

### 3. MEMORY

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In a very general sense an individual could be said to have memory for an event if his properties were in some way changed by the event. This definition of the field of human memory is far too broad. It includes all of the aspects of what might be called "physical memory" such as the persistence of a scar on the surface of the skin as a result of a previous injury. It also includes what might be called "biological memory" such as the changes in the heart and circulatory system in general that accompany several weeks of a regimen of exercise or "immunological memory" which includes the production of substances within the body that either increase or decrease one's sensitivity to allergens. Finally, the general definition encompasses all types of what may be called "psychological memory," which is a change in the nervous system as a result of sensory, motor, or conceptual experience. No single memory system underlies all these diverse types of memory, and it is unreasonable to attempt to consider them within the same theory.

Furthermore, the various types of psychological memory are not thought to reflect a single underlying memory system. It is probably necessary to distinguish fatigue and adaptation effects as well as "sensory memory" (visual, auditory, tactile, etc., afterimages or persistence of vision, persistence of hearing, persistence of touch, etc.) from what might be called "conceptual memory." Conceptual memory refers to a presumably central memory process that includes in an integrated system both short-term and long-term memory for relatively well perceived events. Memory for pictures, stories, paired associates, serial lists, and so forth are all examples of conceptual memory. Virtually all of the psychology of human learning and memory is concerned with conceptual memory, with a few exceptions, such as the series of studies initiated by Sperling (1960) and others on visual sensory memory and studies by Broadbent (1958) and others on auditory sensory memory.

The present chapter is organized into four

sections: experimental methods, coding, dynamics, and retrieval.

The experimental methods section briefly describes some of the major experimental designs and procedures used by psychologists in the study of memory in human subjects. This section will discuss some of the theoretical advantages to using some of the newer three-phase, probe, and continuous designs as opposed to the older, more confounded designs such as free recall, memory span, serial anticipation learning, and paired associate learning. Also, the greater theoretical simplicity of tests of recognition memory, as compared to recall tests, will be discussed. Finally, the special problems encountered in studying memory in children, especially those with verbal handicaps, will be discussed. Experimental methods which yield data for normal adult subjects that are easier to interpret theoretically may in some cases require the use of instructions that are too difficult for a particular group of handicapped children to understand. In such cases, this may require the use of other designs which do not require such difficult instructions. Alternatively, it may be possible to use the superior design, if sufficient time and ingenuity can be devoted to the instructions to subjects. In addition to the choice of a basic paradigm for studying memory in handicapped children, a variety of other methodological issues will be briefly discussed: session length, rate of presentation, modality of presentation, types of materials, instructions regarding learning strategy, etc.

The last three sections of this chapter present the theoretical principles of memory and discuss possible applications to children with different types of handicaps. In each section, both the obligatory structural (*capacity*) aspects of memory and the optional *strategy* aspects of memory will be discussed.

The coding section is concerned with the logical, qualitative aspects of the representation of memory traces in the nervous system. The retrieval section is concerned with the logical, qualitative aspects of the usage of the

information stored in this memory. The section on dynamics is concerned with the temporal, quantitative aspects of acquisition, storage, and retrieval in the memory system.

The reader should note that this organization differs in some important respects from an organization around the three temporally-distinct phases of memory: acquisition (learning), storage (retention), and retrieval (recall, recognition, etc.). Coding is concerned with the logical structure of memory as it is established during acquisition, as it persists through the retention interval, and as it is used in different retrieval tasks. Similarly, the dynamics of memory is concerned with the temporal quantitative aspects of memory during all three phases: acquisition, storage, and retrieval. Finally, the retrieval section is concerned with only the logical, qualitative aspects of retrieval in different situations (the rules and strategies of retrieval). The quantitative temporal aspects of retrieval are discussed as a subsection of the dynamics section. I believe that this subdivision of the field of memory into three content areas is superior to others in the degree to which the phenomena discussed in each area are independent of the phenomena discussed in the other areas. However, there are still a number of points of interaction between the principles and phenomena discussed in the different sections, and some of these will be pointed out.

In each of the three theoretical sections of this paper, certain principles of memory will be discussed along with some of the supporting evidence. I have decided to present a relatively definite, precise theory of memory in this chapter. It must be emphasized that this is my personal theory of memory. The field is hardly a finished area of scientific inquiry. Other memory psychologists would disagree with many of the principles, and the reader should keep this in mind.

However, a clear understanding of learning and memory can come only from a precise, integrated, and general theory of memory, however wrong some components of that theory may later prove to be. Since such a theory must delineate the separate component processes involved in memory, it directly indicates the variety of different aspects of the memory process that may be selectively impaired in

children with different types of handicaps. Thus, it seems to me to be particularly appropriate to the present chapter to present the important phenomena of memory within such a theoretical framework.

In each of the three theoretical sections of this chapter, a number of possible applications to children with different types of handicaps will be discussed. The types of handicaps discussed include mental retardation, hearing deficits, speech deficits, visual deficits, learning disabilities, and emotional disturbances. Within the theory of memory presented in this chapter, it would seem inconceivable that all of these different types of handicaps would have the same general pattern of memory deficits. The present chapter will discuss certain specific patterns of memory deficits that might be expected for different types of handicaps. In addition, some suggestions will be advanced for the training of children with different types of handicaps.

Even within one of the above categories of handicaps, it is likely that there are a variety of different subcategories of individuals with this handicap that have rather different patterns of memory deficits. The category of "learning disabilities" is probably quite diverse with respect to the reasons for the learning disability (e.g., Sabatino, 1968). Hopefully, the separate components of memory described in the present chapter will provide an index to different possible patterns of deficits in different handicapped children. In addition, perhaps some of the newer experimental methods used in the study of memory in normal subjects can be used to advantage to diagnose the nature of a memory deficit in different handicapped individuals. Finally, one can hope that more detailed and adequate diagnosis of memory deficits, in conjunction with a more adequate theory of memory, will indicate better means of training and educating such individuals.

### Experimental Methods

Whether in a memory experiment, school learning, or everyday learning, there are three distinguishable operational phases of human memory: learning, retention, and usage. The learning phase refers to the period of active study or exposure to the material and

the thinking that may accompany or follow such exposure. As a result of this exposure and the subsequent processing, some change is made in the nervous system. This change is called the memory trace. Following the learning phase, the memory trace must be retained over a period of time (retention phase) until there is some occasion to reactivate and use it (usage or test phase).

In memory experiments it is desirable to be able to alter independently the time and other conditions for learning, retention, and usage of information. However, when many items are presented to be learned, the learning phase for each item overlaps with a portion of the retention phase for previously studied items. When many items are tested, the usage phase for each item overlaps with a portion of the retention phase for all subsequently tested items. It is desirable to distinguish the learning, retention, and usage *phases* of a memory experiment for each item from the learning, retention, and usage *periods* of the experiment with respect to the entire *group* of items. When it is necessary to distinguish these concepts, the terms learning, retention, and usage *phases* will be used to refer to individual items and the terms learning, retention, usage *periods* will be used to refer to the entire group of items. Thus, when many items are presented to be learned, the presentation time for the entire list of items will be referred to as the learning period for the group of items, though this includes both learning and retention phases for individual items. Similarly, when many items are tested, the entire period of testing will be referred to as the usage (test) period, though this includes both retention and usage phases for individual items.

It is of some importance to distinguish the operational phases of a memory experiment from the theoretical phases of the memory process in a human being. To aid in maintaining this distinction, it is helpful to use the terms "acquisition," "storage," and "retrieval" to refer to the theoretical phases, with the terms "learning," "retention," and "usage" referring to the independently manipulable phases of a memory experiment or real-life memory situation.

The principal reason for making this distinction at the present time is the possibility

of a fourth theoretical phase, consolidation, which may intervene between the acquisition and storage phases of the memory process. Although there is some evidence for some type of consolidation process occurring in the formation of human long-term memories, the exact nature of this process is not at all understood. It may be that consolidation can be considered a part of the acquisition phase. Alternatively, it may be possible to consider it as part of the storage phase. However, it is also possible that consolidation needs to be considered as a separate phase of the memory process. Hasty identification of the operational phases of a memory experiment with the "corresponding" theoretical phases could lead to an ignoring of this final alternative for the formulation of the consolidation process.

### Study-Test (Three-Phases) Designs

From the standpoint of achieving independent control of each of the three operational phases of a memory experiment, the ideal design is one in which the conditions for the learning, retention, and usage (test) phases can be manipulated at least somewhat independently of each other. Such a design will be called a three-phase design, though the more common name is probably the study-test design.

*Single-Element Memory.* The design that in many ways comes closest to the ideal three-phase design is that originally developed by Brown (1958) and Peterson and Peterson (1959). In the Peterson and Peterson design, a "single" item (consonant trigram) is presented, followed by a three-digit number which signals the *S* to begin counting backwards by three's from that three-digit number until a signal to stop is given, at which time the *S* is to attempt to recall the single item.

Obviously, this same basic design can be used to study recognition memory where the single item is presented again at the time of test and the *S* is required to say "yes" or "no" concerning whether the test item is the same as the previously presented item. The recognition test could also be multiple choice, involving presentation of two or more test items with the *S* instructed to choose the test items that was the same as the previously presented item.

The item presented could be a nonsense syllable, a word, a tone, a line length, etc., permitting one to determine modality-specific deficits in the memory of any group of handicapped children.

Furthermore, a list of items could be presented during learning with a test of only one of those items after the retention interval. Such a procedure is often referred to as a probe design, but the probe technique can easily be combined with the three-phase (study-test) technique.

The interpolated task need not be backward counting by threes. This would often be too difficult for a handicapped child. In studying the memory of a speech-impaired individual, Shallice and Warrington (1970) used forward counting by ones. Any interpolated activity can be used, including learning more items from a different category or even learning more items of the same category as that presented during the learning phase of the experiment.

There is considerable flexibility in this paradigm, but a little thought makes it obvious that the paradigm is unsuited for the study of memory over very long intervals (hours, days, years). One replication of one condition would take a considerable period of time, and to achieve 50 or 100 replications of several long delays with this technique would be out of the question.

However, for experimental studies of memory deficits over retention intervals from zero seconds to 2 minutes, a single-element or probe three-phase design should be considered first (along with the two-phase probe design to be discussed later). There are many reasons for choosing such a three-phase design deriving from the lack of confounding of the conditions for learning retention and usage. For example, a memory span task (with digits, letters, words, blocks, pictures, etc.) provides one measure which is jointly determined in some unknown way by both acquisition and storage processes, as well as retrieval processes. By contrast, a probe three-phase memory design minimizes the problems of retrieval strategy by requiring retrieval of only a single item. Furthermore, by employing a variety of different retention intervals, one can separately determine the slope and intercept of the re-

tention function. The intercept (measured at zero or some short delay after learning) provides an assessment of the initial degree of learning, and the slope of the retention function provides a measure of the forgetting rate. Furthermore, the design can reveal the separate contribution of short-term and long-term components of the total memory trace (e.g., Waugh and Norman, 1965). A long-term memory component shows up in the form of a relatively flat asymptote of memory performance which is usually reached after a 20 or 30 sec retention interval. One is obviously in a superior position to assess the precise nature of any memory deficit in a group of handicapped children, if he can determine separately the contributions of short-term and long-term memory and whether any memory deficit is in initial degree of learning or subsequent retention (the form of the retention function or its decay rate).

*Ordered Recall (Memory Span).* If a list of items is presented once or several times possibly followed by a delay interval, followed by a test of the *S*'s ability to recall the entire list of items in the correct order, then the paradigm falls within the general category of a study-test paradigm. A short-term memory span test is one primary example of this paradigm, though usually there is no appreciable delay interval.

If many elements are presented in the list to be learned, then a relatively larger proportion of the retention phase may be occurring during the learning period than is the case for the "single" element paradigm. This portion of the retention phase is occurring under conditions that are the same as the conditions for the learning phase, and, therefore, this portion of the retention phase is not independently manipulable.

Furthermore, when many elements are required to be retrieved in the usage (test) period, then the conditions depend upon the speed and manner in which the *S* retrieves previous memory traces. This frustrates experimental control of the test phase to some extent and can make precise analysis of the results considerably more difficult. For example, in a memory span test, if the *S* fails to recall the fifth item in the list, it is difficult to say to

what extent one can then assess the strength of any association or connection to the sixth item in the list, given that *S* failed to recall the fifth item.

When there is no delay interval between the learning and test periods (as in an immediate memory span test), one is completely unable to manipulate the retention phase independently of the learning and test phases. All of the losses that are occurring in retention of an item are presumably occurring during presentation of subsequent items during the learning period or during retrieval of prior items during the test period.

Tests of immediate memory span badly confound the three phases of the memory process, and, in many instances, investigations of short-term memory deficits in handicapped children should employ newer methods. The memory span test does have two compensating advantages which may more than compensate for its deficiencies for certain purposes. First, the test provides an overall measure of short-term memory performance. If a particular investigation is not interested in making finer distinctions regarding the acquisition, storage, or retrieval locus of any deficit, then a memory-span test may be the ideal instrument. Second, the memory span test is a much more efficient (less time-consuming) memory test to administer than the single-element or probe three-phase design or the two-phase probe design. There are two principal reasons for this: (a) the time per trial is usually less because there is no delay interpolated between learning and test and (b) the subject makes many memory responses on each trial as opposed to a single one with the newer procedure. Finally, memory span tests are less complex and more familiar to the subjects, requiring less instructional time and ingenuity, as a consequence.

