set size, producing a flat relationship between emotion and set size. This is clearly not the case, and is sufficient to reject the idea that subjects attend first to the emotion and then do the processing of the item information.

A more likely model may be to suppose that each word consists of a constellation of emotional and item information. Thus the adjective "pleasant" is associated directly with its denotative and connotative meanings. In this view, a probe word may be rejected as matching any array word more quickly if the mismatch involved both item and emotion than if it involved only item information. Lively and Sanford (1972) have shown exactly this model applies when a subject receives a list consisting either of digits or of consonants, and is given a probe which is from the opposite category. The category information serves to reduce the slope of the response in a way which would be predicted if the category and item information were searched as an integral whole. This model clearly does not apply to our present data, since the slope of the "no" responses to mismatching emotions is at least as great as for matching emotions.

Next, let us consider a model proposed by Atkinson (1973). In this model subjects are thought first to derive a familiarity constant which says "How familiar is this word?" If the word is either very familiar, or very unfamiliar, subjects can respond quickly. If the word is in the middle, subjects must then search the item information. In one previous study, Atkinson and others considered whether emotional responding would affect reaction times in a task quite similar to the one being described here. In thdr task, subjects memorized a list of 16 words and were required to pair some of the words with a highly positive previous life experience and other words with a highly negative previous life experience. The remainder of the words were not paired with previous life experience. The results of their experiment showed that reaction times paired with a positive or negative life experience were both faster than those paired with no previous life experience. The authors concluded that the emotional pairing produced a stronger familiarity response for words which have a clear emotional tone than for those that do not. Their failure to get any difference between positive and negative emotional tone is similar to the results of our own experiment. However, since set size was not manipulated, they were not able to conclude exactly where the emotional tone manipulation was having its effect.

If in the current experiment the emotional tone was having its effect on the recognition process, one would expect that words highly positive or highly negative in emotional tone would produce more recognition responses than neutral words. Thus, one would expect subjects would be faster regardless of whether the response was yes or no to words which were highly charged in emotion. This is not the case. Thus, it does not appear that our effect is due to increased familiarity of positive or negative words.

In their Loyola Symposium paper Atkinson and others suggest that the slope of the responses to probes which are outside the category of correct response serves as a measure of the degree of semantic analysis required prior to contact with information representing the category of the probe. There is considerable empirical support for this idea (Lively and Sanford, 1972).

Both the reaction time and error data obtained from our experiment seem most consistent with the following analysis of the relation of emotional response to the item information. Suppose there are two independent memory structures. One memory structure consists of a list of the names of the words which the subject has read in the sentence. The other memory system consists of an automatically abstracted impression based on an integration of the information presented by the individual adjectives. The search of the memory structure representing the names of the item would increase in reaction time as a function of the number of items in store.

On the other hand, the impression would tend to get stronger as we increase the number of items on which it is based, and one might expect a reduction in reaction time. Since in our experiment judgments based on the emotional structure would only be reliable for mismatching "no" responses, one would expect errors to pile up for "yes" and for matching "no" responses when the output of the emotional structure occurred prior to the output of the list structure. This would account for the high error rate with four item arrays.

To test this idea for a deliberate impression, we performed an experiment in which subjects received the same lists as described previously, but were asked to determine if the probe item had the same emotional content as the previous lists. Two kinds of positive responses arise. First are responses to those probe items which were identical to the ones in the previous list, and second those which were not identical but shared the emotional tone.

The results favor a two-process view of the matching task. The role of the number of items is to increase the reaction time for those items which match but to reduce it for those which mismatch. The two functions come together at about four item lists.

In brief, what seems to happen is the formation of two memory systems, one consisting of a list of item names and the other consisting of a generalized emotional response to the items. These separate memory structures appear to be oppositely affected by item length. The data seem most consistent with the view that each memory structure has an output to the binary decision. In cases where the two decisions agree there seems to be relatively little effect on overall reaction time or errors. In cases where they disagree, however, there appears to be a lengthening of reaction time as if there were some tendency to make the conflicting response. However, the tendency seems slight unless we let the times for the output get very close together. In that case there seems to be a very difficult decision to be made and a high probability of error.

These data then seem to agree ~~with~~ the view of two separate memory systems laid down by the list items. It seems to be of interest to ask what happens to these choice systems as the retention interval gets long and as learning increases. We turn to this question in the next section.

Long term memory

There is in the psychological literature a number of studies which compare the retention of specific item information with the retention of more abstracted information which stands for a set of items. Much of this literature has random dot patterns to serve as the item instances. The subjects are required to classify a set of patterns into a category. They seem to abstract from that a prototype or central tendency which comes to stand for that category (Posner, 1969; Reed, 1972). We speculated that the abstraction of emotional information and its storage in terms of a central tendency would obey somewhat the same laws as that found in the previous work with patterns. To study this we set up an experiment in which the subjects had to learn a list of ten adjectives associated with each of 6 proper names. On each of four successive days, two types of trials were given, list trials and name trials. On list trials subjects were given a list of four adjectives selected from the ten associated with that name and were then probed with an adjective which was either from that list or not associated with the name being tested. On name trials the subject was merely given the name of the person that was being tested, followed after the same retention interval by a single probe adjective. On the name trials we attempted to assess the long term memory structure which represented the set of items associated with a person's name.

