CHAPTER 3

Memory

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1. Introduction

In recent years the most striking activity in the field of memory research is the strategy to model human cognition after information processing systems. This same approach will be followed to some extent in the present chapter, starting with an outline of the structure of the human information processing system and a definition of its principal activity: coding (section 1). Section 4, on organization phenomena, is a direct consequence of the cognitive viewpoint held by the authors. The intermediate sections have as their central theme a contemporary approach to the classic issues of memory research, namely, the acquisition of information (section 2) and the retention and forgetting of information (section 3).

Within the present framework we shall deal almost exclusively with verbal memory. Perhaps with the single exception of visual memory, one may say that the retention of other kinds of material has not been studied at all systematically. Within the verbal range we shall, furthermore, limit ourselves to relatively simple classes of material such as pairs and lists of letters, syllables and words. Memory for syntactically structured units such as sentences and texts are discussed in chapter 7.

1.1. The structure of the human information processing system

The information processing system with which man is equipped may be regarded as built up from various smaller systems. The central part is made up of what we shall refer to as short-term memory (STM) and long-term memory (LTM). STM has a limited retention capacity: an estimate would be 5–7 unconnected items such as letters, digits, words or short phrases that can be retained over a period of, at most, several tens of seconds. LTM, on the contrary, can contain an almost unlimited amount of information. Apart from certain pathological cases, moreover, it is difficult to prove that a specific kind of information, once it has entered LTM, can ever be radically removed from it and there are no indications whatsoever, that LTM would gradually reach its maximum capacity in the course of a human lifespan.

Besides, man possesses a number of sensory registers (SRs). The stimulation reaching the senses is retained in these registers over an interval that may range from several tenths of a second (in the case of the icon, or the visual SR) to several seconds (in the echo, or the auditory SR). During this short period of time, certain elementary classification processes can be performed – elementary in the sense that the classes involved in the discrimination belong to a relatively fixed and stable set. If, for example, speech sounds strike the ear, these sounds are classified into a few dozen phonemes or a few thousand syllables. The rules providing the possibility for making these classifications are contained in LTM. As soon as a recognition has taken place, the name that is used in LTM for the appropriate class is copied into STM.

The symbols that have thus entered STM through a classification of the SR content, may be maintained in STM for several tens of seconds and here they may subsequently be subject to further, more complex coding processes, such as the combination of syllables to form words, or the search for syntactic relationships among word sequences. It should be explicitly noted here that the more complex coding processes need not always follow the less complex ones in time: there may be an intervention from higher levels into the decisions that are made at lower levels. If, moreover, we add to these various stores the central processing unit where the exchange of information between the stores occurs, we obtain the picture of fig. 1.

1.2. Coding

A cardinal question that may be asked with respect to any kind of memory, either natural or artificial, is: in what symbol structures (codes, representations) is the stored information contained? A problem that is closely related to this question is concerned with encoding and decoding. Coding in the most general sense may be defined as a representation of

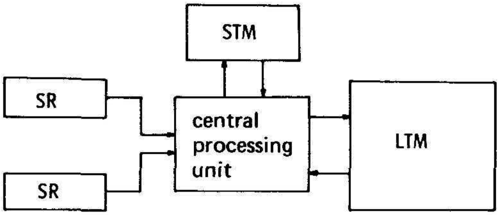

Fig. 1. Outline of the various memory stores and the relationships among them in the human information processing system.

a set A of symbol structures that, following certain rules, are built up from a given list of symbols, into a set B that is composed in an analogous fashion. In terms of formal language theory (see Vol. I, chapter 4) one may state that coding is the representation of language A in language B.

In the following section we provide a survey of the specific meanings that are implied by the term coding within the context of the psychology of memory. In the coding situations that are typical for that context, we either have symbol structures that are entered into the cognitive system and subsequently translated into symbol structures that are to be retained over a longer or shorter interval in the stores involved, which is encoding, or we have a procedure occurring in the reverse direction, which is decoding. The stored symbol structures are called the internal representation of the input symbol structures. (To avoid misunderstanding, we note here that by input we mean the *output* of the senses and not the sensory stimulation. Thus, echoic memory – or ASR; see 2.1.2 – represents in a one-to-one fashion the frequency spectra composed by the inner ear, but not the pressure waves striking the ear drum. For this reason we say that the content of echoic memory is 'uncoded'.)

The coding processes that occur during the performance of memory tasks mainly serve the purpose of optimizing the efficiency of the functioning of the information processing system. In general, only that information will be stored that is necessary in view of the prevailing task requirements. The adopted format will be concise on the one hand and on the other will often have multi-purpose practicability. Complete storage will probably only occur in the sensory registers and for a duration of several seconds at most. The function of these registers is obvious: the elementary classification processes mentioned above (1.1) may be performed upon their content. The status of a different, longer lasting form of uncoded storage, i.e. eidetic imagery, is doubtful. It is not clear whether this storage mode can be regarded as reliable if exceptional circumstances are left out of consideration (cf. Stromeyer, 1970). The following classification of forms of coding is, in fact, a summing-up of a number of strategies which, if applied alone or in combination, can establish an efficient basis for memory.

Input selection

By no means do all memory tasks require storage of the entire input. When studying a text it may, for instance, be sufficient to acquire the main line of reasoning. However, even when a list of paired associates is learned, input selection can easily be demonstrated. If a subject is required to learn the digits two and eight as responses to the trigrams GJM and VTC, respectively, he may limit himself to the associations G-2 and V-8. If the list is lengthened by another pair, VRZ-5, however, he will have to encode an additional stimulus feature. Let us say he chooses the last letter of the two trigrams; this would result in V.C-8 and V.Z-5. Similar selective strategies may greatly facilitate the learning of lists of this type, but they may cause difficulties if suddenly the stimulus items are not presented in their original form but only in part (e.g. .J.–? or .T.–?). What the input components are that will be selected in a given memory task is dependent on a large number of factors such as the subject's preferences, the time available to the subject during presentation, similarities and differences between the items that make up the material to be learned, the order of presentation of the items, and which items are defined as stimuli and which as responses.