*Free Recall.* This paradigm is similar to the previous one, except that during the test period the *S* need not recall the items in their correct order, but is simply scored on how many items he recalls irrespective of order. All of the preceding comments apply. In addition, one has no control over the order in which the *S* attempts to recall the items in the lists, and there is opportunity for considerable variation

in the degree to which the *S* attempts to recall the last items first versus the first items, etc. Differences between different conditions may result from their inducing different strategies during the recall phase, as well as, or instead of, differences during the learning or retention phases.

By the same token, free recall has advantages for the study of learning and retrieval strategies such as clustering of words that are associatively related (e.g., Bousfield, 1953 and 1961; Cofer, 1965; Deese, 1961 and 1962). If one suspects that coding strategy deficits play an important role in the learning problems of any group of handicapped children, then free recall may provide a useful vehicle for the assessment of such coding strategy deficits.

*Study-Test Probe.* This paradigm involves presenting a list of items or a list of pairs of items, followed by a retention interval, followed by multiple probe tests of the items or pairs in the previous list. If the learned list consists of items, then during the test period the *S* will be given a series of items, some of which were previously presented and some not, and the *S* is to recognize the items that were previously presented. If the list consists of pairs, either a recognition test or a recall test is possible. In a recall test, the *S* is given one member of the pair and asked to recall the other member. In a recognition test, the *S* is given a pair of items and asked to decide whether the pair occurred as a pair in the previous list. In a pure test of order (associative) recognition memory, incorrect pairs would consist of items that had both been included in the previous list but not together as a pair.

This paradigm is especially useful in the study of long-term memory, because it permits one to present a very large number of items during the learning period and have the delay intervals for all of the items occurring simultaneously. This permits one to develop a reasonably large sample size for individual *S*'s in the study of long-term memory. If one is not concerned about the possible complications involved in averaging results over a large number of different *S*'s, then other paradigms can be used to study really long-term memory

(hours, days, years). However, for the study of long-term memory in individual *S*'s, the study-test probe paradigm is virtually essential.

Under conditions where the retention interval is long in comparison to the time involved in the learning and test period, it is reasonable to assume that the conditions obtaining during the retention interval are the conditions affecting storage and neglect the small contributions to the storage phase occurring during the learning and test phases of the experiment. The use of probe (cue) techniques during the test period eliminates many of the uncertainties and complications involved in the previously discussed multiple recall techniques.

### Two-Phase Probe Paradigms

*Probe Recall.* Two-phase probe recall involves presenting a list of items, followed immediately by a test period in which a single item is presented and the *S* is required to recall the item that followed it in the preceding list. Alternatively, one could present a list of paired associates followed by one of the members of the pair with the *S* required to recall the other member of the pair. The important thing about the two-phase technique is that no time elapses between the learning and test periods. Thus, all of the retention phase is occurring during the learning period, since no separate retention period exists, and only a single trace is tested for recall.

*Two-Phase Probe Recognition.* This paradigm is the same as the preceding one except that, following presentation of the list of items or pairs an item or pair is presented for a recognition test. All of the same comments apply.

Two-phase probe paradigms have proved to be especially useful in the study of short-term memory, because: (a) the paradigm is optimal for obtaining a pure short-term memory trace with no long-term memory component, and (b) the fastest rates of decay of the short-term memory trace have been obtained using this paradigm. Using other paradigms, it is extremely difficult to eliminate long-term memory components (asymptotes) from the study of short-term memory. If one is interested in testing primarily for the presence of a short-term memory deficit in a group of handicapped children, then the two-phase paradigm is ideal.

It provides separate measure of both the degree of learning in short-term memory (assessed by performance on the terminal item or near-terminal items in the list) and decay rate (assessed by the slope of the retention function).

To obtain simple exponentially decaying short-term memory traces, it is necessary to plot the results in terms of discriminability ( $d'$  units—see Wickelgren and Norman, 1966). Furthermore, it is necessary carefully to instruct subjects not to rehearse previous items in the list, concentrating attention only on the currently presented item at all times. Such nonrehearsal instructions are critical for eliminating most of the "primacy" effects in short-term memory for serial lists. It may be more difficult to instructionally control the rehearsal strategies of less mature or less verbal individuals. However, it is fortunate that such subjects typically engage in less rehearsal and show less primacy as a result (e.g., Bernbach, 1967). Whether or not nonrehearsal instructions are given, rehearsal is discouraged by a fast rate of presentation. Rates of presentation faster than three or four words per sec. virtually eliminate rehearsal, even in the absence of nonrehearsal instructions. When the two-phase probe paradigm is used in conjunction with nonrehearsal instructions and/or fast rates of presentation, and the results are plotted in log  $d'$  units as a function of retention interval, then one can separately determine whether any short-term memory deficit is in degree of learning or rate of decay. Alternatively, one might discover for a certain group of handicapped children that their short-term memory functions were of an entirely different form from that found for normal subjects in the same situations.

### Continuous Memory Paradigms

*Continuous Recognition.* Shepard and Teghtsoonian (1961) developed an extremely efficient technique for the study of "intermediate-term memory" (time intervals of 10's of seconds, minutes or hours): An item is presented and a *S* decides "yes-or-no" as to whether the item had occurred previously in the list, then he encounters the next item and makes the same decision, and so on. Each item is therefore a new item to be learned, a delay-

filling item, and a test item. All of the three operational phases of memory are confounded together, which certainly can cause some difficulties in interpreting the results. For example, when one manipulates the rate of presentation under a continuous recognition paradigm, one is simultaneously manipulating the study time, the density of packing interfering items in the retention interval, and the retrieval time.

There are practical reasons why the continuous design is extremely useful in the study of memory for retention intervals from tens of seconds to a few hours. The reasons are basically that these time intervals are too long for use of the single-element three-phase paradigm, but a little too short for easy application of the study-test probe paradigm. However, the latter paradigm can be used to obtain converging evidence on the interpretations of results obtained using the continuous technique.

*Continuous Recall.* A slight modification of the continuous recognition paradigm permits the use of a continuous procedure to study recall. One presents a pair of items to be learned for a certain time period, followed by presentation of a single item with the *S* being required to recall the other member of the pair, followed by another learning pair and then a test pair, etc. (e.g., Atkinson, Brelsford, and Shiffrin, 1967). Such a procedure, though continuous, does not completely confound all of the phases of memory. The time and conditions under the learning portion of each trial can be manipulated independently of the time and other conditions of the test portion of each trial.

Continuous paradigms are extremely efficient. They generate an enormous amount of data in a single session. When contact with subjects is limited to a single session or few sessions and one is interested in assessing long-term memory performance over delays from 10's of seconds to 10's of minutes or hours, then the technique may be ideal. However, there will usually be great restrictions on the session length using children as subjects. This limits the maximum retention interval (which must be less than the total length of the experimental session). To investigate longer intervals, the study-test technique would be required.

*Paired Associate Learning.* Traditional paired associate learning is actually an example of a continuous recall design. One member of the pair is presented and one is required to attempt to recall the other member of the pair during a certain time interval (e.g., 2 sec). Then one is shown both members of that pair for another time interval. This is followed by the test phase for the next pair and then a learning phase (reinforcement, feedback) for the same pair, etc., until all the pairs in the list have been exhausted. Then there is a delay interval which can be a few seconds in the case of "massed practice" or a few minutes or hours or days or longer in the case of "spaced practice". In the usual paired-associate procedure, the pairs in a list are scrambled between trials. (A trial refers to one pass through all of the pairs in the list.) Thus, retention intervals between the previous presentation of the pair and the subsequent test of it are usually not controlled, except that on the average they will be determined by the time it takes to go through a single trial. Such a procedure is obviously not very suited to the precise study of retention functions, but it clearly has been found useful in the study of the conditions that affect learning. Retention studies usually begin only after the subject had mastered the list by the paired-associate technique and involve simply waiting different amounts of time prior to testing retention.

*Serial Anticipation Learning.* A classic method used by Ebbinghaus is to present a list of items one at a time with the *S* required to anticipate the next item on the list during a certain time interval. After that, the item is shown, and the *S* is required to anticipate the next item. This continues until the entire list has been exhausted. Then following a time interval, the *S* goes through the list again in the same manner. Retention intervals are rigidly determined by the rate of presentation and are constant for every item in the list. This confounds the number of items being learned (list length) with the retention interval. Serial anticipation learning is basically a method for studying learning, not a method for studying retention, though obviously retention is inextricably involved in achieving a learning criterion.



## Recognition vs. Recall

"Yes-no" recognition memory is probably simpler to analyze theoretically than recall memory. The principal reason for this is that recognition memory can be free from competition effects, while recall memory often cannot be free of such competition effects. When the alternative recall responses come from a small known set (such as single digits or letters) recall must logically consist of a choice based on the competing strengths of all the alternatives. On the other hand, it is logically possible for one's "yes-no" response in a recognition memory test to depend on the strength of the test item alone and be independent of the strengths of any other items. Precisely this independence has been found for "yes-no" recognition memory by Bower and Bostrom (1968) and Wickelgren (1967). This permits one to analyze the decay of strength by a recognition test, independently of the growth of competing associative strengths.

## Memory in Children

A number of additional considerations are applicable to the study of memory in young children, normal or handicapped. In the first place the sessions must be relatively short, which means that the amount that can be learned in one session is correspondingly reduced. In paired-associate learning, the list of pairs must be short, perhaps on the order of four or five pairs for a 6-year-old child. The total length of session for a 6-year-old should probably not exceed 20 or 30 minutes, and the shorter the session the better. In addition to the desirability of short total sessions, only relatively short periods of sustained attention can be demanded of a young child. Thus, a continuous learning task longer than 30 minutes may be unreasonable for even normal children below the age of about 8 or 9.

Children are less able to concentrate on the relevant aspects of the situation and ignore extraneous cues (Gollin, 1960). Zeaman and House (1963) interpret their results to indicate that mentally retarded children have particular difficulty in attending to relevant cues. Stevenson and Wright (1966) suggest adapting children to the experimental situation for some minutes before beginning the experiment

and discuss a variety of methods of pretraining children to attend to relevant cues.

Children often require special procedures to maintain the proper level of motivation. On the other hand, a child may have a high degree of motivation to interact with the experimenter, but not in the manner required by the experiment. That is to say, the child may have high motivation, but his motivation is inappropriate for the task. It may be necessary to satisfy the child's curiosity and desire to get to know the experimenter, for a short period of time prior to beginning the experiment. On the other hand, the child may be very unmotivated for personal reasons or because the task is difficult or boring. The courses of action in this case include changing the experimental procedure to make it more interesting, make it less difficult or more interesting (e.g., by making a game of it) or introducing social or other types of reinforcement (e.g., M & M's).

The material to be learned must be carefully analyzed for its degree of familiarity to the child. A child has a vastly smaller vocabulary than an adult, so if one is to use familiar words (for which there are a number of advantages) the experimenter must limit himself to a much smaller total vocabulary of items. In general, for young children, concrete objects tend to be good materials for memory experiments, followed by pictures, and then familiar words. Obviously, it is essential to know whether a child can read, since a child who cannot read must necessarily be given auditory rather than visual presentation of verbal material. In some cases, a child may have a word in his spoken repertoire but not yet to be able to read the word, even though he can read simple books (i.e., other words). Finally, a child may be able to read a word, but only at a slower rate than an adult. Thus, it may enhance understanding of the material to read words to children, even when they have in some sense "learned to read." Experiments studying memory span in children of different ages show that auditory presentation is superior to visual presentation, with the difference decreasing with increasing age, and auditory presentation of the material yields less difference in memory span as a function of age than visual presentation (Conway, 1909; Murray and Roberts, 1968).



Many of the differences found in learning or memory as a function of age can be attributed to differences in reading, recoding, rehearsal, or learning-strategy capability, each of which varies sharply as a function of age. Once these factors have been eliminated from a memory experiment it remains to be seen what, if any, differences remain in the acquisition, consolidation, or decay of either short- or long-term memory. Along this line it has been found that a fast rate of presentation will minimize the difference in short-term memory span as a function of age (Murray and Roberts, 1968). Fast rates of presentation presumably minimize the difference between children and adults because they provide less opportunity for rehearsal and recoding at which adults are greatly superior to children. Along the same lines, I have consistently noted that fast rates minimize individual differences in memory span among adults, presumably for the same reason.

Finally, the most important and difficult consideration in studying memory in young children is to provide instructions regarding a memory task that are understandable to the child. In general, I have found that recognition memory instructions are harder for young children to understand than recall instructions. Thus, a memory span test which, from a theoretical viewpoint, is far more complex than a recognition memory task, is vastly easier for a child to understand than a three-phase recognition memory task. This is extremely annoying, but it is a fact that one must live with. Telling a child to repeat what you say is something that, for one reason or another, children understand at a very early age. By contrast, a delayed matching task, which is in essence what "yes-no" recognition memory is, is a higher level concept, which children attain only somewhat later in life.