Our results were puzzling. Looking first at the development of long term memory structure, we found a rapid decrease in reaction time and a rapid decrease in error as subjects learned to associate a particular set of adjectives with a person's name. Relative difference between "no" responses to adjectives which matched in emotional tone to those which did not was very large, much larger than in short term memory, and remained constant over days. Apparently the subjects very quickly learned to represent a particular name by an emotional value which could be used to quickly reject probes not matching in emotional value. This gave enormous reaction time and error differences.

However, for list trials the picture was a bit different. If all days are combined the overall results from list trials resemble very closely those obtained in the previous experiment. That is, there is longer reaction time for list trials in which a subject must say "no" to material of like emotional tone than to which he must say "no" to material of unlike emotional tone, and a concomitant difference in errors. However this difference was not apparent during the first and second days of learning, but only during the third and fourth day. Moreover, the effects were much larger in the third and fourth day in this experiment than they were in the previous study.

These results suggest that as the long term memory structure develops, the tendency of subjects to base their short term judgments on emotion is increased. This finding may have one or two different implications. One possibility is that the use of the name trials induces subjects increasingly to pay attention to the emotional valence as a means of representing the list that they had just received. Thus, the use of the emotional dimension would be a conscious strategy. Another possibility is that as a long term memory structure develops, the presentation of a list of items from within that structure automatically elicits the emotional value attached to the original name. Thus, once a particular emotional tone is attached to a name, it might be expected that subjects' ability to divorce judgments from that emotional tone would be impeded. In the next section we examine this possibility.

Transfer

In order to determine the ability of subjects to deal with separate short and long term memory structures we ran the following experiments. We trained subjects to develop positive or negative long term memory structures for each of six names. After this had been done, they were informed that they were to be given either the old name or the name together with a new list of traits. On the name trials subjects were much faster to probes which were of a different emotional tone, indicating that the training was successful. However, on list trials there was no effect of whether the emotional tone list matched the long term memory structure of the name. That is, subjects were able to separate the emotional tone of the new list from that of the long term memory structure with no cost.

The failure to obtain automatic transfer effects was surprising to us. We thought the subjects would be unable to search the list without showing some effects from the long term memory structure. Their ability to isolate the two suggests that most of the effects of emotion in our long term memory studies were due to a conscious strategy and not to automatic access to the long term memory information.

Summary

Our experiments showed that a list of adjectives may leave an impression of the overall emotional tone even when there is no instruction to develop one. This impression is accessed at a fairly high level of processing equivalent to other semantic associations to a word. Moreover, the adjectives combine to leave an overall impression which is accessed as a whole and which increases in strength as a function of the number of like toned adjectives.

The emotional tone is a particularly salient aspect of long term memory as the reaction time to different toned adjectives are very much faster than those to like tone. On the other hand, the emotion does not seem to transfer to affect search of new information which is provided about the name. Further transfer experiments are needed to determine more about the way in which emotional tone affects various kinds of judgments.

Motor Control

Work in information processing stages has contained an implicit assumption that limited capacity processes always intervene between the presentation of a stimulus and the emergence of a response. While it is often acknowledged that various processes on the perceptual end may go on in parallel and without interference, it is usually assumed that before a voluntary, overt response may emerge, some sort of limited capacity process must intervene. On the other hand, the literature concerned with the study of skilled performance has suggested that highly automated sequences of activity involving responses which the subject has made habitually may go on without the involvement of attention. For example, Posner and Keele (1968) suggest that stereotyped responding does not require attention, except when one needs to correct errors between the motor program and the movement,

There have always been reasons to doubt that the activation of overt responses necessarily requires attention. One reason for this doubt is the relationship between the time for responding and the amount of information in the stimulus. The usual finding that reaction time increases with amount of information has been used to affirm the notion of a limited channel capacity in certain tasks. However, there have been tasks found in which the subject's reaction time does not increase with the number of alternative stimuli. For example, if the subject's hands rest on vibrating keys, Leonard has shown that pressing the key underneath the vibrator is not affected by the number of possible vibrators which might occur. This might be thought of as a very special situation, except a similar result has been obtained in a task in which the subject is involved in naming letters or words. Here the number of different letters or words which might occur does not seem to affect the rate of information processing. In some sense, this appears to be a kind of functional reflex in which the stimulus and response relationships are so "compatible" that no search process is necessary to emit the response. These highly compatible responding systems may be free from the requirement for attentional capacity in order to initiate the response. Another case in which responses do not seem to require attention for their initiation is found in studies of shadowing. GSR responses to words which have previously been paired with shock can occur on a channel to which the subject is not paying attention.

Thus, there are many reasons to suppose that responding may not necessarily require attention. Instead, one may hold the view that stimulus-response relationships represent one level of information processing, while conscious attentional processes represent an entirely different level of processing. The relationship betwen these levels needs to be specified by an analysis of the particular task configuration, but no particular mental operation is restricted from occurring without the involvement of attentional capacity.