Input condensation

By this term we mean the transformation of the input into an internal representation as concise as possible but still allowing a reconstruction of the entire input. Coding of this kind is in fact concerned with the discovery of relationships, i.e. laws, or redundancy among the symbol structures that have entered. By definition, each regularity governs several elements of a symbol structure, so that the number of elements to be coded independently is reduced. A system of extremely concise codes for a very wide range of visual and auditory patterns has been developed by Leeuwenberg (1971).

Anchoring of the input

The ancient mnemonic device of relating newly learned information as much as possible to knowledge which is already available, and of integrating it with that knowledge, is concerned with a form of coding which may result in a drastic reduction of the number of elements to be stored. In the case of input condensation we saw that such a reduction is brought about by a search for sources of redundancy in the structure of the input itself; in the case of anchoring, any saving is based on the discovery of redundancy, i.e., repetitions in the entire data base of LTM. If the central processing unit is confronted with a new input symbol structure which is a more or less faithful copy of a symbol structure that has already entered, it will not encode the second symbol structure as a whole, but it will, for instance, note that at a certain moment and under given circumstances a new copy was observed of a specific old symbol structure.

An important class of coding types involving anchoring in the available data base is formed by the 'natural language mediators' (Prytulak, 1971). Numerous examples of this coding may be given: the trigram CPT is coded as 'capital' with the notation that only the three first consonants apply; into the association pair '*drawing pin–dike*' an auxiliary word such as 'hole' is inserted; a list of words is retained by means of a story fabricated around them. Another type of knowledge in which new information may be anchored is formed by imagery, to which we shall pay attention in a later section (see 4.2.3).

Adaptation to internal nomenclature

In various memory tasks it occurs that the presented input symbols are coded into verbal symbols, even if this does not result in condensation or anchoring. A very perspicuous example of this type of coding is the transformation during STM tasks of visually presented letter lists into sequences of items that almost exclusively contain auditory or articulatory features (see 2.2.2). Another example has been provided by Slak (1970), who was successful in his attempt to stretch his memory span for digits from about nine to about 13. He achieved this by practising a coding system which transformed three-place numbers into pronouncable syllables (a phoneme was assigned to each digit, depending on its first, central or terminal position in the number). Also in the retention of visual patterns there is a strong tendency towards verbal coding by naming the figures (Riley, 1962). This preference for verbal nomenclature is, among other things, related to the facility of rehearsal for which verbal items are extremely suitable (see 2.2.2).

2. Storage of information

The experimental approach to human memory as an information processing system according to the main outline described above (see 1.1) dates from the middle of the fifties. The first studies on memory in which information theory and model building were essential features (Miller, 1956; Broadbent, 1958) were chiefly concerned with the processing of information in 'immediate memory', or STM. This is no coincidence but a consequence of the typical processing characteristics of STM that we shall discuss. The result is that 'primary' forms of storage have received a great deal of attention during the past decade. The conceptual frameworks of memory, which were developed ten years ago, largely outside the range of the familiar concepts of learning theory, were especially, or even exclusively, adapted to the typical STM situation. As a consequence, there was, in the opinion of many researchers, an actual divorce between memory research on STM and on LTM. Melton (1963), however, was one of those who strongly opposed such a separation. He presented material supporting his viewpoint that there is a continuum in memory for verbal material, encompassing retention over intervals ranging from several seconds to the much longer periods that have been studied traditionally in the field of 'verbal' learning. More specifically, he demonstrated that even in the shortest intervals the principles of association and interference effectively govern retention (see fig. 2). As we shall see below (see 3.2), the study of LTM forgetting already had a long history of explanations in terms of interference.

Melton's arguments have not been able to settle the question. For some time now there has been a serious dispute in the field of STM research: is interference indeed the universal principle of forgetting or can a typical STM principle be demonstrated in the form of trace decay? The dispute over this kind of distinction between STM and LTM has, in fact, never reached a satisfactory conclusion. The main interest of the investigators, however, has clearly shifted towards different topics. As regards STM, the attention has recently focussed on coding characteristics, serial position phenomena in recall, sensory registration (especially in the

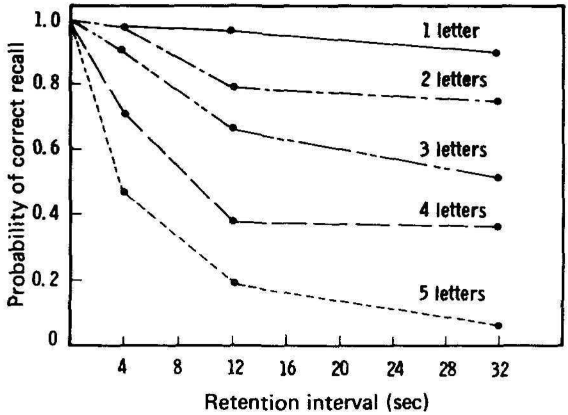

Fig. 2. STM forgetting curves as a function of the number of items (1 to 5 letters) per list. In principle, longer lists imply a greater amount of interference among the list items. Since forgetting appears to be more rapid for longer lists, inter-item interference may be the cause of STM forgetting, as it is of LTM forgetting (after A.W. Melton, Implications of STM for a general theory of memory. J. of Verbal Learning and Verbal Behavior, 1963, 2, 1-21).

auditory modality), and models that deal with different forms of verbal information processing. With respect to LTM, research has moved towards the fields of organization principles, mental imagery, syntactic and, more recently, semantic-linguistic representations in memory.

These developments are reflected in this section and in the following parts of the present chapter (and also in chapter 7). Meanwhile, considerable attention will also be given here to experimental techniques and also to recent developments in the more traditional fields of 'verbal learning'. We shall start with a discussion of various data concerning sensory registration: the most 'peripheral' part of the system as outlined in fig. 1.

2.1. Sensory registration

The perceptual systems of the different sensory modalities are equipped with the ability to maintain sensory impressions for a time after the stimulation from the environment has terminated. Thus, the first classification processes that precede recognition and interpretation may be transferred to STM in coded form. For the different forms of sensory registration (SR) we have drawn two compartments in fig. 1 to indicate that during that early stage of processing the information from the sphere of the different sensory modalities has not yet been combined (for this reason, in fact, more than two registers ought to appear in the outline). The sensory registers may also store different impressions within a single modality such as simultaneously arriving auditory information coming from two speakers along with the voice characteristics of the speakers and the appropriate auditory localization cues. Some aspects of sensory registration will be discussed in chapter 8, e.g., in connection with the concept of 'selective attention' (see section 3.1 in that chapter). Here we shall limit ourselves to a brief discussion of those experiments that demonstrate the existence of sensory registration as a form of memory for the visual and auditory modality, and that reveal certain characteristics of this typical kind of buffer storage.