Along this line, it is my impression that recognition memory for successive auditory material is harder than for either successive or simultaneous visual material. The reason for this is probably that with visual presentation one can instruct the subject regarding the recognition memory task by giving him a simultaneous matching task and following this by delayed matching with increasingly long delays. This is exactly the same procedure

that is used to train monkeys to do delayed matching (recognition memory). With successive auditory presentation, it is much more difficult to teach the child what is meant by a match.

### Coding

Coding refers to the internal representation in memory of our knowledge of the world and to the processes by which representation is achieved. Coding is concerned with what is learned and how this is represented in memory. The present section will discuss both the obligatory structural (capacity) aspects of coding and the optional (strategy) aspects of coding in memory.

Obligatory structural aspects include such topics as the modalities of memory, the nature of the representation of concepts in these modalities, the associative or non-associative nature of any memory modality, concept learning (the establishment of new internal representatives), etc. Thus, the capacity aspects of coding are concerned with the logical structure of memory; what its components are, and how they are organized into a system.

Let us assume for the moment that all human beings possess certain basic associative-memory and concept-learning processes. Even if the parameters for these basic memory processes are the same for two individuals, the degree to which one uses these processes and the types of associations or concepts formed depend critically on the strategy the individual chooses to adopt. In the investigation of memory capacity, it is desirable to attempt to control these coding strategies, but one can only control them if he has some idea of what they are. Furthermore, these coding (recoding) strategies are of intrinsic interest and any extension of memory principles to everyday learning situations requires one to understand fully the range of strategies open to an individual in learning and memory tasks. Coding strategies include such mechanisms as selective attention, relating current material to previously learned material, verbal mnemonics (such as embedding word pairs in sentences or devising mediators to link both members of a word pair), visual-image mnemonics, representing order information by group and serial position labeling, etc.

The first topic in the coding section will be the issue of the associative vs. nonassociative organization of human conceptual memory. After carefully defining these theoretical alternatives, it will be argued that human conceptual memory, both short term and long term, is associative. As a basic structural feature of the organization of memory, it is not reasonable to imagine that any handicapped individual would have a nonassociative, rather than an associative memory. However, a variety of quantitative features of the associative memory, such as the number of internal representatives, the ease of forming new internal representatives, the number of associations between internal representatives, the ease of forming new associations, or the longevity of associations once formed, etc., might vary as a function of different handicapping conditions. Such quantitative deficits are more properly discussed in conjunction with later sections of the paper, but the theory of associative memory provides perhaps the most important component of our understanding of memory, and so it is appropriate that this be discussed at the outset.

The second topic in the coding section concerns the probable existence of a "chunking" process in human memory. Chunking refers to forming a new internal representative to stand for a conjunction of old internal representatives. This ability to define new internal representatives is extremely crucial for the reduction of interference in an associative memory. It is quite conceivable that some groups of handicapped children are deficient in their ability to form new chunks. Alternatively, mentally retarded or learning disabled children may less often adopt a strategy of forming new chunks or the chunks they do form may be less appropriate to the needs of the situation.

The third topic in the coding section is concept learning. Concept learning is hypothesized to be the result of both the chunking process and the associative memory process. One likely consequence of a deficiency in chunking or associative memory is that the individual has a smaller "vocabulary" (dictionary) of possible concepts to employ in any new learning situation and/or the concepts he has

are of less value in coding knowledge of the world.

The fourth topic in the coding section concerns the different possible modalities of memory. The number of modalities of memory with different coding properties is unknown at the present time, but the verbal modality and the visual-spatial modality are most often distinguished. It would probably be a mistake to strictly identify these memory modalities with "corresponding" sensory input modalities, namely verbal memory being auditory memory and visual-spatial memory being visual memory. Obviously, verbal memory can be established via visual input for any individual who can read and, very likely, for everyone who cannot read, as well. Also, it is likely that the same spatial memory modality can receive input from touch and audition, though vision is surely responsible for virtually all such spatial memories. Nevertheless, vision is the primary input modality in spatial memories, and audition is probably the primary input modality for verbal memories, at least in the developmental sense (since normal children learn to speak long before they learn to read). Thus, it would not be surprising if deaf children had deficiencies in verbal (sequential) memory, and it is almost certain that blind children have deficiencies in spatial memory (due to the restriction of appropriate input, even if their spatial memory capacity is unaffected by blindness). Finally, special learning disabilities may arise in some cases from deficiencies at a strictly central (nonsensory) level in the functioning of one memory modality but not of other memory modalities. Correct diagnosis of a specific memory modality deficiency in a handicapped child may indicate that training should be in a manner which will permit storage in an unimpaired memory modality.

The fifth topic in the coding section will be the selective attention process and its role in the minimizing of "irrelevant" (background) context cues in memory performance. It has been suggested by Zeaman and House (1963) that mentally retarded children have particular problems in effective use of the selective attention process. Some types of learning disabilities may also be largely the result of an inability to ignore irrelevant context cues or

an inability to discriminate what is relevant from what is irrelevant. Special training procedures which draw attention to the relevant cues and minimize the attention-getting potential of irrelevant cues may prove extremely successful in training such children.

The sixth and final topic in the coding section is concerned with the role of coding strategies and the employment of previously established cognitive structure in new learning. It is rarely optimal to attempt to learn anything "by rote," that is, simply rehearsing the material over and over again in one's mind, without thinking of any other related concepts or images. Effective learning generally involves encoding the material presented into concepts that will make the appropriate distinctions within one's own cognitive structure, thinking of relations between currently presented material and previous knowledge or using a variety of special mnemonic devices such as embedding material in sentences or visual images. It should be kept in mind that the memory deficiencies of any group of handicapped children are as likely to be due to deficiencies in coding strategy as they are to be due to deficiencies in underlying coding capacity. Very likely, some children with learning disabilities have learning disabilities which are entirely due to poor coding strategy with no deficiencies in underlying coding capacity. If such strategy deficiencies can be identified, then teaching such a child the appropriate learning strategies may completely eliminate the learning disability. A child who has an underlying capacity deficit will very likely have coding strategy deficits as well. The latter deficits may be removable, even though the capacity deficits are not. The result of this should be greatly improved learning performance, despite the absence of any change in underlying coding capacity.

#### **Definition of Associative and Nonassociative Memory**

Two basic types of memory structures have been proposed as models for human memory: associative and nonassociative. In an associative memory, each event or concept has a unique or relatively unique internal representative, and internal representatives have different degrees of association to each other

depending upon how frequently they have been contiguously activated in the past. An associative memory uses a single element or a small group of elements in the system to represent any concept or set of concepts. When an event occurs that is an example of a particular concept or a signal for a particular concept, the internal representative of that concept is activated. The assumption is that the system allows a more or less direct connection from an event to a single internal representative or a small set of alternative internal representatives. Thus, when the word "dog" is presented today to a person, it activates a particular internal representative in memory, and the same internal representative will be activated by "dog" when "dog" is presented a minute later, an hour later, a day later, a week later, a year later, or 10 years later.

It seems likely that human beings have a small range of alternative representatives for any given event and that furthermore the range of alternative representations is subject to change over a period of time as the individual learns new concepts. This does not basically alter the hypothesis that, at any given time in a person's lifetime, there is a relatively unique internal representative for every concept.

In computer memory terminology, such a memory is referred to as "content-addressable," to distinguish this type of memory from the more ordinary computer memory that is "location-addressable." In a location-addressable memory, all one can do is encode an event in a particular location, and, if the same event should occur later on, one would have to search through all the locations in memory to find the prior occurrences of that same event. In a location-addressable memory, one cannot directly single out the exact location which has a certain concept stored in it. By contrast, in a content-addressable memory, one can simply ask where in the memory has this event been stored previously and single it out in an immediate (parallel-search) manner.

Thus, an important defining property of an associative memory is parsimony of representation of concepts. The parsimony comes in that time is largely irrelevant to defining the internal representative of an event. No matter what time that event occurs, there are relatively unique internal representatives for the con-

cepts cued by the event. So much for the representation of events in the system.

What about the representation of the order of events that have occurred to an individual. In an associative memory, the representation of order is accomplished by having connections (associations) between the internal representatives whose strengths (degrees of connection) are incremented every time two representatives are activated close to each other in time. Although it does not appear to be logically necessary, there does seem to be a close affinity between the content-addressability property of an associative memory and the associative property of an associative memory. Generally speaking, these two properties are taken together to define an associative memory.

By contrast, in a nonassociative memory there is an ordered set of locations (cells, registers, boxes, etc.) into which the internal representative of any event or concept can be coded, and sequences of events or concepts are stored in order in this ordered set of locations. A tape recorder is a good example of a nonassociative memory. As each successive sound occurs, a pattern representing that sound is impressed on a successive portion of the magnetic recording tape. From a hardware point of view, virtually all computer memories are also nonassociative, though with suitable programing, an associative memory can be simulated.

In a nonassociative memory the representation of an event is by a particular pattern that stands for the event being impressed upon any location in memory. Thus, there can be numerous representations of a single event or concept occurring at different times in the individual's life. These different occurrences of the concept are represented by the same pattern at physically different locations in the memory. In a tape recorder, if one pronounces the same word at different points in time, each pronunciation will impose approximately the same pattern on physically different sections of the tape, for example.

The representation of the order of events in a nonassociative memory is usually assumed to occur by virtue of having a fixed order in which one fills the locations in memory. Thus, a tape recorder fills successive sections of the magnetic tape in a single, linear order preserv-

ing the information concerning the order of events. The representation of events in a non-associative memory is said to be location-addressable, because one can go directly to a particular location, but cannot know what he will find in that location. This applies to both the initial acquisition and the retrieval of a memory trace.

It is possible to assume a kind of hybrid between these extreme forms of associative and nonassociative memories such that the memory is location addressable, but the locations are associated one to another rather than being in a fixed order. However, no especially useful consequence has yet appeared from any such hybrid.

Most human conceptual memory is probably associative. At least one type of human sensory memory, namely, visual, very short-term (sensory) memory (e.g., persistence of vision, afterimages, etc.) is probably nonassociative (Wickelgren and Whitman, 1970). No type of human memory appears to be of the hybrid location-addressable type. Other types of memory found in nature, such as immunological memory or physical memory, fall into neither of these two classes.

### **Long-Term Memory Is Associative**

Existing evidence overwhelmingly favors the hypothesis that long-term memory is associative rather than nonassociative.

First, long-term memory has an enormously large capacity. There must be hundreds of thousands, perhaps millions, of associations between events or concepts stored with reasonable strength in long-term memory. A non-associative memory with a serial search process would, on the average, have to search half of all the locations in the storage system looking for the cue word in order to come up with the correct response word, say in paired associate learning. A reasonable neurophysiological estimate of the time required to "search" a location might be on the order of 10-100 msec, since a single synaptic delay is on the order of 1 msec. This yields response times for long-term memory that are completely absurd. Of course, acquisition of a memory might be by way of a location-addressable process, but with retrieval proceeding by a content-addressable system (i.e., parallel search).

Such a hybrid memory might get around the present argument and still preserve the location-addressable feature in original learning, while giving-up this feature in retrieval. Nevertheless, it should be noted that a non-associative system for original learning puts substantial strain on the retrieval system to achieve integration of temporally distributed information concerning identical or similar ideas or concepts. This integration is achieved automatically during learning by an associative storage system. The kind of apparatus required to realize a content-addressable system in retrieval is precisely the same type of apparatus required to realize it in learning, so the hybrid would seem foolish, unless there was some substantial advantage to recording separately every occurrence of every event.

Second, the major advantage of a non-associative memory is that it could be extremely precise in its temporal resolution of events. A nonassociative memory might tell you the exact time at which different events occurred, and surely would store the exact order, frequency, spacing, etc., of events. A number of recent studies (e.g., Fozard, 1970; Hinrichs, 1970; Hintzman and Block, 1970, 1971; Peterson, 1967; Yntema and Trask, 1963) indicate that human beings do have some ability to judge the recency, temporal ordering, spacing, and frequency of events.

However, to me, the level of this ability seems to be abysmally low in relation to what could be achieved by a nonassociative memory. One often observes that a *S* can recognize nearly perfectly whether an event has occurred in the last hour or so, but has very poor ability to say which of two events occurred first, if they are not too greatly separated in time. It is not at all obvious why a nonassociative memory should have recorded perfectly the existence of the events, but somehow scrambled or otherwise lost the memory for the order of the events, when this seems to be the primary advantage of using a nonassociative storage system in the first place.

Intuitively, it seems that the large majority of all of our factual knowledge about the world (generic memory) is of the form where, although we remember concepts or facts we previously learned, we cannot remember the time or context in which we originally learned

them. There are, of course, many exceptions to this where we do remember the time and the context in which we learned certain things, but these seem to be exceptions rather than the rule.