This sort of analysis also fits with results emerging from the new ability to record from single cells in freely moving animals. For example, Evarts has shown that EMG and pyramidal activation can occur in some cases within 50 msec of stimulation. Thus, the signal is transfered from sensory input to motor output at a very rapid rate. Similar results have been obtained in the eye movement system by Wurtz, who shows that rapid adjustments in collicular cell activity can occur when the subject is required to move his eyes to a stimulus. These ideas have led Evarts to propose a notion of cortical reflexes, in which the cortex is involved in the control of the movement pattern, but it does not seem to be involved in a way which gives rise to attention. Because of the ability of motor programs to be contacted directly from input without the necessity for attentional processing to intervene, it now becomes much more interesting to study the structure of such motor programs. Under this grant two main papers were written in this area, and a third line of research has not yet produced final results.

Motor programs

The first paper was presented by Keele at the meeting of Attention and Performance V. It deals with the way in which motor programs consisting of a number of simple elements may be represented in the nervous system. In a sense it is an effort to respond to Lashley's old question about how the serial order of events is controlled. The paper defines the representation in memory that guides a sequence of actions in a well learned skill as a motor program. One hypothesis about motor programs posits that successive events are associated. The occurrence of one event prepares a person for the event that normally follows it. Another hypothesis posits that successive events are associated with successive positions in the program. These hypotheses were tested by comparing reaction times to the first event back in sequence following an event that was out of place in sequence. In one condition, the first in sequence event was the one that normally would follow the misplaced one. In the second condition, the event following an out of sequence one was one that normally would occur at that position in the sequence regardless of the preceding event. The former condition resulted in faster reaction times at short response stimulus intervals, suggesting that motor program representation consists of event-to-event associations, at least for unpatterned sequences.

The method that Keele has developed here may allow a better understanding of the representation of complex sequences of activity. The key to this understanding is that short response-stimulus intervals should demand that subjects use natural associations present in the motor program, but with long response-stimulus intervals they may generate alternative hypotheses at higher levels of processing. Just as in the study of levels of processing in perception, it may be possible to distinguish here between the kinds of representations that are implicit in the already existing motor structure and those which are not. In order to do this, Keele hopes in future studies to build in patterns of events which have higher level grammatical structure. If the grammatical structure is represented in the motor program itself, then it should show up even at the briefest response-stimulus intervals. However, if the grammatical structure is somehow used to correct the already existing motor program, then it should not be evidenced at short response-stimulus intervals but only as additional time between stimulus and response gives the possibility of the subject to bring to bear context information. Although this work is closely related to that of Restle, the use of highly skilled responding and the careful measurement of time may allow us to piece apart levels of processing in a way in which the Restle work has not so far done.

Visual and kinesthetic components of skill

A second paper produced under this grant represents the work of Raymond Klein. This work is an attempt to bring together physiological and behavioral results in the study of movement control. In particular it examines the control of movement which is exercised by the attentional system. The general idea comes from our previous work in attention and implies that many different input codes arising from a movement may be influential in the control of the movement at some level. However, should the subject commit himself to the conscious processing of a particular code, there may be an important inhibitory consequence upon other unselected codes. The current paper explores this theme by studying the role of visual and kinesthetic codes in the acquisition, initiation and control of movement.

The paper can be inspected as a whole as it will be published shortly in Brain Research, but some idea of the nature of the findings can be obtained from the following summary.

The performance of skilled movements gives rise to several sources of feedback. It is important to determine whether and at what level these cues are used. This article considers those used at the highest level of conscious control. Several experimental techniques are outlined to investigate the role of attention in the processing of visual and kinesthetic cues during the acquisition, initiation and control of movements.

The mere presence of a visual pattern disrupts the acquisition of a kinesthetic pattern, while the presence of a kinesthetic pattern does not affect the acquisition of a visual pattern unless the subject is forced to attend to the kinesthetic information. In the initiation of simple movements, kinesthetic cues seem to be ignored when visual cues are present, even though this delays initiation. These results support the view that vision dominates kinesthesis at the level of central attention.

Attentional mechanisms may be involved in the initiation of discrete movements. Within the context of a continuous tracking task anticipated corrections appear to demand more attention than those which are not anticipated.

Eye movements

Because of our interest in the study of more natural responding systems which can be closely related to perceptual input, a substantial effort has been made in the study of the control of the eye movement system. Eye movements are measured by electrodes placed on the temporal aspect of each eye, thus allowing us to obtain changes in electrical activity due to horizontal movements.

Our experiment involves having the subject examine a central fixation point which consists of a single letter. After half a second a matching letter occurs at one of three positions either to the left or to the right of fixation. In one condition the subject's task is to move to any letter which occurs. On half the trials the letter which occurs happens to match the input letter, while on the other half of the trials it does not. In another condition, the subject is required to determine whether the letter matches or not, and is instructed to move his eyes only if the letter matches in one subcondition, and only if it mismatches in the other.

The logic of this study is as follows. Our results have indicated that when a pathway is activated, a letter sharing the same pathway will reach the central attentional mechanisms more quickly than one which does not share the same pathway. Thus, we expect matching letters to reach attentional mechanisms more quickly than mismatches. For this reason overt finger responses which involve matching are more rapid than those which involve mismatching. We expected the same results for voluntary eye movements which require the subject to determine first whether the signal matches or mismatches. When the subject was instructed to move only to matches he obtained faster reaction times than in the mismatch trials for letters which occurred close to the fixation. On the other hand, for positions further out there was a tendency for mismatches to be responded to more quickly. Unfortunately this trend toward an interaction left us without a sufficient amount of data to guarantee the significance of the results. Thus, we are not sure whether pathway activation is limited only to those things which occur near the fovea. If this is true, it will in itself be an important finding.