2.1.1. Visual sensory registration (VSR)

Different authors have given different names to this preliminary form of information storage. Thus the term 'icon' comes from Neisser (1967); Sperling (1967) uses 'image' and 'visual information storage'; Norman (1968) and many others prefer 'visual STM'; along with, e.g., Atkinson and Shiffrin (1971) we shall use the term 'visual sensory registration' (VSR). The experimental results on the basis of which a sensory registration in the visual modality may be assumed to exist, have in common that under certain experimental conditions a subject is able to name a relatively large number of verbal symbols from a card that has been exposed to him tachistoscopically. Under normal circumstances one will only be able to be recall some four or five letters from a card containing nine letters in a 3 x 3 array if it is exposed 50 msec. If, however, the subject is given an auditory cue immediately after the presentation indicating what part of the card he is required to recall (Sperling, 1960) or if he is given a visual marker indicating the individual symbol that he is required to recall, then he appears to have available a number of symbols that may be more than twice the number of four or five items that he is able to name if complete recall is attempted.[1] The exact relationships, of course, depend on the conditions of presentation (contrast, spacing and post-exposition fields, etc.) that will not be discussed here (see Vol. I, chapters 6, 7 and 8).

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[1] A difference in favor of the partial recall technique does not necessarily imply that under complete-recall conditions fewer items are coded and retained than are registered. The difference can, in principle, also be due to greater output interference during the attempt to recall the entire list than during partial recall.

The partial recall technique has the advantage that one is able to insert an interval between the exposition of the verbal symbols and the presentation of the marker, which allows the experimenter to study the course of the sensory memory representation. The results show that the relative advantage of partial recall declines rapidly and that it approaches an asymptotic value already after 250 to 300 msec, a value that is equal to the score for complete recall. Within this period of time, however, there is apparently an initial amount of information present in VSR which is much larger than the amount that can be read out of it. One limitation of this kind of registration is its short duration: the classification by the central processing unit occurs too slowly compared to the rapid decline of the visual availability. A second characteristic of registration in VSR is its sensitivity to masking by new information. The effects of the appearance of a second stimulus, e.g., random patterns at the location of the verbal symbols, or a circle around the position where shortly before a symbol appeared, are fatal to the VSR contents. The effects themselves may be complex, involving both the reduction of the contrast of the first stimulus and a blockage of its transmission in a 'higher' part of the perceptual system.

The course of the representation of information in VSR has recently been determined along a slightly different line by Vanthoor and Eijkman (1973). Their subjects were asked not to recall the marked stimulus but they had to indicate upon every trial how certain they were that each of

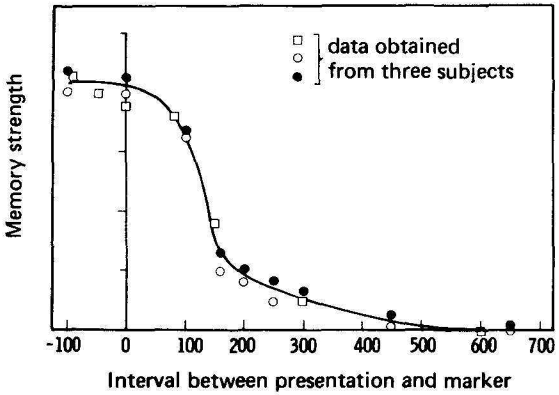

Fig. 3. Time course of the strength of the memory representation in VSR, based on confidence ratings and signal detection measures (after Vanthoor and Eijkman, 1973).

the presented stimulus items had been marked. By means of signal detection measures, the 'strength' of the sensory registration was determined over an interval ranging from −100 to +650 msec.

From the results (see fig. 3) it appears that over this period of time the strength continually declines and that the greatest loss of information occurs between 100 and 300 msec, which concurs with the data based on recall obtained by Sperling (1960).

2.1.2. Auditory sensory registration (ASR)

Outside the sphere of the laboratory one may envisage a situation in which one is deeply involved in reading a book while someone is apparently saying something. In that case one's reaction is too slow to listen to the message 'real time' but while one is asking for the message to be repeated (What did you say?), the message is as yet received (Would you like another cup of coffee?) and one is still able to provide the answer (Yes, please!) to the auditory event of several seconds before that has thus been 'played back'.

In accordance with this phenomenon it appears from research with dichotic listening tasks – in which the subject is given two *simultaneous messages*, one in each ear, often with the instruction to pay attention to only one of them – that subjects are able to a certain extent to react adequately to the neglected message. This applies especially in the case where they are allowed to listen now and then to what has meanwhile been presented to the 'neglected' ear (Broadbent, 1954). This performance relies on the *delayed* transmission of speech sounds that are represented in the sensory register of the auditory system, ASR. Different names that may be found in the literature, though not always with strictly identical implications, are, e.g., 'echoic memory' (Neisser, 1967), 'auditory information storage' or AIS (Sperling, 1967) and 'precategorical acoustic storage' or PAS (Crowder and Morton, 1969).

In STM experiments this kind of buffer storage appears in several different ways. Firstly, there is the procedure employed by Moray, Bates and Barnett (1965), which is closely related both to the dichotic tasks that we have just mentioned and to the partial reproduction technique referred to in the last section (2.1.1). These authors presented four simultaneous messages by means of headphones. To the subjects these messages gave the impression of being localized at the two ears and at two locations on the left and on the right 'inside' the head. When the subject was subsequently instructed by means of a light signal to recall one of the messages (spoken letter names) it appeared that the subject initially had available more information than one would decide on the basis of his score for complete recall. This result, therefore, is the analogue of what has been found in the case of VSR. The temporal characteristics of ASR were closely examined in a study by Darwin, Turvey and Crowder (1972). They required the recall of one out of three simultaneous lists, each containing three spoken digits or letters. The result was that especially the last item of the recalled list showed a steadily declining advantage of partial recall lasting at least 2 sec. The fact that this effect could only be noticed for the last item is in agreement with the notion that the earlier items are 'overwritten' by later items, so that their availability in ASR is seriously damaged. This too is analogous to VSR, although it should of course be noted that in ASR other stimulus characteristics play a role other than spatial overlap or proximity, which determine the masking of VSR information. There is, however, a difference of a more fundamental kind, namely the fact that acoustic information is in the first instance continuous; also within the boundaries of a segment – that is later to be recognized, e.g., as a syllable – there is a succession of speech sounds and thus there is in principle a chance that earlier information will be erased by later ininformation.