Furthermore, from a teleological viewpoint it is primarily the generic knowledge that is useful for survival and not the more temporally or context-specific knowledge. Thus, an associative memory seems like just the kind of memory that would be extremely efficient for survival.

Third, recall and recognition of learned material varies with the nature of previously or subsequently learned material. That is to say, recall and recognition show interference effects, and the magnitude of these interference effects varies with the similarity between the material.

When a *S* is given the stimulus member *A* and attempts to recall the response member *B* of a previously learned *A-B* pair, he is less likely to recall *B* when he has previously or subsequently also learned an *A-C* association than when he has previously or subsequently learned a *C-D* association. The negative effect of prior learning on the ability to acquire, consolidate, store, or retrieve subsequent learning is termed *proactive interference*. The negative effect of subsequent learning on the ability to consolidate, store, or retrieve prior learning is termed *retroactive interference*. Both proactive and retroactive interference depend upon the similarity of the prior or subsequent learning to the learning that is being tested. Similarity-dependent proactive and retroactive interference is a direct and obvious consequence of an associative memory system. Since the separate occurrences of event *A* activate the same representative, learning a pair *A-B* along with a pair *A-C* could cause each trace to be weaker in storage (storage interference) and could also produce competition, blocking, or other problems at the time of retrieval (retrieval interference).

Similarity-dependent retrieval interference can be explained by a nonassociative memory provided one again assumes that the non-associative memory has lost perfect ability to distinguish the order of the locations on the tape in which one learned the *A-B* pair versus the *A-C* pair. Clearly, if one were required to

retrieve the response to A, and A appeared at two different places on the tape with two different successors, one would have more uncertainty in determining the correct response than if A only appeared with a single concept following it on the tape. Again, however, the nonassociative memory is forced to give up perhaps its most distinguishing feature, precise temporal separation, in order to account for the phenomena.

Storage interference refers to the effect of (usually) subsequent A-C learning to lower the strength of an A-B memory trace. Assessment of storage interference is achieved by using recognition tests rather than recall tests. If one asks an *S* whether or not A-B occurred as a previous pair and characterizes his ability to determine whether A-B occurred as opposed to A-D or some other incorrect pair, there is no logically necessary reason why there should be any competition at the time of retrieval between previously learned A-B and A-C pairs. Furthermore, there is experimental evidence to support the hypothesis that recognition tests avoid this type of retrieval interference (competition), and thus provide purer measures of decay or storage interference (Bower and Bostrom, 1968; Wickelgren, 1967).

Every study with which I am familiar of the similarity dependence of retroactive interference in recognition tests of long-term memory has shown that such storage interference is greater with more similar interpolated materials than with less similar interpolated materials (e.g., Keppel and Zavortink, 1969; McGovern, 1964; Postman, 1965). Storage interference effects are much smaller than retrieval interference effects as evidenced by the fact that the amount of retroactive interference shown in a recognition test is much smaller than the amount shown on a recall test (Postman and Stark, 1969). However the similarity dependence of storage interference in verbal long-term memory is an extremely reliable phenomenon, despite its modest size in experimental studies with small amounts of interpolated learning.

Thus, we may regard similarity-dependent storage interference as well established, and its existence is quite difficult to explain with a nonassociative memory. There just does not appear to be any reason why storing A-C in

one pair of adjacent locations should cause greater decay of A-B in another pair of locations than should storage of C-D in the prior pair of locations. In an associative memory, it is perfectly reasonable to suppose that the connection capacity of any single internal representative is limited, so that increasing an A-C association will tend to weaken an A-B association. Furthermore, it may well be quite adaptive for the survival of an organism to have forgetting depend upon whether new associations need to be formed to the same internal representatives or not. If an internal representative does not have any new associations that need to be established to it, the old ones might well be allowed to exist for a long time. However, if the contingencies of the world are changing, one might well need to quickly "unlearn" prior associations as well as learn the new associations. An associative memory can achieve such similarity-dependent, storage-interference in a very natural way. A nonassociative memory would have to have some special *ad hoc* device in order to accomplish this objective.

Other arguments for the associative nature of long-term memory and also verbal short-term memory are given in Wickelgren (1964, 1965a, b, & c, 1966a & b, 1967b, in press).

### Chunking

In information theory, the amount of information conveyed to a human being by the occurrence of a particular event is greater the greater the number of possible alternative events that could have occurred at that time. Information is equal to  $\log_2$  of the number of alternatives, provided each of the alternatives is equally likely to occur *a priori*. It might seem reasonable that the difficulty in remembering a sequence of events would be greater, the greater the information conveyed by the events. That is to say, the difficulty in remembering the events would be greater the greater the number of alternatives that existed for each of the positions in the sequence.

However, as Miller (1956) has argued, the effect of the number of alternatives (information) on short-term memory, for example, are extremely small. Memory span appears to be limited primarily to a certain number of events

or "chunks" and is relatively independent of the amount of information in each chunk.

Thus, one can increase memory span by recoding a sequence of events into a sequence of fewer chunks, with each chunk conveying information concerning the occurrence of several events. Miller cites an experiment by Smith which showed that S's could greatly increase their memory span for binary digits (sequences of 1's, and 0's) by learning to recode binary digits into octal digits according to the following rules:  $000 = 0$ ;  $001 = 1$ ,  $010 = 2$ ;  $011 = 3$ ;  $100 = 4$ ;  $101 = 5$ ;  $110 = 6$ ;  $111 = 7$ . This recoding scheme maps three events (symbols) into one event (symbol) reducing the number of chunks while preserving all of the information in the original sequence. Memory span almost triples using such a recoding procedure.

Such tripling of the memory span by binary to octal recoding requires considerable practice in learning the recoding system. Furthermore, learning the recoding system would undoubtedly be more difficult, if the new chunks were new concepts rather than already existing concepts (the digits 1 through 8). Nevertheless, it seems quite apparent that human beings possess the ability to find new symbols to stand for long sequences of previously defined symbols, and indeed this practice is used in mathematics and science all the time. The difficulty of learning a list increases with the number of different internal representatives that must be used to encode the list, but people appear to have the ability to define new informationally richer units in which to encode events. This process of defining a new internal representative to be a conjunction of old internal representatives will be called the *chunking* property of human memory, following Miller (1956).

A little thought concerning the previously discussed similarity-dependent interference phenomena indicates why such a chunking process would be an extremely desirable property. Such a process of defining new units to stand for a conjunction of old units would allow one to avoid some otherwise extremely serious associative-interference problems connected with the representation of events by a set of attribute representatives. Attributes would necessarily be present in many different

events, and in an associative memory each of these attributes would have to be associated to the various attributes of contiguous events in hundreds of different event-complexes of attributes. Such a process would produce an enormous degree of A-B, A-C type retrieval and storage interference when the A's, B's, and C's are considered to be the component attributes of hundreds or thousands of different events. The chunking process allows one to achieve as great a difference in representation of highly similar concepts as is desired.

Phenomena consistent with a chunking process abound in the area of human memory. First, there are the sometimes dramatic improvements in memorizing efficiency that can be achieved by learning a recoding scheme to reduce the number of chunks that must be learned (e.g., Miller, 1956).

Second, it is well established that sentences are easier to remember in both short- and long-term memory than comparably long lists of random words (Coleman, 1963; Marks and Jack, 1952; Miller and Selfridge, 1950). Indeed, these studies have shown a gradual increase in the ease of memorizing material as one increases the degree of approximation of a random sequence of words to a grammatical English sentence. This has been considered to reflect the fact that we have higher order units for a sequence of several words when the words are arranged in certain grammatical phrases, but not when the words are randomly ordered. There is, of course, considerable uncertainty regarding the degree to which we have previously established a single internal representative for an entire phrase of two or more words in the English language. Some of the superiority of sentence memory over memory for random words might consist of strong associations among the component concepts in a sentence. However, it seems likely that many of the phrases that occur in sentences occur repeatedly and, if we had a chunking process, each familiar phrase could be represented by a single unit in the system, facilitating memory for any sentence that involved that phrase.

Third, there is considerable evidence to support the proposition that when a subject attempts to learn either a serial list or a list of paired associates there are two different phases of the list learning process. First, there is the



phase of response learning or unit (response) integration and, second, there is the period in which the stimuli are associated to the "integrated" responses (e.g., Underwood and Schulz, 1960). The unit integration phase is short or nonexistent for meaningful words, which presumably already exist as concepts in the system. By contrast, when the materials in the list are nonsense syllables or consonant trigrams, the response learning phase can be quite long, reflecting the fact that these units are not already defined by single internal representatives in the memory system. The definition of a single internal representative for each unit being learned in the list is considered to be an important first step in establishing a high level of association between units that will survive the effects of both intralist and interlist interference.

### Concept Learning

A concept can be defined to be a disjunction of a variety of conjunctions of attributes. Thus, the printed word "dog," the spoken word "dog," the sight of a dog, the sound of a dog barking, etc., can all elicit the same concept representative. Similarly, the sight of a dog from various perspectives and the sight of dogs of different species with very different physical properties can all elicit the same general concept of a dog. It is hopeless to think that one can find some common set of physical attributes in all of the adequate cues for the concept "dog." Thus, it is erroneous to define concepts in a manner that requires abstraction of common properties.

It would probably be much too difficult by virtue of associative interference to associate sets of attributes one to another, without first chunking each set of attributes and defining a new internal representative to stand for the chunk. For this reason, it seems likely that one stage in human concept learning is to chunk each set of attributes that constitutes a set of sufficient cues for the elicitation of the concept. After two or more chunks have been defined, if these chunks are sufficient cues for the elicitation of the same concept, then these chunks are associated to each other (or to some higher level concept representative). This association of chunks is the second stage of concept learning.

According to this theory, children should learn very specific concepts at first, where by "specific concepts" is meant concepts which are elicited by only one or a few sets of cues. Only gradually would a child learn all of the different sets of cues that are considered sufficient by adults to elicit the concept (i.e., learn "general" concepts). The contrary argument is often made that children learn "overgeneralized" concepts initially and only later learn to apply concepts to the right specific instances. Examples are cited that a child may call every man "father." Saltz (1971) cites a number of studies that indicate that the overgeneralization position on concept learning is not correct and that children in fact learn much too specialized concepts at first.

However, the terms "specialized" and "overgeneralized" are usually not very clearly defined, so it is difficult to evaluate the present hypothesis with the previous findings. Usually, the terms "specialized" and "generalized" refer to *logical* (set-theoretic) generality, not *psychological* generality in the sense proposed here. Logical generality is a property of "dictionary definitions" of concepts. In this sense, the concept "dog" is more general than the concept "Saint Bernard dog" and less general than the concept "living thing." Clearly, the average child learns the concept "dog" before he learns either of these other two concepts. It is doubtful that any important psychological principle can be formulated regarding the degree of *logical* generality of concepts learned initially by children. With the currently proposed *psychological* definition of concepts as disjunctions of chunks, it is quite plausible that concepts develop increasing generality in the sense of having more and more chunk representatives associated to them (that is more and more sets of cues to elicit the same concept representative).

In summary, concept learning is considered to be composed of two basic learning processes: *chunking* a set of attributes to define a new internal representative and *association* of chunks one to another. The first establishes a conjunction of attributes. The second establishes a disjunction of these conjunctions. This theory of concept learning and speculations regarding possible neural mechanisms to achieve

it are presented in more detail in Wickelgren (1969).

• *Concept Learning Deficits.* It is possible that many or all mentally retarded individuals may suffer to a large extent from an inability to form new concepts via deficits in the chunking process or deficits of the associative memory process. The simplest explanation might simply be that they have fewer free internal representatives available to become specified to stand for new concepts, but there are many alternative physiological difficulties that could impair concept learning. Whatever the reasons for this, the consequences for learning and memory of learning fewer concepts are that the encoding of anything one wishes to learn will be (on the average) less distinctive from other materials coded into memory. This results in more retrieval and storage interference. For mentally retarded individuals, it may be very important to spend considerable time at the concept learning process, that is to say, learning the vocabulary in any area of knowledge, before proceeding to learn facts and principles (statements, propositions) involving those concepts. It could turn out that the learning of facts and principles would be almost normal in such an individual after sufficient time has been spent to teach him the basic concepts of the area.

Again, normal children learn many concepts that are later replaced by better concepts or are of no value to them in what they do later on. Although it is more costly and limits the choice of the handicapped person somewhat to decide in advance exactly what concepts he should learn, this can greatly increase the efficiency of concept learning for a person with this type of handicap.

### Modalities of Memory

For a while some people thought that memory might be in a modality of its own, separate from the various sensory, motor, and cognitive modalities. Lesion studies have failed completely to discover an area of the brain that is the repository of memories, which is not also intimately concerned with perceptual, motor, or cognitive aspects of functioning. There is one exception to this general statement; namely, a few human neurological patients have a rather specific loss of the ability to

*consolidate* new long-term memories, while their old long-term memories remain relatively intact, and other aspects of sensory, motor, and cognitive functioning are well preserved (Scoville and Milner, 1957; Milner, 1966). Thus, there may be a special area of the brain concerned largely or exclusively with a consolidation process. However, the actual storage of both long-term and short-term memories must be considered to be distributed throughout the various sensory, motor, and cognitive modalities of the brain.