If we had found clear results that matches were faster than mismatches for eye movements which required the subject to make the distinction between the two, it would then become interesting to ask whether matches are different than mismatches when the subject need not make the distinction. If the eye movement system is controlled by mechanisms which are different than those controlling attention, the fact that matches arrive more quickly at the attentional mechanisms than mismatches may not affect the eye movement. Our preliminary results show that the reaction times when the subject need not make a distinction between matches and mismatches are rapid (between 150 and 180 msec, as compared to between 400 and 450 for those which require the distinction), and that there is no difference between moving to matching and mismatching letters. However, further analysis will be necessary in order to substantiate this result.

Summary

Woodworth began a program of research on movement which sought an understanding of the nature of voluntary as distinct from reflex control. Although progress has been made in understanding some aspects of movement control, there have been few efforts to explore the light which movement control can shed upon the nature of volition. Recent advances in the psychology of attention during perceptual tasks, many of which have been reviewed in this paper, coupled with the rapid progress that microelectrode techniques have made in physiology, seem to us to offer promise of fresh advances in the direction of understanding the role of conscious attention in the control of human movement. But in order to do so, a further analysis of voluntary and involuntary movement control, and a better understanding of the structure of motor programs, will be necessary. These results obtained in our studies seem to provide a preliminary basis for such an analysis.

Attention

The major contribution of research under the current grant is our effort to understand the role of attention in the processing of tasks. We have attempted to apply a new method which is called a cost benefit analysis to the understanding of the process of attention. Our main focus is the question of conscious attention and how it might be separated from more automatic types of processing. But we have also applied the same analysis to problems such as the study of alertness and stimulus and response set and their role in attention. In previous work we have distinguished between three components of the process of attention. These are alertness, selectivity and conscious attention. The cost benefit analysis provides one means for the study of these components of attention.

Theories of attention

Information processing theories of attention have been proliferating lately. It is difficult to characterize the many different theories of attention which have emerged in the last several years. However, one dimension on which theories tend to differ is the role which they assign to the inhibition of unattended items as compared to the facilitation of attended items. Some theories of attention, for example the filter theory of Broadbent (1958), the attenuation theory of Treisman (1970), and the lateral inhibition theory of Walley and Weiden (1973) place emphasis on the inhibition of unattended messages. A process in the nervous system at some level blocks the processing of unattended material, and thus prevents it from getting access to higher levels of analysis. On the other hand, there are also theories which stress the facilitation of attended information. For example, the analysis by synthesis view made popular in Neisser's 1967 book, and Donald Norman's pertinence theory (1969) both stress the facilitation that occurs when an item is given attention.

Empirical techniques have been used to examine both of these types of theories. For example, the effect of set on perceptual threshold has been used to study the facilitation which occurs when a subject is expecting a given stimulus. On the other hand, the psychological refractory period studies emphasize inhibition of signals which occur during the reaction time to a prior signal. These experiments have been carried on more or less separately and have not been brought together into any single paradigm.

Recently theories which represent a combination of facilitation and inhibition in the processing of signals have been presented. For example, Broadbent (1971) discusses a combination of inhibition and facilitation. The inhibition is an early stage in the processing and filters some aspects of input from being represented in sensory evidence. On the other hand, pigeonholing represents a facilitatory process which occurs when a particular category state has been preactivated by context. Kahneman (1973) presents a theory which involves undifferentiated units which can be allocated to one or another task. This view seems to suggest a symmetry of facilitation and inhibition since units given to one task are withdrawn from another. The particular view which we will emphasize is one that has been outlined most thoroughly by Keele (1973) and by LaBerge (1974). This view discusses two different mechanisms in the processing of signals. The first is an automatic lookup of information about the signal in the memory system. This automatic lookup provides access to the habitual pathways which relate an input signal to memory systems. A second and quite separate system is of more limited capacity and is closely tied to our ability to be aware of and apply effort to the processing of a signal. The idea is that any input signal, for example a word, will automatically activate internal units representing its physical form, its name and its semantic character. The activation process of such units was discussed in Section 1 on pattern recognition. This activation process is automatic in the following senses: (1) it goes on even without the subject's intention, (2) it does not require any conscious awareness on the part of the subject, and (3) it is parallel and without interference. A number of our studies have been involved in showing this characteristic of automatic information processing.

Automatic processing

Warren (1970) used the Stroup effect to show the widespread characteristic of the activation pattern of words. He presented subjects with triples of words aurally, such as oak, maple and elm, and followed this with a single visual word. The subject's task was to name the color of ink of the word. In his 1970 paper Warren showed that the time to name the color of the ink of a word which was in the previous list or was a category to which the words on the list belonged (e.g., tree) was greatly increased over control words. The interpretation is straightforward. When a word has been preactivated in the nervous system, the visual pattern which makes the base of the Stroup item will contact that pathway more rapidly and will deliver an output to the response system more quickly, thus interfering with the ability of the subject to name the color.