A striking feature of the results thus far is the relatively long effective duration of ASR (several seconds) compared to VSR (several tenths of a second). This is possibly the cause of the so-called *modality effect*: subjects who have heard a list of verbal items being read out (or who have read out this list themselves) are able to recall the last items of the list better than when presentation was merely visual (or the subjects' articulation silent). The suggestion that has been made, e.g., by Crowder and Morton (1969), is that ASR (PAS in their terminology) of the last item is available long enough to provide additional support to the implicit rehearsal by the subject that precedes his explicit recall. For a similar support from VSR during visual presentation, however, the sensory registration in that modality would have deteriorated too rapidly.

The last phenomenon we shall discuss in the context of ASR is the so-called *suffix effect*, i.e., the phenomenon that the modality effect discussed above is demolished if within a period of two to three seconds an additional spoken item follows the auditory list that is to be recalled. The suffix effect occurs even though the additional item (suffix) is redundant and does not require any response, such as the word 'stop'. After the above discussion on the erasure of older auditory information by more recent information, the phenomenon of the suffix effect itself does not need any further attention, except perhaps to emphasize the fact that for entry into ASR it does not seem to matter whether or not the (last) speech sounds belong to the material that is to be committed to memory.

Of special importance is the use of the stimulus suffix to determine the various characteristics of auditory sensory registration. No disturbance appears to be caused by an extra stimulus in the visual modality or by an auditory stimulus such as a buzzer, noise or any other sound that does not resemble speech. The suffix has an effect only if it is spoken or if it is a synthetic sound with the characteristics of speech (see fig. 4). It makes little or no difference whether the suffix is a word belonging to the same class as the words of the list that is to be recalled (e.g., the digit 'nought' as a suffix following a list of digits) or whether it is a completely meaningless word (e.g., an utterance like 'eh'), or a segment of speech played backwards. The suffix effect occurs in moderate form if differentiation between the items to be recalled and the spoken suffix item is possible, for example, on the basis of directional cues, loudness or voice characteristics. (For a survey of these experimental data, see Crowder, 1972.)

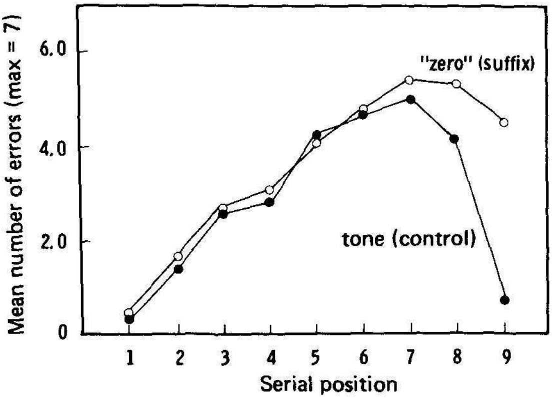

Fig. 4. Serial position curve for the recall from STM of an auditorily presented list of nine digits, followed either by the redundant digit 0 or by a tone (control). The experimental condition shows a relatively large number of errors at the last serial position: the suffix effect. The curve obtained for visual presentation is approximately equal to that for the suffix condition: the modality effect (after Crowder, 1972, with perm. from MIT Press).

The fact that the meaning of the suffix does not play a role in the size of the suffix effect is in agreement with the localization of the effect in the sensory register, i.e., at a pre-categorical level. How exactly it exerts its influence there is not at all clear. A plausible assumption may be that the subject cannot neglect a speech sound with, for example, the same voice characteristics and localization cues as the items to be recalled, when he is busy retrieving these items from STM. In that case the results would be very similar to those obtained in experiments on selective listening to one message while another simultaneous message is to be discarded (for a survey see Treisman, 1969). The above results indeed show several striking parallels to the data in the literature on selective attention (see chapter 8).

A point of discussion that has been brought up recently is whether ASR represents all the information that is present in the acoustic speech signal in an equally reliable fashion. Crowder (1973) suggests that, for example, especially long vowels are well maintained in ASR in contrast to plosive consonants. These differences might be related to differences in the manner in which these speech sounds are supposed to be processed linguistically (see Shankweiler and Studdert-Kennedy, 1967). Before attributing too much weight to these arguments, however, one must question whether the data obtained by Crowder is in fact decisive for a differential retention in ASR of different types of speech sounds. It cannot be ruled out that the consonants he used in this experiment were less well discriminable from one another than the vowels used. Given a certain degree of deterioration due to noise in the system, ASR information would in that case still be effective in the retrieval of the vowels but no longer in the retrieval of the consonants. Recently, Darwin (1973) has presented data that do indeed show that a modality effect and a suffix effect can be obtained with consonants if they are sufficiently discriminable among themselves.

In the preceding paragraph the effect of the stimulus suffix, as it has been studied in the experiments of Crowder, has been related to the masking stimulus in experiments concerning VSR. It may, however, be asked whether this analogy holds. For masking in VSR, the structure of the second stimulus is irrelevant; every light flash has an equally strong masking effect. Also, within the auditory modality there is a distinction between suffix conditions in memory experiments and masking in perception tests. It appears that the detection of a sound in the backward masking paradigm is subject to a greater influence if the masking stimulus is louder, irrespective of whether this is a buzzing tone or a second speech sound. (For a survey, see Massaro, 1972). In view of these findings, the locus of action of the suffix cannot any longer be sought at a purely sensory level. Neither, however, may the suffix effect be simply localized at a postperceptual STM stage; we saw that there is no effect of class membership. It appears, moreover, that common phonemes in items belonging to the memory list and the suffix item do not play a role (Crowder and Cheng, 1973), whereas we shall see (2.2) that exactly this form of acoustic similarity has a predominant influence on postperceptual STM forgetting. In short, the question where exactly the suffix exerts its influence can as yet not be answered. It is not impossible that – in analogy to data obtained in visual experiments by, for example, Posner, Boyes, Eichelman and Taylor (1969) – a 'postperceptual' but still purely auditory storage exists which is under the control of the subject's strategy but which is not resistent to later auditory stimulation.