It is difficult at present to specify the different modalities of the brain that have memory capacities (memory modalities). It is generally thought that visual-spatial memory is a somewhat separate modality from verbal-semantic memory. At the same time, verbal-semantic memory is often considered to be a separate modality from verbal-phonetic memory. There is evidence to support a general distinction between verbal versus various nonverbal memory modalities in studies of the asymmetry of the two hemispheres of the brain. Brain damage to the left hemisphere appears to affect various aspects of verbal cognitive functioning, including verbal memory, more than brain damage to the right hemisphere (Milner, 1966). By contrast, damage to the right hemisphere affects a variety of nonverbal tasks, including memory, more seriously than brain damage to the left hemisphere (Milner, 1966).

It may be that there is considerable similarity in the dynamic and retrieval properties of memory across different modalities, with the only differences being in the attribute or dimension systems used to encode memories, but the differences may be more extensive. Comparison of long-term memory for meaningful verbal and pictorial material indicates rather similar retention functions and rates of loss of memory in both cases. The most striking dynamic distinction between verbal and visual-spatial memory appears to be in the speed of acquisition and consolidation. A rather sizable long-term memory trace for a picture can be established within a few seconds (2-5 seconds). For example of such studies of visual long-term recognition memories see Shepard (1967) and Nickerson (1968). To achieve comparable levels of learning in say a verbal paired associate learning task requires

usually many trials of several seconds each (e.g., Nelson, 1971). The difference is perhaps not intrinsic to the comparison between visual and verbal modalities. Rather the visual material may be simply much more detailed and redundant than the usual verbal material presented in laboratory learning tasks. A picture may be "worth a thousand words." To achieve comparable levels of memory for verbal material one might have to present an entire paragraph as the "item" being remembered. However, in such a case it would usually take considerably longer to read the entire paragraph than it takes to encode a picture. Thus, because of differences in simultaneous versus sequential input, the visual and verbal modalities may have different speeds of learning.

An interesting study by Paivio and Csapo (1969) provides evidence that the verbal memory modality is specialized to learn and remember sequentially ordered material, while the visual-spatial memory modality is specialized to learn and remember nonsequential material. One might speculate that the type of nonsequential material for which the visual memory modality is ideally suited is memory for a large number of simultaneously presented attributes (as in a picture).

Visual sensory input is surely primary for the visual-spatial modality, and auditory input is at least developmentally primary in establishing traces in the verbal modality. However, it is surely a mistake to identify these modalities of memory with the "corresponding" sensory modalities. In the first place, for adults who can read, it is clear that much long-term verbal memory is established by way of visual sensory input. Whether or not this occurs to some extent as a result of an individual "saying the words to himself" is largely irrelevant to this observation. Even in short-term memory for visually presented verbal materials, there is often storage in a verbal phonetic modality, instead of, or in addition to, storage in visual memory (Conrad, 1964). In the second place, auditory sensory input apparently can lead to storage in the visual-spatial memory modality. Paivio, Bower, and their associates have repeatedly shown that the establishment of long-term memory traces in paired-associate and other learning tasks is facilitated by using words with high visual imagery

ratings (see Paivio and Okovita, 1971 for a study that used auditory presentation). The visual-spatial and verbal memory modalities are clearly cognitive, rather than sensory, memory modalities, and, as such, they can receive input from several sensory modalities.

*Modality Deficits.* As noted above, the left hemisphere of the brain seems to be specialized for the representation of verbal material and the right hemisphere of the brain specialized for a variety of nonverbal information processing (especially visual-spatial material). At the present time, it is certainly not clear how many different nonverbal modalities one ought to distinguish, nor is it clear how many verbal modalities or levels of a verbal modality one ought to distinguish. However, it is clear that many individuals suffer moderate to severe deficits in a particular modality, without showing any deficits, or even showing a partially compensating superiority, in other modalities of functioning.

One good example of the dissociation of performance in different modalities is provided by some recent studies of short-term memory in handicapped persons. Deaf, severely hearing impaired, and speech impaired *S*'s typically perform more poorly than normal *S*'s on tasks considered to be facilitated by auditory imagery (Hartman and Elliott, 1965) and on memory span tests or other tests of verbal (sequential) short-term memory (Blair, 1957; Olsson and Furth, 1966; Withrow, 1968-69). However, when material is presented that even normal *S*'s might be expected to code visually rather than verbally, deaf *S*'s can perform as well as or even better than normal *S*'s (Blair, 1966; Olsson and Furth, 1966; Ross, 1969; Withrow, 1968-69).

The remarkable patient of Warrington and Shallice (1969) demonstrates a memory span of about one and a half digits when the digits are sequentially presented at a rate of one digit per 500 msec. However, the same *S* can achieve a memory span of about 3.5 digits when the digits are presented simultaneously tachistoscopically for only 250 msec. Such a striking discrepancy between verbal sequential short-term memory and visual simultaneous short-term memory indicates clearly that memory impairments can be extremely selective with regard to modality.

Paivio and Okovita (1971) studied paired-associate learning by congenitally blind vs. sighted subjects of nouns rated high or low in auditory or visual imagery. The long-term memory performance of blind subjects was facilitated by auditory, but not by visual, imagery, whereas the reverse effect was obtained for sighted subjects.

Evidence for the need to dissociate conceptual memory from sensory-motor memory has been obtained from studies on the famous patient H. M. of Scoville and Milner (1957). Corkin (1965 and 1968) has shown that H. M. shows substantial capacity for motor and sensory motor learning in a variety of tasks such as rotary pursuit, bimanual tracking, and tapping. His substantial improvements from session to session in motor and sensory-motor performance occurred despite the fact that H. M.'s conceptual memory was so poor that he did not even remember being in the same experimental situation from one session to the next. Some types of visual-perceptual memory may also be preserved in patients who have nearly complete inability to consolidate new conceptual memories (Warrington and Weiskrantz, 1968; Milner, Corkin, and Teuber, 1968).

It is a testimony to the extraordinary flexibility of the human mind, that deficits in one modality can often be partially overcome by use of a different modality. For example, there is now considerable evidence to indicate that deaf and hearing impaired *S*'s frequently make use of visual or dactylic (finger-spelling) coding to remember sequentially presented verbal material that normal *S*'s encode phonetically (Conrad, 1970; Locke and Locke, 1971), though some deaf *S*'s who have high speech quality appear to employ articulatory coding in verbal short-term memory (Conrad, 1970). Depending upon the modality in which the *S* encodes material to be learned, some types of material are easier or more difficult to learn (Conrad, 1970; Allen, 1971). Elliott and Vegely (1969) suggest that rewarded training may be helpful for hearing-impaired children in sequential-processing and memory tasks.

Knowledge of the modalities of encoding used by a particular handicapped child in a particular task would be of considerable benefit in determining how to present the material

and how rapid to expect learning to be. The two principal methods of assessing the type of coding used by a *S* in a task are: (a) to determine whether errors tend to be phonetically similar, visually similar, dactylically similar, etc. and (b) to determine whether interference and/or facilitation in learning and memory varies with the phonetic, visual, dactylic similarity of the material. The type of similarity that affects errors and speed of learning indicates the encoding modality used by the *S* for that type of material.

### Selective Attention and Background Context

It is sometimes asserted that cues from the learning context become strongly associated to the material being learned, and the presence or absence of these context cues at the time of retrieval can enhance or depress the memory performance as a result. The underlying assumption is either explicitly or implicitly that the representatives of all potential stimuli in the situation become associated one to another as a result of learning. McGeoch and Irion (1952, pp. 448-451) have stated the case for the importance of context in coding and retrieval from memory in a very detailed manner.

However, close examination of the experimental work cited by McGeoch and Irion and other studies on the effects of "irrelevant" context in learning reveals that only a few studies find significant effects of altering the background context cues from learning to retrieval. Unpublished work of my own has also failed to reveal any significant effect of altering the context on either recall or recognition of Russian-English word pairs. Since some of the alterations in experimental context have been deliberately designed to be as extreme as possible, the negligible or unreliable effects observed argue strongly that "irrelevant" context often plays a rather small role in the coding and retrieval processes of memory.

There is a very good teleological reason for this which can be illustrated by the example of learning to identify a poisonous species of mushroom in the forest. One would hardly want the exact conditions of time, place, and emotional attitude under which one learned to identify the characteristics of the poisonous mushroom to play any important role in one's

ability to recognize another example of a poisonous mushroom at a different time, place, and emotional context.

The actual psychological mechanisms by which this relative unimportance of context in memory is achieved are probably: (a) selective attention at the time of learning and (b) storage interference processes which selectively weaken whatever associations do get established involving irrelevant context cues.

Selective attention is an important control process determining what gets coded in memory. Besides filtering out the effects of irrelevant background context, selective attention permits each individual to concentrate his limited learning and memory capacity on those principles of greatest use to him. Selective attention is thus a valuable mechanism exerted at the time of acquisition, for providing motivational control of the contents of memory.

*Selective Attention Deficits.* A child with only a selective attention deficit should be considered to have a special learning disability. Such a child finds it difficult to concentrate on certain aspects of a situation and selectively ignore other aspects. Alternatively, the child may be selectively attending, but does not very adequately distinguish what is really relevant and what is irrelevant. The latter type of selective attention deficit suggests either that the child has a general mental deficiency or else that he has not received proper instruction that will permit him to discriminate relevant from irrelevant aspects of a learning situation. Zeaman and House (1963) in their research on discrimination learning in mentally retarded children concluded that selective attention deficits are a major feature of the learning deficits of retardates. They suggest that successful training of retarded children should very carefully direct the child's attention to the relevant cues in each situation.

Theoretically, there are two classes of approaches to counteracting selective attention deficits on a short-term basis. First, one can attempt to minimize the presence of distracting stimuli or the attention-getting value of these stimuli. Second, one can attempt to enhance the attention-getting value of the relevant stimuli. At an immediate sensory level, it is the changing or novel stimulus and the more

intense or otherwise stressed stimulus that has the greatest attention-getting value. At a higher cognitive level, the interest of the material to the *S* is critical for maintaining attention to the relevant stimuli for any considerable period of time. These principles apply both to the minimizing of the attention-getting value of irrelevant stimuli and the maximizing of the attention-getting value of relevant stimuli.

On a longer term basis, it is perhaps possible to train some children with selective-attention deficits to learn to ignore distractions and concentrate on relevant stimuli. This is particularly true if the selective-attention deficit is a strategy deficit rather than a capacity deficit. Individuals appear to differ considerably in the degree to which they control what they learn on the basis of their goals via the selective attention mechanism. In deciding on a course of training in regard to selective attention deficits, it seems important to discriminate whether the problem is due to: (a) a poor strategy in the use of the selective attention mechanism, or (b) a capacity limitation in the functioning of the selective attention mechanism when attempts are made to employ it (i.e., the subject is attempting to "concentrate").

### Coding Strategy and Structure in Learning

Most learning in adults involves embedding new material in a rich already existent cognitive structure of previously learned material. Even so-called laboratory "rote" learning tasks have been shown to involve substantial use of cognitive structure in the learning by experimental *S*'s. In memorizing word pairs, *S*'s attempt to: (a) embed the words in a phrase or sentence, (b) think of some other mediating concept that is strongly associated to both the stimulus and response members of the pair, (c) think of a single visual image in which to embed both members of the pair, etc. Even in learning nonsense syllables, *S*'s try to make words out of the syllables and then go through the same processes previously mentioned for words (e.g., Prytulak, 1971).

When phrases are provided in which to embed the members of a word pair, learning is facilitated even when this phrase context is not presented along with the stimulus member of the word pair at the time of recall (e.g., Ep-

stein, Rock, and Zuckerman, 1960). *S* or *E* generated natural language mediators (e.g., A (Apple)-Pie) for various paired associates also assist recall even when the mediators are not supplied by *E* at the time of recall (e.g., Montagne, Adams, and Kiess, 1966; Schwartz, 1971). Likewise, supplying the members of a pair in the form of a unitary visual image improves recall of one member of the pair given the other member. This occurs even though the recall test involves a decomposition of the picture into parts, which might be expected to depress memory by comparison to a condition in which the parts of the picture are presented as two separate visual images in both learning and test (Epstein, Rock, and Zuckerman, 1960; Asch, Ceraso, and Heimer, 1960). Word pairs that have higher probabilities of spontaneously evoking natural language mediators have higher probabilities of being remembered (Walker, Montague, and Wearing, 1970). Likewise, word pairs that have high probabilities of evoking visual images have high probabilities of being remembered (Paivio, 1969). These studies show the overwhelming importance of the ability to embed newly learned material into a previously learned cognitive structure as an aid to both learning and retention.