Under this grant Warren has greatly extended and elaborated this result. He showed that a single word will activate items according to the strength of their associations in word association norms. Moreover, Warren showed that only the forward association from the auditory word to the subsequent visual word mattered, not the backward association from the visual word to the previous auditory word. This is an important finding, since it follows from the theory which Warren used to account for his data. Notice that this experiment does not give the subject any incentive to activate related words. In fact, many subjects become aware during the experiment that a word which is related to the one they have received aurally gives longer reaction times. However, their efforts to avoid this delay are not successful. Thus, these results suggest that a word automatically activates a large number of different items in the nervous system. Presumably this is the basis for the finding in memory that subjects will sometimes falsely recognize associates to a word which has been presented in a running recognition experiment (Underwood, 1965). Warren's results also show that the activation pattern occurs without the subject's intention.

Conrad (1974) also working under this grant extended Warren's notion by using ambiguous sentences. She presented sentences to her subjects which ended with an ambiguous word. The ambiguity of the word was either disambiguated by context or not. Following the aural presentation of the sentence she showed her subjects a single visual word which was printed in colored ink. The subject's task was simply to name the color of ink. In agreement with the Warren effect, she showed that the time to name the color of ink was longer when it was related to the sentence. This was true both for the word itself and also for words related to either one of the two meanings of the sentence. The size of the interference effect was approximately equal whether the sentence had been disambiguated by context or not. These results are shown in Table 1. Since the sentences which were disambiguated by context are consciously perceived in only one way, the fact that both meanings of the ambiguous word are activated is clear evidence that the activation pattern is not dependent on the subject's conscious percept.

Cost-benefit analysis

These results led us to a more explicit statement of the theory with which we began. The idea is that an input item activates its pathway in the memory system. The activation of this pathway will have facilitory effects for other items which share the same pathway as in the Warren and Conrad results, but will have no inhibitory effects on other items. Thus, as long as the activation process is within the memory system, and does not involve the conscious attention of the subject, it will have benefits but no cost. On the other hand, once the subject begins to commit his attention to the processing of a particular item, whatever benefits occur from pathway activation will be accompanied by significant inhibition or cost. The basis of the cost benefit analysis was first outlined in a paper by Posner and Snyder (1974), in research supported by this grant. The first set of experiments used a matching task. The prime could either be a neutral warning signal or a single letter. It was followed after a short interval by a pair of letters to which the subject had to respond "same" or "different". We manipulated the probability that the prime would match the array, in hopes that the subject's attention would be focussed on a letter prime which was highly predictive, but would not be attracted to a letter prime which was not highly predictive.

In order to obtain the cost we subtracted the neutral prime

TABLE 1

Mean RTs and Their Differences for Correct Color Responses in Each Condition

Display type	Trial type		
	Experimental	Control	Difference
Ambiguous sentences			
Ambiguous word	1044	971	73
Appropriate category Inappropriate category	1015[a]	938[a]	77
Unambiguous sentences			
Ambiguous word	1059	1001	58
Appropriate category	997	936	61
Inappropriate category	993	943	50

Note -- RTs are expressed in milliseconds.

Note -- Difference = Experimental mean minus Control mean.

[a]Since there was no difference between appropriate and inappropriate category conditions for ambiguous sentences, these were combined into a single mean.

from the mismatching prime, and to obtain the benefit we subtracted the matching prime from the neutral prime. We found in general conformity with the theoretical account that when a prime was highly predictive there was very significant cost and benefit, but when the prime was not highly predictive there was still benefit, but this was not accompanied by cost. These results are illustrated in Table 2.

A more interesting prediction from the original theory is an asymmetry in the temporal development of cost and benefit. To study this we varied the interval between the prime and the presentation of the letter array. The theory predicts that due to pathway activation, one should expect the facilitation function to rise sharply from the origin. However, the inhibition will not occur until the subject has been able to bring his active attention to the processing. Thus, it should not occur until sometime later. The results produced good conformity with the theory and are shown in Figure 6.

The remainder of the paper applies the cost benefit analysis to several related tasks. These include both searching for a digit in a field of letters, and trying to determine whether the array includes an animal name. Detailed analysis of these experiments is given in the paper. In general, they provide some conformation of the overall theory, but also raise certain problems with it, as particularly when applied to the digit search task.

Level of inhibition

One important question is the level at which the material is inhibited when the subject's attention is focussed on another item. According to the general theory that we have been presenting, an unattended item is not inhibited except at the stage when it would normally require the limited processing system. Although our own data have not been addressed to this question, a search of the literature discovered an interesting result in a study by LaBerge (1974) not previously pointed out. In this study the subject's attention was focussed either on the visual or auditory modality. In most cases the input signal occurred on the modality to which the subject's attention was called. However, on a small percentage of the trials the item was presented to a different modality. In all cases the subject was required to make a discrimination in order to report which of two stimuli had occurred. An examination of the reaction times showed that in these cases when the signal occurred in the modality to which the subject's attention was called, subjects were fast. In fact, they were about as fast as if they were in a block where only signals of one modality occurred. When a signal occurred on the unexpected modality, subjects were very much slower. These findings were incorporated by LaBerge into a general theory of attention switching between modalities which fits quite well with the type of theory that we have been proposing above. LaBerge, however, did not call the reader's attention to the error rate data but did present them. He found that when the subject