Sanders (1974) provides a somewhat different explanation for the modality effect and the suffix effect. He starts from the assumption that, especially during auditory presentation, the memory items are connected with position cues. The last of these are directly available during recall; the last items therefore have a retrieval priority. Under suffix conditions they would to a large extent lose this priority to the more recent suffix item. During visual presentation, there would be a strategy that is completely different from the start: cumulative rehearsal. On the one hand, such rehearsal is necessary because of the poor equipment of the visual modality for maintaining sequences; on the other hand, it is fairly well possible because of the greater degree of freedom that is allowed to the subject during visual presentation to choose the moment when he adds the lastly arrived item to his rehearsal cycle. The result is that, upon visual presentation, especially the first items of a list are well rehearsed, whereas the latter ones receive a decreasing amount of attention because of an increasing lack of time for cumulative rehearsal towards the end of the list (see also 2.2.2).

2.2. *Storage of information in STM*

The flow chart of fig. 1 represents human memory according to a multistage model. The sensory registers were discussed in the last section. In that section, however, recognition and coding of sensorily registered information were assumed to allow recall. As soon as the informtion is coded, i.e., has been related to categories in LTM, different principles of retention and forgetting apply. It is useful here to make a distinction between the fate, on the one hand, of unconnected items that are presented only once for almost immediate recall or recognition (STM, the first stage) and, on the other hand, of items from a set with a certain internal coherence or presented under such conditions that certain connections can be established (LTM, the second stage). This distinction corresponds to differences in coding that are, among other things, related to opportunities for and to the desirability of anchoring the information in the data base of LTM (cf. 1.2).

Multi-stage models of memory have been proposed in the literature with some regularity (e.g., Waugh and Norman, 1965; Glanzer and Cunitz, 1966; Atkinson and Shiffrin, 1968; Morton, 1970). According to Craik and Lockhart (1972) they have the advantage of being specific and concrete: "information flows in well-regulated paths between stores whose characteristics have intuitive appeal; their properties may be elicited by experiment and described either behaviorally or mathematically". In the following sections, however, it will appear that the properties of the components and the relations between them are not so unambiguous. It will become apparent that it is not merely a matter of giving more precise definitions of the successive stages and a more precise statement on their mutual relationships that prevent us from formulating the ultimate universal model of memory. On the contrary, many investigators are now of the opinion that the system as a whole is subject to the extremely flexible and idiosyncratic control strategies that are adopted by the subjects.

The present section is devoted mainly to the first stage, STM, which – as indicated above (1.1) – is distinguished from LTM by, for example, its limited capacity. Although there is also another measure of capacity (see 2.2.), the usual measure is the extent of the *memory span*: the maximum number of verbal items (digits, words) that can be recalled correctly in their original order immediately upon their single presentation. Apart from the coding characteristics that we shall discuss later (2.2.2), STM is further distinguished from LTM both by, on the one hand, the fast rate of retrieval of its information and on the other, the rapid onset of forgetting without leaving any permanent trace if attention is distracted from the STM content.

The steep decay of memory information and the conditions that have an effect on this rate have, during the past decades, received a great deal of attention from a large number of investigators. (The first authors were Brown, 1954; Broadbent, 1958; Peterson and Peterson, 1959.) The results of their research are a series of new techniques, a large amount of data and a number of fruitful theories that, because of the central role played by 'storage' during various information transmission processes, generally have a bearing far beyond the range of the typical STM tasks themselves. In the following sections these will be discussed: we shall start with some technical data.

2.2.1. *Some technical data concerning STM*

Memory research is usually referred to as STM or short-term memory research if the material to be retained is presented only once and if its retention is tested within 30 sec or at most within one minute after its presentation. This test may involve the complete recall of the list of items in the order of their presentation, such as is done in memory span tests, i.e., *serial recall.* Modifications of this kind of recall are, for example, order changes. Thus one may ask the subject to recall the last items first. By manipulations of this kind an important feature of serial recall is revealed, namely the fact that retrieving and recalling an item from memory exerts an unfavorable effect upon the recall of later items from the same list. This then is the result either of the course of time (trace decay) or of the retrieval and recall activity itself (output interference). If, for example, the subject is allowed to start his recall at the later half of the list of verbal items, far fewer errors are made in the last serial positions than in the first, whereas, under conditions of recall in the order of presentation, the majority of errors are made in the second half of the list. We shall return later to the typical distribution of errors over the serial positions of the list, within the context of memory tasks involving *free recall.* In these tasks the length of the presented list usually exceeds the memory span; in his recall attempt, however, the subject may choose the order of recall that suits him best.

A technical improvement that meets the objection that recall of an item inadvertently affects the recall of other items is the use of a 'probe'. Upon the presentation of a list one merely tests one single item from the list. As '*probe word*' one may present, for example, the preceding word; the subject is required to respond with the next word from the list. This technique (that thus allows a more accurate measurement of the retention of one single item at the cost of the presentation of a larger number of lists) again yields a typical distribution of errors over the positions of the list: the most recent items are recalled best and the majority of the errors are made on the oldest items (e.g., Waugh and Norman, 1965). This is most likely the result of the entrance of later items (input interference), but possibly also owing to passive decay of the memory trace in time (see 3.1).

It is also possible to test the retention of paired associates over the short STM interval. In this condition the list of pairs is kept short (e.g., five pairs) and immediately after the single presentation of the list one pair is tested for retention by presenting the appropriate stimulus item and asking the subject for the response item that was paired to it. This technique of *minimal paired associate learning* was first applied by Murdock (1963).

Directly related to the emergence of interest in 'immediate memory' is the technique of 'distractor' tasks that themselves do not involve retention and in which are presented items of such a kind that their confusion with the items to be retained cannot occur. The subject may be presented with a list of items or with a single item under the instruction that immediately after its presentation he is to perform another task that may be regarded as a *filler task*, for example, copying arrows, naming ('shadowing'), copying a number of letters, or counting backwards in steps of three from a three-digit number, e.g., *489*, *486*, *483*, etc. Such counting backwards is done aloud at a rate (e.g., one per second) imposed by a metronome. At a signal from the experimenter – the termination of the retention interval to be investigated – the subject stops his distractor task and attempts to recall the retained items. The data by Peterson and Peterson (1959), from which it appears that a trigram (e.g., *CSL*) is almost completely forgotten within 18 sec if the retention interval is filled by such a counting task (see fig. 5), are by now classic.