It seems likely that learning in a young child involves much less use of previously existing cognitive structures, for the simple reason that a child has less previously learned cognitive structure. Thus, for example, memory for the meaning of spoken or written words and the ability to pronounce an arbitrary sequence of sounds to make a given word is likely to be more or less "rote" learning process. There is a completely arbitrary connection between a sound or spelling of a word and its meaning. Likewise, there is a completely arbitrary association between the meaning of a concept and the sequence of articulatory gestures necessary to speak a word signifying that concept. Thus, there would seem to be literally no basis for anything other than a rote learning process involved in such elementary learning of the lexicon of a language.

As a child grows older, however, the nature of the things he is learning indicates a larger role for cognitive structure. In addition, the child has more cognitive structure to employ.

Thus, it seems entirely reasonable that the degree of influence of prior cognitive structure on new learning should increase as a individual grows from childhood to adulthood.

Contrary to what one might suspect on the basis of proactive and retroactive interference, the ability to learn most types of material appears to increase steadily with increasing age from childhood to adulthood. Thus, the net positive advantages of having a rich prior cognitive structure must outweigh the interference effects. We conclude this without in any way detracting from the reality of both retrieval and storage interference phenomena in memory.

A rather different type of coding which is very helpful in sequential short-term memory for visual material is the use of a verbal label for each visual stimulus (picture). Instructing and training children to attach verbal labels to pictures in sequential short-term memory tasks has facilitated short-term memory performance in children, making them more nearly equivalent to adults in performance on such tasks (Bernbach, 1967; Kingsley and Hagen, 1969). As mentioned previously, the verbal modality appears to be specialized for sequential memory whereas visual-spatial memory is specialized for simultaneous memory. Thus, when sequential memory is required for pictorial material, it is advantageous to recode the pictures into a sequence of verbal labels. The degree to which the subject employs this strategy will have a substantial effect on his memory performance in this type of tasks.

*Coding Strategy Deficits.* The associative nature of memory implies that what is stored consists of associations between concepts that were thought of in close temporal contiguity. A normal individual, when learning some new material, thinks to some extent about relations to other previously learned material and forms a whole host of associations, not just the associations based on what was presented to him. If a handicapped individual has coding strategy deficits, he may form far fewer of these associations based on logical deductions at the time of learning. Even normal individuals are often quite deficient at encoding the relationships between current material and previously learned material and may require that these

relationships be pointed out quite explicitly during learning. However, it may be critical to point out such relations to a mentally retarded individual with a coding strategy deficit, for example.

Although the notion that memory is associative has been around since the British associationists in the 17th and 18th centuries, and even possibly since Aristotle, popular understanding still too often considers learning to consist of dropping some event into a place in memory. As previously indicated, memory consists of storing connections or associations between the representatives of different events or concepts. Putting a fact into a person's mind in such a way that he can repeat it shortly thereafter, in no way guarantees that he connects this fact to everything that the teacher regards it as logically related to.

I have known teachers to be shocked when they give an examination question that tests knowledge of some material presented in the course in response to slightly different cues than it was originally presented with, only to discover that virtually none of the students recall the material. From this they erroneously concluded that the students remembered nothing about the material. Such conclusions demonstrate ignorance of the principle that memory is associative. The students' failure to perform on such a question very often reflects their lack of ability to see the relationship between the material and the cues presented on the test question. To achieve such generalization of knowledge to all of the appropriate conditions where it is applicable, it is frequently necessary to explicitly teach those relations one wishes the student to see. With normally intelligent *S*'s, we rely to a larger extent than is possible for some types of handicapped children on the ability of the learner to draw logical deductions from the material given and see relationships to other previously stored knowledge.

### Dynamics

Dynamics refers to the time course of the quantitative properties of different traces through the acquisition, consolidation, storage, and retrieval phases of the memory process. Developing a theory of memory dynamics appears to require three types of decisions.

The first decision concerns the types of quantitative properties to be assigned to memory traces. For instance, will each trace be characterized by a continuous or a discrete (finite-state) variable? If continuous, will the fundamental trace be characterized by a response probability or by a trace strength which is linked to response probabilities by the retrieval rules? Does the memory trace need to be characterized by a vector or a matrix of two or more real variables, as opposed to a single variable?

The second decision concerns the number of memory traces that have different dynamics, that is, different laws of acquisition, consolidation, storage, or retrieval of memory. At present, it is widely believed that two dynamically different traces, short-term memory and long-term memory, will suffice. However, within the area of experimental psychology, short-term memory is usually considered to persist for a period of seconds or 10's of seconds following learning, with long-term memory being responsible for retention after delays of 10's of seconds, minutes, hours, days, weeks, months, and years. On the other hand, in studies of the neural basis of learning, it is usually assumed that short-term memory is responsible for retention up to delays of a few hours, with long-term memory taking over only after that. This enormous discrepancy suggests the possibility that there are three dynamically different traces: short-term memory, intermediate-term memory, and long-term memory.

The third decision concerns the number of different dynamic phases of the memory trace (such as acquisition, consolidation, storage, and retrieval) and the laws of operation of these dynamic phases. This is really the major area of experimental work, since characterizing the laws of the different phases of a memory trace is the primary means of validating theoretical decisions regarding both the quantitative properties of memory traces and the number of dynamically different traces. Within the continuous strength formulation of memory (that I have adopted), characterizing the dynamical law for a phase requires one to develop a function or several functions characterizing the form of the function which relates properties of the memory trace to the passage of time within each phase. The function or



functions describing a phase will necessarily involve a small number of parameters (degree of learning, rate of decay, rate of consolidation, etc.) and there should be additional laws characterizing the values of these parameters as a function of the major experimental conditions that affect them. The view expounded here will be that the phases are not overlapping in time and that the output of the prior phase constitutes the input for the subsequent phase. However, alternative assumptions involving some degree of temporal overlap between the phases have not been very fully investigated.

The present theory of memory dynamics suggests the possibility that children with certain types of handicaps might be impaired in short-term memory but not in long-term memory and vice versa for children with other handicaps. There do appear to be individuals who have very large deficits in long-term memory with little or no deficit in short-term memory (e.g., Milner, 1966). It may also be possible to have the reverse (a deficit in short-term memory with little or no deficit in long-term memory), as in the patient of Warrington and Shallice (1969), but this is less well established as a dynamical deficit as opposed to a modality deficit.

Also, the present theory suggests the possibility that certain phases of the memory process might be selectively impaired in certain individuals with no impairment to the functioning of other phases. Evidence for this already exists as well. The patient H. M. studied by Milner (1966) shows a severe deficit in the acquisition-consolidation of new long-term memory traces but it is apparently unimpaired in the retrieval of previously established long-term memories, and unpublished data of my own indicate that he may be unimpaired in the storage of what little long-term memory he can now acquire and consolidate. Selective deficits in the storage phase with little or no deficit in the acquisition and consolidation phases are also possible. There is considerable evidence that decreasing arousal during learning, regardless of the cause, produces a faster rate of decay during storage of the long-term memory trace. An individual might have a special learning disability of this type as a result of chronically low arousal.

Administration of stimulants or the use of background noise to increase arousal could facilitate retention in individuals with this type of learning disability.

### Properties of Memory Traces

I characterize all memory traces by a continuous, real-value variable; namely, its *strength*. Greater strength of a memory trace implies greater probability of recall or recognition, but strength is related in a nonlinear manner to the probability of correct recall or recognition (see Wickelgren and Norman, 1966; Wickelgren, 1968). In addition, it appears to be necessary to assume that long-term memory traces must be characterized by two different dynamic properties: *strength* and *resistance* (see Wickelgren, 1971). During storage, the strength of the long-term memory trace decreases monotonically with trace age, but its resistance to the forces of decay increases monotonically with increasing trace age. No comparable trace resistance property seems to be necessary to characterize short-term memory, and this constitutes one type of indirect evidence for the need to distinguish short-term and long-term memory.

Many studies have been done in the attempt to decide whether memory traces are discrete (all or none) or continuous (incremental). There are serious problems in drawing any definite conclusions from virtually all of these studies. At present, only one type of direct evidence has been shown to be potentially conclusive in rejecting finite-state as opposed to continuous theories; namely, that suggested by Krantz (1969). Using this approach, all that has been shown so far is that short-term recognition memory traces could not be two-valued, but must have some larger number of states or be continuous (Krantz, 1969). At present, the principal means of validating any decision regarding the properties in the memory trace is to determine how simple, valid, and general are the laws of memory that can be formulated within that framework.

### Number of Memory Traces

At present, the evidence favors the assumption that there are two dynamically different types of memory traces: namely, short-term memory and long-term memory. Short-term

memory is assumed to be established within a period of fractions of a second and to last for seconds or 10's of seconds, though it can be maintained for a longer time by conscious rehearsal in the case of verbal short-term memory. A potential long-term memory trace may be established in a few seconds, but it requires several seconds or 10's of seconds thereafter to become consolidated into a usable memory trace. However, long-term memory can persist for hours, days, weeks, or years following acquisition.

There is considerable evidence to support the need for assuming two different memory traces. First, it appears to be necessary to assume two component memory traces in order to account for the form of the retention functions of normal human subjects over delays of zero seconds to 2 minutes following learning (Waugh and Norman, 1965; Wickelgren and Berian, 1971). Second, as previously mentioned, long-term memory requires the resistance property, while short-term memory does not (Wickelgren, 1971). Third, a variety of conditions have a different effect on short-term retention (delays of seconds) than on long-term memory (delays of minutes or longer) such as number and spacing of study trials (Wickelgren, 1970a & b; Wickelgren and Norman, 1971). Fourth, storage interference of short-term memory is similarity-independent (Bower and Bostrom, 1968); Wickelgren, 1967a) while storage interference in long-term memory is similarity-dependent (see coding section). Fifth, certain brain-damaged patients demonstrate normal or nearly normal short-term memory while having little or no ability to consolidate new long-term memory traces (Scoville and Milner, 1957; Milner, 1966).

At present, there is no need to assume the existence of any more conceptual memory traces than these two. That is to say, the psychological properties of memory assessed at retention intervals of a few minutes appear to be the same as the properties of memory assessed at retention intervals of hours, days, weeks, or years. Furthermore, the retention function for intervals from a minute to several years appears to be parsimoniously handled by a single long-term memory trace. Memory over retention intervals less than 10 sec appears to be mediated primarily by short-term memory.

Memory over retention intervals between 10 sec and 1 min must be assumed to result from a combination of long-term and short-term memory. I am in complete agreement with Deutsch (1969) that the physiological evidence for distinguishing intermediate-term memory (less than 1-3 hr.) from long-term memory is not conclusive.

### Phases of Memory

Many investigators of human memory have assumed that there are three theoretical phases of memory: acquisition, storage, and retrieval, corresponding to the three operationally distinguishable phases of a memory experiment: learning, retention, and usage. In the case of short-term memory (retention intervals of a few seconds or 10's of seconds), these three theoretical phases may indeed be sufficient to describe the dynamics of memory. However, in the case of long-term memory, there is some evidence favoring a consolidation phase of the memory process, in addition to, and interpolated between, the acquisition and storage phases.

*Acquisition.* Acquisition refers to the phase of memory in which an individual is actively (consciously) studying the material to be learned and laying down potential short-term and long-term memory traces. In the case of short-term memory these traces are presumed to be consolidated almost immediately, and there may be no necessity to assume that consolidation is a separate phase from acquisition. In the case of long-term memory, however, these potential memory traces may have to be converted by the consolidation process into usable (retrievable) memory traces. All of the coding and recoding aspects of learning and memory are assumed to take place during the acquisition process. It is here, when an individual is consciously considering the material, that he can think of a mnemonic or visual image to aid in the memory or chunk the separate elements of a list into a single element or meaningful phrase, etc.

*Consolidation.* The consolidation phase of the memory process is assumed to be an unconscious process in which the potential long-term memory traces, established during acquisition, are converted into a stable usable

form. Note that consolidation is not being thought of as a logical recoding type of change in the memory trace. Any and all recoding is assumed to take place during acquisition and is assumed to be a conscious process. Consolidation is assumed to be a relatively automatic, unconscious process which may be affected by arousal, by certain drugs, etc., in its speed or extent of operation, but nothing during the consolidation process is assumed to change the qualitative (logical) nature of the memory trace established.

Consolidation of long-term memory appears to take place during the first minute after learning, primarily the first 10 to 30 seconds after learning. There are a number of different studies that indicate approximately the same time course for consolidation of long-term memory.

Studies of the retention function for normal human *S*'s invariably indicate that the rapid exponential decay observed during the first ten seconds after learning is sharply retarded from delays of 10 seconds to 30 seconds after learning (see Wickelgren and Berian, 1971), but this could simply be due to the presence of a long-term trace immediately after learning. However, some studies have found a temporary increase in the memory trace (reminiscence) occurring from delays of about 10 seconds to delays of about 20 seconds (Keppel and Underwood, 1967; Peterson, 1966). Reminiscence can be explained by assuming that a decaying short-term memory trace is compensated for to a greater or lesser extent by a consolidating long-term memory trace. In this case, the long-term trace is assumed to appear over the interval from 10 seconds to 30 seconds after acquisition (Wickelgren and Berian, 1971). However, reminiscence is not a very reliable phenomenon, and there is really very little psychological evidence for consolidation in normal human retention.