Table 2

Mean Correct RT and % Correct ( ) for the Trial

Types in three Probability Conditions of Matching Task

Response Conditions	N	Yes: + A A	A A A	B A A	Benefit	Cost	No: + A B	A A B	C A B
80-20	12	414 (91.3)	329 (97.6)	450 (60.7)	85** (5.5)**	36* (30.5)**	426 (92.5)	412 (91.6)	400 95.3
50-50	6	429 (95.7)	358 (98.8)	443 (86.1)	71** (3.1)**	14 (9.6)*	443 (94.0)	438 (92.9)	422 94.4
20-80	9	439 (94.3)	408 (97.7)	439 (91.7)	31** (3.4)**	0 (2.6)	447 (92.6)	460 (91.7)	437 95.5

* p < .05
**p < .01

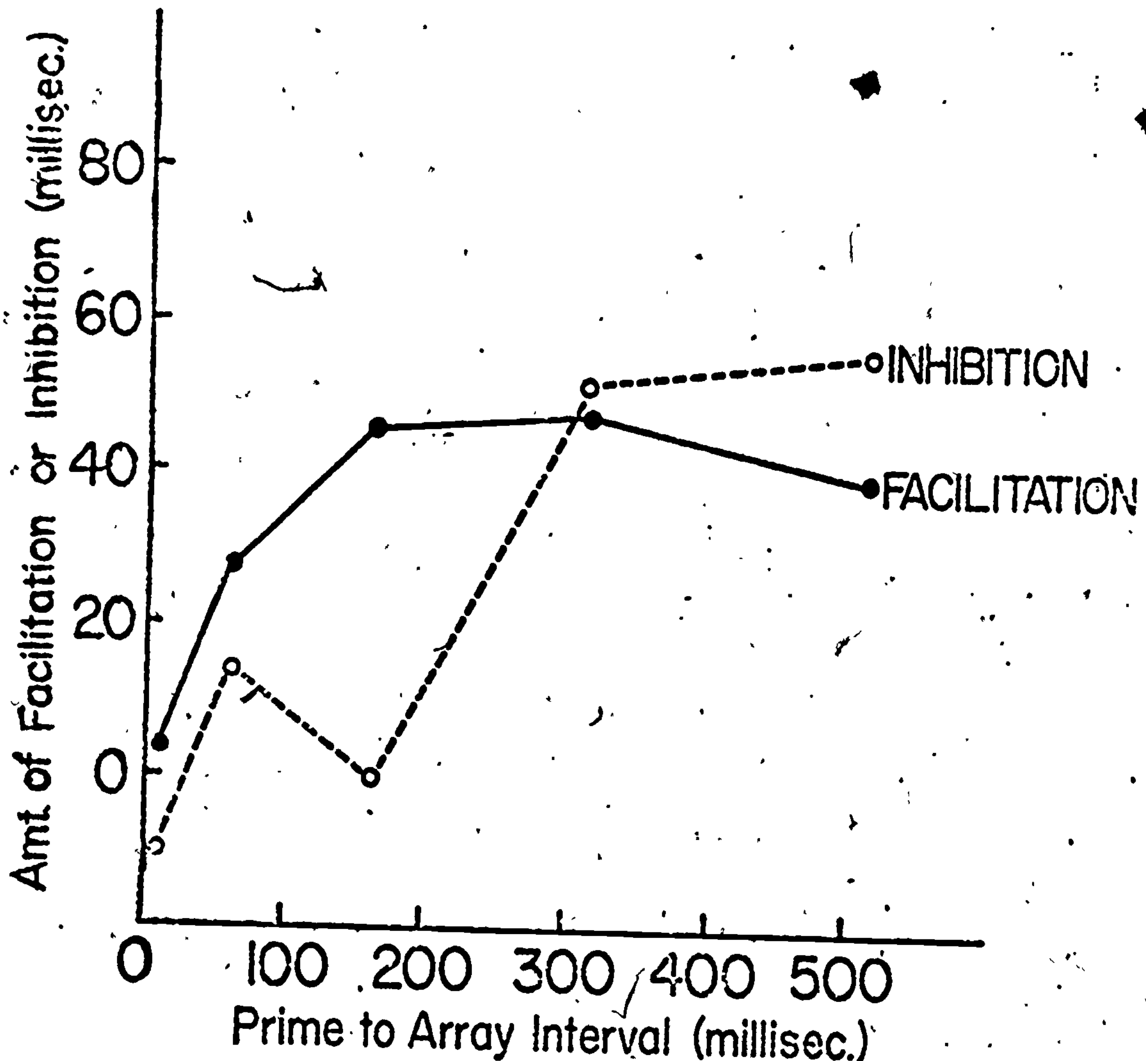

FIGURE 6

The time course of facilitation (benefit) and inhibition (cost) of RT in the matching task.

switched modality he was highly accurate. Thus, presenting the subject with an unexpected signal produced long reaction times but low error rates in comparison with presenting him with an expected signal. The result suggests, though it does not prove, that the buildup of information from the unexpected signal occurred in a perfectly normal way, and thus the delay in the subject's processing it produced a reduced percentage of errors. We hope to pursue this result in future work and report it together with additional explorations of the same phenomenon. It gives every promise of allowing us to determine the level of processing of unattended information.