A refined recall technique is *partial recall* which we have already mentioned (2.1.1; 2.1.2). It differs from the probe technique mainly in that the cue for recall is not an item presented beforehand as one of the stimulus items to be recalled, but is a different signal that, in accordance with the instruction, corresponds to a part of the presented material that is to be recalled. This may be, for example, a tone corresponding to a row from a matrix or a light indicating the spatial location of one required item out of various simultaneously presented items.

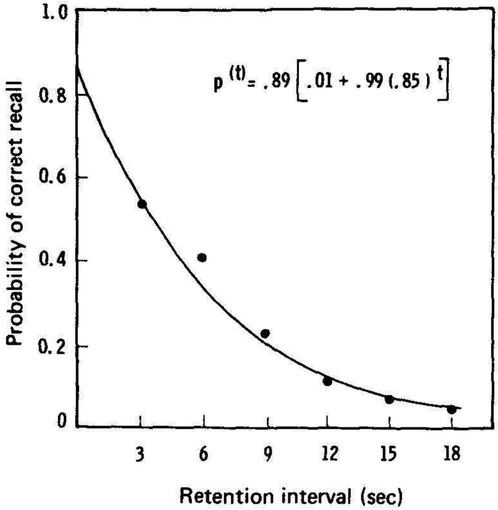

Fig. 5. Retention curve for a single trigram during the performance of a filler task (counting backwards). The curve is based on the responses with latencies below 2.83 sec. The asymptotic value, which is very low (0.0089), is reached within 20 sec (after Peterson and Peterson, 1959).

Apart from the recall tasks mentioned, *recognition tasks* are also used in the study of short-term memory. A certain time after the presentation of the list, the subject is required to recognize one item out of several alternatives. The item may also be presented by itself with the instruction to the subject to index it as 'old' in contrast to the response 'new' that applies to (distractor) items that were not presented earlier as list items. The latter technique allows the application of measures from signal detection theory by the use of confidence judgments or reaction times (see, e.g., Banks, 1970). The recognition paradigm, in combination with the recording of reaction times, is appropriate for the study of *search processes* that look for information in memory. The subject is asked to indicate as fast as possible whether or not a test item was present among the items of an earlier presented memory list. If the set of items in memory is varied systematically, various properties of the scanning or search process, such as its rate, may be derived. The results obtained by means of this method by Sternberg (1969) are regarded as support for a serial search procedure that, preceding a response, searches all items in STM exhaustively for correspondence with the test item.

2.2.2. Coding, rehearsal and retention in STM

Acoustic coding

Sperling (1963) mentioned the fact that in the tachistoscopic experiments discussed above (2.1.1) his subjects made systematic recall errors that could not be explained on the basis of features typical for the visual presentation modality, but rather on the basis of certain phonological properties of the material to be retained (e.g., *T* for *D*). Conrad (1964) made a more thorough study of the errors occurring in the immediate recall of a visually presented memory sequence. His results, put down in confusion matrices, generally display a striking correspondence with the results of a listening test in which individual items are heard against a background of noise. In other words, if a subject is presented auditorily with the letter name for *V* together with a considerable amount of noise, he will often perceive the item imperfectly and respond, for example, more often with the erroneous response item *G* than with *T* or *N*. Similarly, a subject who has partly forgotten the *V* belonging to the list *P, R, L, D, V, S* in STM will be inclined more often to respond instead with the letter *G* than with *T* or *N* even if the list is presented visually and recalled in written form. Since 1964 it is generally assumed that in STM the 'acoustic' code prevails. The symbols recognized from SR are adapted to the class names that are stored in LTM (adaptation to the 'internal nomenclature'; see 1.2), and they are in some way or other realized in an acoustic or articulatory mode.

Some models specify the code at the level of the phonemes (e.g., Sperling and Speelman, 1970); others demonstrate an effect at the level of the distinctive features of the phonemes (Cole, Haber and Sales, 1973). In the example given above, the prevalence of a *V*–*T* confusion over a *V*–*N* confusion may be ascribed to the difference between the vowel phonemes /e/ and /ɛ/. The prevalence of a *V*–*G* confusion over a *V*–*T* confusion, however, must be due to the distinctive features (e.g., affriction) of the consonant phonemes according to which the similarity between *V* and *G* is greater than that between *V* and *T*. Mutual agreement between verbal items on a larger number of 'feature' dimensions generally leads to a larger number of confusions in STM tasks (cf. Thomassen, 1970; Cole et al., 1973).

Since 1964, the role of acoustic (phoneme) similarity in STM has been the theme of many studies. Typical are the findings of Baddeley. In an STM experiment he presented his subjects with lists of words having a high degree of phoneme similarity and he found that the inter-item interference was very disturbing in these lists as compared to control lists. Semantic similarity, however, was hardly effective, if at all (Baddeley, 1966a). When he presented his subjects with longer lists to be learned in a number of presentations, so that there was in fact an LTM situation, he obtained the contrary effect, namely, a large disruptive influence of semantic similarity between words and absolutely no effect of phoneme similarity. In order to eliminate the influence of STM factors in the LTM task, Baddeley (1966b), in this experiment, used a filler task as a control measure: he took care that every presentation of the list of words to be learned was followed by a number of short digit sequences to be recalled immediately. The effect of acoustic similarity on proactive and retroactive inhibition in STM has also been demonstrated (Wickelgren, 1966a). In a study employing the probe word technique, Kintsch and Buschke (1969) found that in a list of 16 words the effect of phoneme similarity is present only at the last serial positions, whereas the effect of semantic similarity remains limited to positions early in the list. Although different results have also been reported (for an overview see Schulman, 1971), the data quoted are representative for what has been observed under a large number of experimental conditions, that is to say, when use is made of the presentation mode (rate, material) that is generally adopted for experiments of this kind. We shall return later to the latter restriction. Under less strict conditions, such as, for example, in reading tasks and in listening to speech, it must indeed be assumed that upon perception at a certain elementary level, coding and retention are achieved in terms of syntactic and semantic units.