A second line of evidence for a consolidation phase comes from the effects of electroconvulsive shock (ECS) in animals and concussion injuries in people. Studies of the effect of electroconvulsive shock delivered to animals shortly after a learning trial indicate that the most consistent and damaging effects of this ECS occurs when the ECS is delivered within a few seconds or 10's of seconds following learning

(see Weiskrantz, 1966). Occasionally, deleterious effects of ECS on memory are obtained with longer delays between learning and ECS, but this is much more variable and several investigators have concluded that it is probably due to a different sort of process.

In human beings, severe head injuries frequently cause permanent loss of memory for the last few seconds or 10's of seconds preceding the injury. This "short" retrograde amnesia, which is invariably permanent, is to be distinguished from "long" retrograde amnesia, which may extend for 10's of minutes, hours, days, weeks, or years prior to the injury and is usually reversible with time. Short retrograde amnesia may reflect inadequate time for consolidation of long-term memory. Long retrograde amnesia probably reflects a quite different process.

Unfortunately, neither the physiological nor the neurological evidence for distinguishing short retrograde amnesia and long retrograde amnesia is completely convincing. There is really no sharp temporal cutoff between short and long retrograde amnesia, suggesting the possibility that these are merely on a continuum. If this view is correct, then perhaps all short retrograde amnesia phenomena can be explained in the same manner that long retrograde amnesia will be explained in the subsequent section concerned with the storage phase.

*Storage.* During acquisition and consolidation, the memory trace is assumed to be protected to some extent from various degradative forces. At the end of the acquisition and consolidation phases, the memory trace enters the storage phase in which it becomes subject to these degradative forces. Existing evidence clearly indicates that the degree of degradation of the memory trace depends upon the nature of the activities the *S* engages in during the retention interval as well as the time involved. That is to say, we cannot assume a pure time decay process for either short-term or long-term memory. We must assume that subsequent activity causes storage interference. Storage interference refers to a reduction in the strength of previously established memory traces as a result of intervening activity. By contrast, retrieval interference refers to a reduction in the probability of correct recall as a result of

establishing competing memory traces during the retention interval, but not necessarily weakening previously established memory traces.

In the case of long-term memory, the degree of storage interference caused by interpolated activity is greater for interpolated activity that involves material which is similar to the previously learned material (Wickelgren, 1971).

In the case of short-term memory, however, interference increases with the amount of material learned or processed in the retention interval and the difficulty of such learning or processing (Wickelgren, 1970b). Also, interference is greater when the interpolated material is in the same modality or is of the same type as the previously learned material. However, within these *gross* limits of similarity there appears to be no further dependence of storage interference on the fine-grain similarity of interpolated material to originally learned material (Bower and Bostrom, 1968; Wickelgren, 1967). Thus, the storage interference properties of short-term and long-term memory are somewhat different, but both types of memory do show storage interference effects and cannot be described by a passive temporal decay process.

There appears to be an active trace-maintenance process (unconscious rehearsal) for short-term memory that serves to maintain the trace against the forces of decay. This trace-maintenance process operates more effectively the less time is spent on learning (as opposed to nonlearning information processing) during the retention interval. This accounts for why one obtains storage interference effects which are nevertheless independent of fine-grain similarity of the interpolated material to the previously learned material (Wickelgren, 1970b).

The short-term memory trace can be characterized by a single quantity which we might call the strength of the short-term memory trace. However, long-term memory traces appear to have two important dynamic properties: *strength* and *resistance*. The strength of the memory trace determines the subject's ability to recognize or recall material based on that memory trace. The resistance of the memory trace determines how sensitive that memory is to the subsequent forces of decay (stor-

age interference). More resistant memory traces are less affected by the same force of decay than less resistant memory traces.

A rather simple theory appears to describe the principles of the dynamics of storage in long-term memory (Wickelgren, 1971). The theory makes four assumptions: (a) the rate of decay of strength equals the force on the trace divided by the resistance; (b) force is proportional to trace strength and to the similarity of current traces to the previously established trace; (c) resistance increases as the square root of trace age; (d) the resistance of a trace transfers completely to subsequent increments.

The meaning of the first two assumptions is relatively obvious. The third assumption indicates that a trace increases in its resistance (susceptibility to decay) the longer it has been since it has been established (learned). The fourth assumption asserts that multiple, separated, learning trials contribute increments to degree of learning that all have their resistance determined by the time since the *first* learning trial. Alternatives to the fourth assumption include assuming that resistance is determined entirely by the *final* trial of a series of learning trials or that the increment to learning contributed by each learning trial has its own resistance.

Wickelgren (1971) shows that this theory of storage in long-term memory accounts for the form and relative decay rates of a large variety of different long-term retention functions obtained for delays from 1 minute to 2 years for a variety of different subjects and a variety of different types of verbal materials learned under a variety of different conditions. In this respect, the theory provides a quantitative formulation of Jost's Second Law (in Hovland, 1951) that the rate of forgetting decreases as the retention interval increases. The close fit of the present quantitative formulation to a large variety of different retention functions over the relatively enormous span of time from 1 minute to 2 years argues rather persuasively that this quantitative formulation is not far off.

In addition to accounting for the form and rates of retention function, the greater resistance of older traces accounts qualitatively for long retrograde amnesia (Wickelgren,

1971). Such long retrograde amnesia is characterized by S's losing all memory for events that have occurred over a period of minutes, hours, days, weeks, months, or years preceding some serious insult to the brain. The remarkable thing about this long retrograde amnesia is that it is in no way explainable by the strength of memory traces. That is to say, it is not the weak memories or the strong memories that one loses in long retrograde amnesia. Rather it is the *recent* traces, irrespective of strength, which are lost, with the period of time lost being apparently continuously variable over different subjects with different degrees of severity of brain injury (Russell, 1959).

The theory also incorporates similarity-dependent storage interference (discussed in the coding section) by means of the assumption that the force of decay is proportional to the similarity between currently learned material and previously learned material.

The theory accounts for the smaller rate of decay following spaced learning trials than following massed learning trials (Keppel, 1964; Wickelgren, 1971). Accounting for the beneficial effects on long-term retention of spaced learning trials is the primary justification for the fourth assumption of the theory that the resistance transfers completely to subsequent increments.

A variety of other phenomena may be simply described by the theory, but further study is required before definite conclusions can be drawn. These phenomena include the possibility of slower forgetting rates following relearning of forgotten material, judgments of the recency of different events, and the effects of arousal on retention (to be discussed in a subsequent section).

*Retrieval.* Of course, it must require some period of time to retrieve memory traces in recall and recognition memory tasks. However, very little is known concerning the dynamics of retrieval. If one distinguishes between retrieval time (which selects traces) and decision time (which selects a response in a recall or recognition memory task), then nothing definite is known about each of these two possibly independent components of retrieval time.

However, there have been a considerable number of studies concerned with recognition memory and recall latencies. These studies demonstrate consistent patterns of differences in memory response times, although we cannot, at present, decide how much of the effects to attribute to differences in retrieval time vs. differences in decision time.

The one well-established generalization that can be drawn from all of the studies of memory response times is that memory response time decreases with increasing difference in the memory strengths of correct and incorrect alternatives. In long-term recall tasks, increasing the strength of association between two items decreases the recall time, even for many trials after the last error (e.g., Millward, 1964). In short-term recall tasks using non-rehearsal instructions, the recent items (which have the greatest strength as measured by recall accuracy) have the shortest probe recall times (Norman, 1966). In short-term recognition memory, greater strength of correct alternatives leads to faster response times when strength is manipulated by changes in list length (Sternberg, 1966) or recency (Corballis, 1967). Furthermore, Norman and Wickelgren (1969) have shown that strength as measured by confidence judgments correlates with strength as measured by latency judgments in the obvious way: namely, high confidence correlates with short latency. Essentially nothing is known regarding response time in long-term recognition memory tasks, but presumably the same correlation between strength and response would hold.

There is apparently some relatively continuous speed-accuracy trade off in memory. In a paired-associate recall task, Murdock (1968) showed that requiring subjects to begin their vocal response within 1 second after the cue was presented resulted in lower recall accuracy than the somewhat more lenient requirements of 2- or 4-second latencies between probe presentation and the beginning of recall. However, the effects were far from disastrous and a rather similar decay curve of accuracy vs. recency was obtained.

### Dynamic Capacity Deficits

It is possible to have a severe deficit in the ability to acquire and/or consolidate new long-

term memory traces while having little or no deficit in the retrieval of old long-term memory traces or the ability to acquire and retrieve new short-term memory traces, as discussed previously (Milner, 1966). Some recent evidence obtained by Warrington and Shallice (1969) may indicate that it is possible to have the reverse deficit, namely, a deficit in short-term memory with little or no deficit in the ability to acquire and consolidate new long-term memory traces, but this is by no means certain, at present. Whether children classified as retarded differ among themselves with respect to short-term memory versus long-term memory deficits remains to be seen. However, the evidence from brain-damaged patients suggests that this is a lively possibility.

Essentially nothing is known regarding whether it is possible to have a deficit in storage of long-term memory with no deficit in consolidation of long-term memory. Such a person presumably would form a memory trace as strong as a normal individual, but the rate of forgetting would be markedly increased. This is a possibility, but there is no directly-relevant evidence at the present time. Studies which purport to find differences in decay rate for normal versus a variety of handicapped individuals suffer from little or no theoretical motivation for the dependent variable (generally the probability of correct recall or recognition). Without some theory of the relation between the probabilities of correct recall and recognition and the underlying memory strengths, it is virtually meaningless to compare changes in response probability as a function of time for different individuals. This is especially true when the individuals differ in degree of learning measured at the shortest retention interval, but even individuals that are matched for retention by a probability-correct measure at some short delay cannot be meaningfully compared for rate of decay without justification of the dependent variable. The latter point requires a somewhat complex argument beyond the scope of the present paper. However, one should be extremely wary of comparing decay rates across different groups of individuals or as a function of different conditions, in the absence of any explicit mathematical theory of the memory trace and

how it is used in retrieval for either recall or recognition.

Another issue in the comparison of decay rates for long-term memory across different groups of subjects is whether the shortest retention intervals used may be presumed to be mediated entirely by long-term memory without any contribution by short-term memory. Within the context of a two-trace theory of memory, it is obviously inappropriate to include immediate tests as measures of the degree of learning in long-term memory, since they may contain substantial amounts of short-term memory as well. One cannot be certain, at present, how long a time must elapse before the short-term trace is completely gone, but a delay of 1 or 2 minutes *filled with some rehearsal-preventing activity* is generally considered sufficient (Wickelgren, 1971).

Although there is no evidence on these matters, it is of some interest to note that within the context of the theory it ought to be possible to have an individual with a deficiency in the growth of trace resistance who would as a result have a faster rate of decay than a normal individual.

The reverse type of deficit ought to be possible as well, namely, an individual might have deficient consolidation of long-term memory with no difficulty in storage. Some very limited unpublished data of my own on certain human neurological subjects indicate that this type of disorder may well be possible.

Very likely the most typical long-term memory disorder is inadequate acquisition with perhaps no deficits in either consolidation or storage. A deficit in acquisition may be largely a matter of inadequate coding of the material in memory. Thus, a less intelligent subject may not encode the material as related to those previous memories to which it ought to be related. He does not embed the material in the kind of structure that will make it distinct from what it ought to be distinct from and related to what it ought to be related to. From a dynamic point of view, this will result in lowered degree of original learning, but according to the theory, very likely this would also increase the similarity of the material to other material increasing the decay rate. Thus, empirical demonstration of a disorder in acquisi-

tion, but not storage, could prove to be extremely difficult.

Although no consolidation process is assumed to be necessary in establishing a short-term memory trace, it is still possible that some individuals might have a deficit in acquisition of short-term memory, but no deficit in storage, while other subjects might have a deficit in storage, but no deficit in acquisition. In the area of short-term memory, according to the theory this might be relatively easy to assess by asking whether subjects have deficiencies in degree of learning as measured at the shortest delay or have deficits in the rate of decay of short-term memory. However, all of the previous comments regarding the difficulties in comparing rates of decay are applicable.

### **Motivational Control of Learning and Memory**

*Selective Attention.* A person's goals control what gets learned via the selective attention mechanism. Thus, it is critical that a person have some reason for wanting to pay attention to material in order for him to learn anything about the material. Selective attention was previously discussed in the coding section.

*Rehearsal.* Rehearsal is another mechanism by which goals can influence learning and memory. Rehearsal aids both short-term and long-term retention by increasing the degree of learning of the material being rehearsed. As long as the amount of material being rehearsed is sufficiently small that no errors are introduced in the rehearsal process, time spent in rehearsal with the material absent is at least as valuable as the same amount of time spent with the material present. In addition, rehearsal aids short-term memory by periodically renewing the short-term trace, effectively preventing decay for small amounts of material that are within the "rehearsal span." Because of the effectiveness of rehearsal in maintaining verbal short-term traces, it is essential to use rehearsal-preventing tasks in order to study the decay of verbal short-term memory traces. However, this should not obscure the importance of rehearsal in ordinary short-term retention.