Response set

In the studies reported previously the cue stimulus never provided information about the overt response the subject was to give. Regardless of the cue, the probability of each overt response remained at .5. There is a large literature on choice reaction times showing the subject's knowledge about the response he is to make greatly improves reaction time and errors when that response in fact is called for. The inhibitory consequences of response set, however, have not been discussed in the literature.

One of our experiments involved eight subjects who were run individually for three days. The subject's task was to classify a single digit which appeared on a trial as to whether it was odd or even. At a fixed interval prior to each trial a prime signal was presented which was on half of the trials a plus sign and on the other half the letter O or the letter E. This was followed after a variable interval by a single digit selected from the digits 2 to 9. The prime letter indicated the correct response on .8 of the trials, and the incorrect response on .2 of the trials. The neutral cue produced a small decrement in reaction time and a small increase in errors. The effect is similar to what has occurred in many tasks when a warning signal is presented. When the prime matched the correct response there was a rapid improvement in reaction time which was significant by 150 msec, and continued to grow out to 500 msec. This was matched by an equally rapid increase in reaction time when the prime did not indicate the correct response. The change in reaction time is accompanied by like changes in error rates. The increase in error with a mismatching cue is particularly pronounced even 50 msec following the prime stimulus.

One finds little evidence of the temporal asymmetry between facilitation and inhibition which occurred in the letter matching studies reported previously. Rather, in this study, there is a rapid and reasonably symmetric change in facilitation and inhibition. In the "response set" study the cue leads the subject to infer the nature of the correct response. The prime cannot activate a pathway which will automatically facilitate processing. For this reason, it might be expected that no asymmetry would occur. It is something of a puzzle that the effects do occur after as brief as a 50 msec interval. It seems likely that the subject has time during the processing of his task stimulus to perform in parallel the operations which will facilitate the correct response, since reaction time in these tests is at least 250 msec. The finding that errors are highest at intermediate values of foreperiod suggests that the response set is most susceptible to error during the time it is being completed. If the task signal arrives while the set is increasing, errors are quite likely. When the set is completed, the effect on errors is somewhat smaller. This is most striking when individual data are examined.

Stimulus set

Treisman and Geffin (1967) have shown that when the word "tap" occurs on an unattended channel it usually does not produce the instructed response, while the same word on the attended channel produces the instructed response on nearly every occasion. A ~~difi~~ different result has been obtained by Shiffrin and his coworkers (1974). In these experiments a subject's knowledge about the channel of entry of a signal does not serve to improve his ability to detect a target nor determine its identity. There are many differences in procedure and method between the work of Treisman and Geffin and that of Shiffrin which may be used to reconcile the apparent differences. We desire to focus not on the details of the method, but rather on the theory that arises out of the two kinds of study. Treisman and Geffin conclude that attention has a very important effect on perceptual processing. The unattended stimulus is so badly inhibited in its effect on the organism that he rarely responds to it. Shiffrin, on the other hand, concludes that attention does not affect perceptual processing, but only later stages dependent upon memory. Much of this dispute may be semantic, but one difference between the two is that Treisman concentrates on the striking inhibition of an unattended message over one to which the subject is paying active attention (cost + benefit in our terms). Shiffrin concentrates upon the lack of facilitation (benefit) when the subject knows the channel of entry over when he is uncertain about it.

There are good reasons for suspecting that the failure to commit one's attention to any channel (the low attending conditions in Shiffrin's work) is very different from attending to the wrong channel (the Treisman and Geffin low attending conditions). For example, LaBergé (1974) has shown that the depth of attention to a channel greatly affects the time to switch to a new source of information. Thus, if the subject is engaged in actively attending to a channel, the effects on the unattended message may be quite different from when his attention is not specifically focussed.

According to our cost benefit analysis, these are quite different aspects of attention. It is altogether possible that stimulus set provides no facilitation of an unattended channel over a neutral control, but at the same time provides inhibition of an unattended channel in comparison with the neutral condition. Conditions for this to occur may be exactly the conditions which reduce the probability that the subject will be able to shift attention to the unattended channel during the time that the message can persist in the nervous system.

We have run experiments to investigate this question. In our experiments the stimulus could either be presented visually or aurally. In the neutral condition the subject never knew which type of signal might be presented. On prime trials he was given a signal which was in the same modality as the later signal to which he was to respond on .8 of the trials, and in the opposite modality on .2. In other words, his attention was directed to a particular channel which matched the channel of the input .8 of the time. The results of our preliminary analysis of these experiments indicate that the benefits obtained from directing the subject to the correct channel were rather small. The exact size of these benefits depends upon the way in which they are measured. On the other hand, the cost involved in directing the subject's attention to the wrong channel was large and stable. Moreover, much of our data, in agreement with the earlier analysis of LaBerge, suggested that the error rate obtained when the subject's attention was on the wrong channel was somewhat lower than when his attention was directed to the correct channel. This suggests that the information is building up from the wrong channel in the normal way and the cost is due to the subject's having to shift attention sometime following the signal.