Level of coding

Paying attention to verbal input implies the making of contact between the input units and the information stored in LTM. This may be done quite efficiently by applying the uniform code that has been made available *par excellence* by the learning of speech. This memory code, which, as we saw, occurs in most STM experiments, may be regarded as the result of the first perceptual processing during the read-out of SR. Under normal conditions, a complete hierarchy of perceptual-linguistic processing operations would also involve a grammatical and semantic analysis, but considering the often unconnected ‘meaningless’ material and the high rate of presentation, such a complete processing of input will rarely be attained. On the other hand, there will generally be no need for such an analysis if the task requirements in STM experiments are taken into account. Often it may be desirable, and usually it is also possible, that already during presentation rehearsal (see below) of the information that has been coded as a phoneme sequence takes place. The time required for such rehearsal will most likely be subtracted from the total time available for further processing, and therefore for the attained level of the code. Comparatively little time is required for grouping the verbal items into a rhythmic structure (see 2.4.1), but all other kinds of recoding, even the relatively simple use of natural language mediators (see 1.2), presuppose making contact with the more complex semantic structures in LTM which are not as directly accessible as the name code. Reference to LTM is most often too time-consuming for an effective use in STM experiments. Evidence that indeed the time factor determines the level of coding is provided, for example, by the observation of Sperling and Speelman (1970) that a number of their subjects had applied 'recoding'. This group did not show any effect of the phoneme similarity present in the material. Also, the results obtained by Kintsch and Buschke (1969), mentioned above, stress the importance of the time variable for the nature of the code that is adopted.

However, it appears that a large amount of time available during presentation does not necessarily result in such a code that the information can be retrieved exclusively along a semantic-associative route and no longer along acoustic-articulatory lines. Examples of this are the effectiveness of rhyme in LTM (see also Bower, 1970) and the 'tip-of-the-tongue' (TOT) phenomenon (Brown and McNeill, 1966). The latter effect occurs when the subject has a word almost ready for pronunciation but not yet quite sufficiently for its articulation; in this state, however, one can remember, for example, the word's rhythmic structure and its initial sound. In experimental conditions that are typically characterized as LTM, acoustic cues may appear to form even the primary cues. This has been observed for conditions where the material was absolutely meaningless, where the time available during the learning stage was limited, where a secondary task was to be performed simultaneously, and also where, for example, an instruction was given to deal with the items in a 'passive' fashion during acquisition (see Schulman, 1971). If, on the contrary, 'semantic coding' is observed in STM experiments, this might be due to the opportunity for the subjects to let LTM factors play a role during learning or to let semantic retrieval cues be effective during the retrieval of acoustically coded information. This data itself constitutes a plea for making a distinction not between an STM code and an LTM code but between acoustic and semantic codes, with the notation that the former will often suffice in STM experiments whereas the latter is generally both possible and required in LTM experiments.

Unit of coding

As regards the extent of the unit of coding, highly different sizes may be assumed. The most obvious assumption is that the STM code has the size of the items presented in the memory task, i.e., syllables, words, or letter names. If the latter are grouped, for instance, as *CCC* (Murdock, 1961), or if the words constitute standard expressions (Glanzer, 1972) then the trigram or the expression as a whole may be the coding unit that needs no further processing. Following different lines of reasoning, the model of Sperling and Speelman (1970) assumes coding at the level of the phoneme and, as we saw, even phonologically distinctive features and other attributes have been mentioned as the unit of coding. It remains to be seen, however, to what extent an 'independently' coded property, for example, the initial phoneme of a word that may possibly serve as a retrieval cue, can also be regarded as the coding unit. At any rate it is likely that the unit size – also within the acoustic form of coding – is again dependent on the degree of perceptual processing, which will be higher when a list of words is studied than when a sequence of bigrams is committed to memory. Such differences would correspond to the fact that even within STM optional selection from a variety of different coding formats plays a role.

Auditory or articulation code

A specific problem is represented by the question whether representation in STM is mainly in terms of auditory images or in terms of articulation (images or feedback), or even perhaps 'abstract' without any direct connection with the perceptual or productive equipment for speech processing. Sperling (1967) has theoretical grounds for preferring 'acoustic' memory representation. Hintzman (1967), however, concludes on the basis of confusion data that STM coding would be in terms of articulation. Levy (1971) demonstrated that whether subjects code auditorily or articulatorily may depend on the task. The coding reactions that, under the experimental conditions, are given to the individual items are subjects' *responses* and, as such, they may at first bear articulatory motor features. If oral recall is required (and, in analogy, also during written recall), the articulation code may be the most preferable because it is highly compatible with the overt response. The question now is whether it can be determined empirically if the STM code does indeed show articulation features rather than features of the acoustic patterns which in speech communication are by necessity causally related to the articulatory patterns. The possibility of distinguishing between these forms of coding has been denied by several authors (e.g., Wickelgren, 1969; Sperling and Speelman, 1970).

A possible opportunity to differentiate between an STM code and an auditory perception code is, in our opinion, provided by the circumstance that, in the STM recall of the last serial positions of an auditorily presented sequence, a contribution is made by the sensory aftereffect of the auditory signal (see 2.1.2: ASR information). If it is found that the type of errors made in the terminal positions after auditory presentation is different from the pattern of confusion errors normally obtained in STM studies, and if, moreover, it is found that the confusions observed here are indeed more similar to those found in auditory perception tasks, then this is evidence of a real difference between an auditory code and an STM code. Under these circumstances it would then appear to be possible that the former plays a role in the use of ASR information during an STM task. Thomassen (1975) presented data indicating that information on the place of articulation of the phonemes contributes more to STM recall than to either auditory perception or ASR recall, whereas these relationships are reversed where information on voicing is concerned.