There has long been speculation regarding the possibility that imaging is a visual ana-

logue of verbal rehearsal. Intuitively, imaging has usually been considered less effective in trace maintenance than rehearsal, but there was really little definite evidence on the matter. Recent findings by Conrad (1964) and others indicate that visually presented sequential material is translated into a verbal short-term trace (when possible). This suggests that visual rehearsal processes are less effective than any verbal rehearsal process for most people, but, of course, it does not rule out the possibility of some beneficial visual rehearsal process. However, Shaffer and Shiffrin (1972) have recently found that while increased exposure time improves the degree of learning for pictures, blank time for visual rehearsal following a picture has no effect on recognition memory for the picture. Their results provide rather strong evidence against the possibility of a visual analogue to verbal rehearsal. Thus, rehearsal may be a unique property of the verbal memory modality. Anyhow, rehearsal is apparently not a property of the visual-spatial memory modality. This lends some support to the notion that rehearsal is in some way a consequence of a special correspondence between auditory and articulatory speech representatives.

*Rehearsal Strategy Deficits.* Flavell, Beach, and Chinsky (1966) have shown that probabilities for spontaneous verbal rehearsal in a memory task increase as a function of age, accounting for at least part of the increasing memory performance as a function of age. Kingsley and Hagen (1969) found that nursery school subjects could be instructed to engage in rehearsal with consequent benefits for memory performance. Belmont and Butterfield (1971) found that retarded children were less likely to engage in rehearsal in a short-term memory task as compared to normal children. When the retarded children were instructed to follow a rehearsal strategy more like the normal children, their performance substantially improved. These results suggest that at least some of the short-term memory deficiencies of retarded children might be eliminated by a program of instruction regarding the importance of rehearsal for short-term retention.

*Arousal.* In addition to selective attention and rehearsal, there may also be an opportu-



ity for motivational control of learning via some arousal-mechanism. An enormous body of converging evidence now indicates that low arousal is deleterious for long-term learning and memory. Drugs which act as central nervous system depressants, such as alcohol, nitrous oxide, chlorpromazine, ether, etc., impair the establishment of long-term memory traces when administered either shortly before, during, or shortly after a learning experience in both humans (Steinberg and Sumnerfield, 1957; Goodwin, Othmer, Halikas, and Freeman, 1970) and animals (Johnson, 1969; Leukel, 1957). Drugs that increase arousal (central nervous system stimulants), such as caffeine, amphetamine, nicotine, strychnine, picrotoxin, etc., facilitate long-term learning and memory when administered in close temporal proximity to the learning experience (see McGaugh and Dawson, 1971, for a review). Normal fluctuations in the degree of arousal evoked by a particular learning event (measured by the galvanic skin response, GSR) have been shown to correlate strongly with the amount of long-term memory established by a learning experience (Kleinsmith and Kaplan, 1963, 1964; Butter, 1970; Walker and Tarte, 1963). Finally, arousal induced by pairing the presentation of white noise with a learning experience also increases long-term learning and memory (Berlyne, Borsa, Craw, Gelman, and Mandell, 1965; Berlyne, Borsa, Hamacher, and Koenig, 1966; Uehling and Sprinkle, 1968).

Thus, even after the *S* has attended to the material he probably has the capability of determining the strength of the long-term memory trace that will be established for the attended material. One mechanism by which this may occur is the degree to which he encodes the material by making use of a rich and distinctive cognitive structure. Material which one regards as not very important may receive very little processing and not be encoded in any very detailed or distinct manner. Such memories are rapidly lost due to interference. On the other hand, material which is judged to be important may be encoded in a rich variety of ways, establishing a strong memory trace. Also, more important (arousing) material may be consciously rehearsed more than less important (less arousing) material. How-

ever, there is also the possibility that arousal affects learning and memory in a more automatic and less conscious way.

There has been some work on whether *S* can intentionally forget material after he has learned it when told to forget it. The evidence seems largely to indicate that there is relatively little ability to erase previously established memories in storage by instructional means alone.

*Low Arousal (Depression).* I would imagine that many handicapped children are more susceptible than the average child to low arousal and depression, irrespective of the type of handicap. This would be a natural emotional reaction to any serious handicap. In addition to the emotional causes of depression, the deaf, hearing-impaired, blind, or visually impaired handicapped children may be subject to an additional factor leading to low arousal. This additional factor derives from the fact that all sensory modalities provide input of a "non-specific" nature to the reticular activating system which is responsible for maintaining an adequate degree of arousal. Thus, people with serious auditory or visual sensory deficits may be particularly susceptible to chronically low arousal.

For any handicapped person, except one with a serious selective attention problem, a rather high level of background (noise) stimulation may be an important aid to learning. Especially in the case of emotionally disturbed children, this high level of background noise stimulation may be quite the opposite of what one would ordinarily think to be indicated as a part of an emotional and intellectual relearning program. An emotionally disturbed individual whose arousal has been greatly depressed, either through normal fluctuations or drugs, is probably in an extremely poor condition to learn anything. Thus, while it may be more difficult to manage such a person under a state of higher arousal, it may also be essential to have at least moderately high arousal, if any significant learning is to take place.

In the case of an individual with a selective attention deficit, the problem may be that the individual has chronically high arousal, since he is so easily affected by a broad range of

stimuli. Thus, rather low levels of background noise may be indicated for such a person despite all of the previous comments regarding the importance of arousal for learning and memory.

For blind or deaf individuals, all of the background noise stimulation must be concentrated in modalities to which the individual is sensitive. Thus, high levels of visual noise may be necessary for a deaf person to maintain adequate arousal. High levels of auditory noise stimulation may be necessary for maintaining adequate arousal in a blind person. In addition, it is conceivable that air currents, odors, and tastes induced by eating during learning might be aids to maintaining arousal in children with various degrees of sensory deprivation in particular modalities.

Little is known at present concerning the relative importance of the absolute level of arousal during learning versus the degree of change in arousal contingent upon the learning event. The drug studies, of course, influence learning by way of the overall level of arousal over a considerable time surrounding the learning event. By contrast, the galvanic skin response (GSR) and white noise studies are usually concerned with a short-term *change* in the degree of arousal immediately contiguous with the learning event. Further research is needed on this point, since it is quite possible that too high a level of arousal might limit the degree of further increase in arousal that could occur immediately contiguous with the learning experience. If *change* in the degree of arousal is of significant importance for long-term learning and memory, then it may be that, beyond a certain point, increases in the absolute level of arousal are deleterious rather than beneficial.

### Retrieval

The logical (nondynamic) aspects of retrieval refer to how memory traces are used in a variety of situations. The coding assumptions specify the different traces that are acquired and stored in memory, but also it is necessary to say which of these traces are used in various tasks (recall, recognition, etc.). For each of these tasks we must decide, "What is judged in retrieval?" Also, we must specify the decision rules which translate the value of

these traces into responses in different types of elementary memory tasks.

Somewhat different retrieval mechanisms must be involved in recall and recognition, and it has sometimes been suggested that individuals can be handicapped in recall tasks, but not in recognition memory tasks. It is difficult to assess such disparities between recognition and recall performance without explicit understanding of the logical relationship between recall and recognition memory, but there is certainly a possibility of differential memory capacity deficits in recall vs. recognition retrieval mechanisms.

In addition to the possibility of capacity deficits in retrieval mechanisms, there is the likely possibility that retarded children and some children with learning disabilities may have retrieval strategy deficits. Optimal retrieval from one's memory in most real-life situations requires a complex sequence of elementary recall and recognition tasks, with one's own enrichment of the retrieval cues playing an important part in retrieval accuracy. Some children may have much poorer strategies in this regard than other children.

### Elementary Retrieval

I assume that there are three elementary retrieval processes: recognition, recall, and recency, the three R's of retrieval. In "yes-no" recognition an individual is assumed to judge the strength of the memory trace for the item or pair of items that is presented in the recognition test. Only that strength is assumed to be judged, and a criterion decision rule used in Thurstonian scaling or signal detection theory is assumed to be applicable (Wickelgren and Norman, 1966). The criterion decision rule specifies that, if the strength of the memory trace is above some criterion, an individual decides he has encountered the test event previously. If the strength of the test event is below the criterion, he decides the opposite. The criterion is assumed to be under an individual's control and can be affected by his biases. The statistical decision theory that results from these assumptions, in conjunction with an assumed normal distribution of noise in the memory process, allows one to compute the average strengths of memory traces. These decision making assumptions for recognition

memory have both direct and indirect experimental support (Bower and Bostrom, 1968; Wickelgren, 1967, 1970a).

In multiple choice recognition memory, an individual is given two or more alternative items or pairs of items and is required to choose which was presented previously. This is assumed to be accomplished by choosing that item or pair of items that has the maximum strength of association. Evidence supporting the validity of this decision rule has been obtained by Green and Moses (1966) and Kintsch (1968), but there are some complicating factors (Wickelgren, 1968; Norman and Wickelgren, 1969).

In recall tasks where the number of alternative responses is very large (e.g., words, phrases, sentences), the most natural assumption is that the correct response will be selected, if and only if the strength of association from the cues to that response is above some (rather high) threshold.

Logically, recall is more difficult than "yes-no" recognition because one must choose among a large (sometimes very large) number of alternatives. Thus, recall is open to competition effects at the time of retrieval which "yes-no" recognition is not. In many circumstances the probability of correct recall will be extremely low, while the probability of correct recognition is extremely high. From a practical point of view, the greater difficulty of recall is extremely real, despite the fact that the underlying memory traces involved in recall and recognition memory may be of exactly the same type. Recall is just logically much more difficult than recognition, and human performance in this case directly reflects the difference in logical difficulty.

### Complex Retrieval

Much of our everyday retrieval of memory traces involves a complex sequence of recognition, recall, and recency judgments. Thus, for example, in attempting to recall someone's name, we may try to go directly from a visual image of the person to his name. If that fails, we may attempt to generate alternative names, testing each one via recognition memory. A common scheme is to go through the alphabet trying to use the first letter in conjunction with various information about the individual

(such as an image of him) to attempt to generate his name, testing via recognition memory. When we attempt to remember how long ago something occurred (at what point in time), we may use both a direct recency judgment and also attempt to recall time concepts directly or indirectly associated to the event in question. Thus, by the latter process we may remember that some event occurred 3 days ago, because we remember that it occurred just after some meeting, which we remember was on a particular date.

### Distraction

Although one ordinarily assumes that recall is a desirable process, there are very likely substantial advantages for human happiness in being able to not recall certain unpleasant events. Sometimes this is deleterious, if one really needs to deal with a problem, but in other cases the painful events are over and done with and are best forgotten. Loss of the memory in storage can be a long slow process, especially for material that was extremely salient at the time it was learned. To keep from remembering these events and causing ourselves needless pain, people have the ability to prevent recall by way of distraction. Because of the associative nature of memory, an unpleasant event will be recalled only if the cues that are associated to the internal representatives of that event are present in consciousness. Thus, if we can avoid contact with all the cues associated with that event or selectively not attend to them, then we can prevent the recall of the unpleasant memories. Obviously, distraction can play only a very limited role in recognition memory, but it can play a very large role in preventing recall.

### Repression

Freud and other psychoanalytically oriented psychologists have presented considerable clinical evidence that some emotionally disturbed individuals are capable of preventing recall of unpleasant memories, even when they are forced to attend to cues that would be sufficient in a normal individual to produce recall. There is no question that the memories are there, and they can be elicited by association, hypnosis, etc. However, the S, despite some apparent effort to attend to the cues and recall

the unpleasant memories, appears unable to do so under normal circumstances. This phenomenon has been termed repression, and besides the clinical evidence for it there is some limited experimental evidence as well (Glucksberg and King, 1967).

### Retrieval Deficits

It has frequently been observed by memory psychologists that failure to recall some material does not necessarily imply that the memory trace for that material has been completely lost in storage. There are many reasons why an individual may not be able to retrieve some memory at a particular time, but may be able to retrieve it at another time under other circumstances. This is presumably much less true for retrieval of memory in a recognition test than in a recall test, but the exact extent to which recognition is free of retrieval interference phenomena of any kind has not yet been established.

Limiting our attention to recall, it is quite possible that some individuals have a deficit in retrieval with little or no deficit in acquisition, consolidation, or storage of memory traces. Most recall tasks, even most laboratory recall tasks, are not free-association tasks. We do not speak the first thought that comes into our mind upon being given the cue in a recall task. One usually goes through a process of enriching the cues by recall of associated contextual material and rejecting various incorrect thoughts via a recognition test, for some time, before deciding upon the correct answer. In a laboratory task this may be a matter of only a few seconds of such thinking. However, in real-life recall tasks, sometimes, the process of enriching the context by recall and rejecting incorrect associations by recognition goes on for many minutes. If an individual has certain cognitive deficits that lead him to be less adept at initiating and executing such a sequence of cognitive operations, then he will have a retrieval deficit that will affect his memory performance on recall tasks. In any event, it is certainly logically possible for an individual to have a retrieval deficit without an acquisition, consolidation, or storage deficit.

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