Psychobiology of attention

It should be clear from our results that our information processing methods lead to ways of analyzing the facilitation and inhibition which occur during the processing of messages in the nervous system. It is natural, therefore, to attempt to link the results of the experiments reported above to findings which have involved recording electrical activity. This is a difficult thing to do because the majority of studies involved in electrophysiological recording have used animal subjects and techniques which are far different than the ones outlined in these experiments. A possible means of linking the information processing literature with humans and the physiological results is through the use of pathological material and evoked potentials recorded from the scalp. As part of this grant I have attempted to examine the relationships between information processing psychology and physiological analyses of attention. The results of this examination appear in a chapter prepared for a new Handbook of Psychobiology. In many cases I have found convergence between the physiological results and those obtained from information processing techniques. Because the chapter is available for examination, I have included only one example in this final report.

What is the mechanism by which a warning signal affects the processing of information from a signal which follows it? A variety of physiological results suggest that the mechanism by which a warning signal works is subcortical. That is, a warning signal leads to an alerting process which presumably involves stimulation of some portions of the reticular activating system. The subcortical nature of this process is most clearly revealed in work with the split brain monkey. The warning signal produces a particular pattern of EEG activity sometimes called the contingent-negative variation. This is a negative drift in the EEG which fills the interval between the occurrence of the warning signal and the signal to which the subject is to respond. If the signal is presented to only one hemisphere in the split brain monkey, the contingent-negative variation is found in both hemispheres. This result suggests that the mechanism is subcortical. However, it does not tell us where the site of action of the alerting response is. Indeed, the contingent-negative variation spreads across the entire cortex. Thus, though the mechanism can be isolated physiologically as involving subcortical activity, the physiological data tell us nothing about how that mechanism functions. Here we need psychological data. Our results suggest that the way the subcortical mechanism works is to affect association area cortex and not primary area cortex. Although our results are only inferential, they do provide considerable enlargement of the physiological hypothesis. The reason that we believe these effects are those of association cortex and not primary cortex is as follows. First, if the subject is presented with a clear long-lasting signal, the improvement in reaction time which follows the presentation of a warning signal is accompanied by either no change in error or an increase in errors. On the other hand, we have shown that a warning signal improves the detectability of a brief stimulus flash followed by a mask (Klein and Kerr, 1974). If the warning signal was improving the buildup of information about the signal, one would expect the improvement in reaction time to be accompanied by an improvement in errors regardless of its duration, as it is when the warning signal activates a pathway related to the following imperative signal. Moreover, it is also found that the improvement in reaction time in the response is not accompanied by any change in the process of pathway activation. As we have pointed out previously, when a subject is presented with one letter followed by a second letter against which he is to match it, the time between the first letter and the second letter is positively related to an improvement in reaction time and errors when the second letter occurs. This is the phenomenon of pathway activation. If one prewarns the subject of the occurrence of the first letter so that the pathway activation takes place when the organism is alert, there is no effect on the rate of pathway activation. Thus, once again we find clear evidence that although responding is affected by the warning signal, the rate of buildup of sensory or perceptual information is not affected. By using a combination of physiological and behavioral data then, we are able to trace out the means by which a particular subcortical mechanism produces its functional effect. Similar results are discussed in the paper for other mechanisms which may be involved in the study of attention.

Summary

In summary, our work on attention has taken several different forms. First, we have attempted to understand the automatic processes which occur outside of the subject's conscious attention. We have shown evidence for processes in the recognition of words which occur without intention, without interference. Second, we have applied our cost benefit analysis to look at the relationship between this parallel automatic process and more limited capacity processes which we believe subserve awareness. Finally, we have examined in some detail the possible relationships between these hypothetical behavioral mechanisms and those obtained from more direct measurements of electrical activity in the brain.

Applications

We have developed two applications related to the research done under this grant. The first of these is an elementary textbook which describes for the introductory student some of the aspects of mental structure. While rather little of the experimental research done under this grant was reported in the textbook, some of the thinking, particularly that incorporated into the first section of the grant, led to the particular organization used in the textbook.

The second application also cited in the bibliography is a course meant for students specializing in cognitive psychology. This laboratory course has a number of features which follow from the analysis of mental structure which we have made. The idea is that it is necessary to convert theoretical ideas absorbed through reading to kinds of mental organizations which will underlie the production of experimental work in the field. To do this we developed a course which takes students in one quarter from an introduction to the nature of experimentation to the point where they are designing and executing complicated experiments. To do this we used the power of the electronic computer. The basic idea is to begin by simulation experiments which can be conducted directly by querying the computer. We start by giving the student an idea of the type of noise present in psychological studies in an experiment which requires them to measure sensory thresholds. We then give the person the idea of the logic of experimental design in a program of research based upon the discovery of the lateral inhibition mechanism underlying the limulus visual system. From this point we transition ~~students~~ from running simulations on the computer to actual experiments. These experiments are programmed under a higher level language called experimentwriter. In a succession of experiments we phase the student out of a mode of operation where he merely fills in parameters in already programmed experiments to one in which he takes an aggressive role in the construction and design of the experiment. The final exam introduces the student to a variety of experimentation using the additive factor method to reaction time. Within this broad outline the student then designs an experiment, programs it, and executes it himself. Osgood, Posner and Lyon (1973) presented a paper at the Fourth Conference on Computers and Undergraduate Instruction outlining this course material.

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