Rehearsal

In its strictest sense, 'rehearsal' is the repeated, successive application of (implicit) LTM speech codes upon verbal information in STM by the central processing unit. Thus the representations of the items and of their order in memory are temporarily made more resistant to forgetting. 'Rehearsal' was already an essential feature of the memory model of Broadbent (1958). In this model the total capacity available in STM (the *P* system) is divided between the coding of new items and the rehearsal of items that have already been coded. At present this is still the common opinion; only the notion of rehearsal of verbal items has acquired a more specific content so that it is no longer tenable that the rehearsal output of the coding mechanism is put into the sensory registers (the *S* system) in the same mode as the original sensory information. Apart from STM information, rehearsal can also involve LTM data. An illustration of this is provided by the experiments of Sternberg (1969) in which no difference was found between search processes involving memory lists that were held constant (LTM condition) and lists that were varied (STM condition) (see 2.2.1). Apparently, the LTM items were held in an STM 'working memory' by means of rehearsal.

For some time there has been a discussion as to whether repetition strengthens the memory trace in STM or merely delays the onset of the forgetting process. It is known – and in some models this has been explicitly stated (Atkinson and Shiffrin, 1968) – that transfer of information into LTM can take place during rehearsal, where the transfer may or may not entail a change of the format of the code. Craik and Lockhart (1972) distinguish Type 1 rehearsal, where the information remains at the same level of processing, and Type 2 rehearsal, where a further stage of processing is attained. According to the authors, only the latter type causes a permanent advantage due to rehearsal. Below we shall discuss the serial position phenomena during free recall. In that context it will appear that only a certain part of the memorized list, a part that is associated with STM rather than LTM, is dependent upon the opportunity for rehearsal. If the subject is given permission to recall immediately, his recall of the last items of the list seems to profit very little from such rehearsal. This constitutes evidence against the hypothesis that STM representations, as such, are strengthened by rehearsal. This does appear logical in the perspective of our discussion on the level of coding. It is most likely that with repeated rehearsal an increasing role is played by various organization principles and that more and more items are recoded through verbal mediation, or otherwise, and thus entered into the LTM data base (see 1.2).

The capacity of STM as defined according to, for example, the memory span has been claimed to equal the number of items that can be rehearsed in one cycle, i.e., the number of items that can pass through the processing unit up to the moment that the first rehearsed item has deteriorated so much that it is only barely recognizable for retrieval and inclusion in the next rehearsal cycle. However, the relationship between rehearsal and capacity is not sufficiently clear. An example of this is a proverb containing four words but constituting only one coding unit and thus taking only one memory position in STM (see above). The question is whether one must assume that the entire proverb is entered into the rehearsal cycle or, for example, only the first word through which the whole expression can be rapidly retrieved from LTM. A further issue concerned with STM capacity is its determination (see p. 107) on the basis of serial position phenomena. Such determinations yield a capacity that is a factor two or three lower than the classical digit span; the question is how rehearsal of the entire memory span is possible in such a small-capacity store.

There are various other themes concerned with rehearsal, that we shall only mention. First, rehearsal is not always implied to involve a serial process where the items are successively brought under the subject's attention; sometimes a more or less parallel, general monitoring of a number of items is meant. Furthermore, rehearsal need not always be a strategy that is deliberately chosen by the subject. Finally, rehearsal as a voluntary implicit verbal activity is at any rate suppressed with a certain high probability if one employs a filler task that also requires intensive verbal processing (e.g., counting backwards, shadowing, naming colors, etc.). The rapid rate of forgetting under these conditions may once again appear from figs. 2 and 5.

STM associations

If repeated rehearsal can strengthen the representation of a list of items in STM, there is the possibility that this strengthening is merely due to an improvement of the relations among the items, i.e., to the forming and strengthening of inter-item associations under the influence of repetition (see, e.g., Sanders, 1974). Research on the establishment of associations in STM has been performed by Wickelgren (1965a). In recall errors of STM lists containing several occurrences of the same item (e.g., *4373968*) he observed that the items *7* and *9* which follow the repeated item *3* have an increased chance of taking each other's place during recall, obviously as a result of a specific form of interference. Wickelgren named these errors 'associative intrusions'. He assumes that there is a single internal representation corresponding to a certain verbal item; the internal representation is activated every time that the item is presented and it is connected to the internal representation of other presented items, especially of the one immediately following, through associations. Thus, as a rule, correct serial recall is possible. In lists containing repeated items, however, associative intrusions are the inevitable result of the fact that through direct forward associations one internal representation is connected with more than one other internal representation (see fig. 6a).

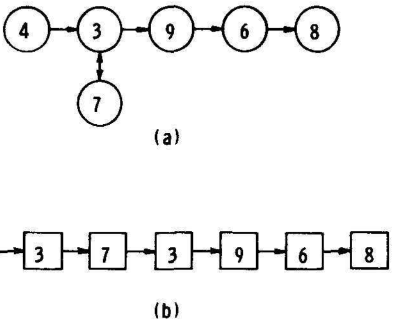

Fig. 6. Associative model (a) and 'slot' model (b) describing the storage and retrieval of a short list of verbal items (digits) in STM (after Wickelgren, 1966b).

The explanation, however, of why in such sequences there are always many more instances of correct order recall (and, in fact, also many more other order errors) than there are associative intrusions, would require the postulation of a different form of association. Possibly effective as further connections are, of course, more remote and also backward associations; but according to Wickelgren there are also associations between the item representations and serial position features such as 'beginning', 'middle', 'penultimate', etc. These are association types that are not part of the inter-item connections to be discussed here. As an explanation of the correct serial recall, they are in fact akin to the main alternative for the inter-item association model that we shall soon discuss. With Wickelgren (1965b) one may regard a list of items (e.g., letter names) in STM as a sequence of phonemes. One might assume that the associative relations would also hold at the level of the phonemes. Predictions concerning such connections, however, are usually not confirmed. Thus, there are no more frequent associative intrusions between *S* and *F* than between *S* and *P* (Wickelgren, 1966b), although within the first pair of letter names – and not in the second pair – the initial phonemes are the same. Neither could Baddeley (1968) demonstrate a relatively large number of intrusions between the letters following a single phoneme (e.g., following *P* and

G, the letter names of which have an identical final phoneme). We regret to say that this data, which presents evidence against the existence of inter-item associations in STM, only has a bearing upon the deduction that sequences of items may be regarded as sequences of phonemes. To our knowledge, inter-item association hypotheses concerning integral items have never been confirmed in an unambiguous fashion in the STM literature either.

A demonstration of associations of this kind would have the advantage of placing STM and LTM phenomena on one continuum. Supporters of the continuity hypothesis have, in line with the above associative reasoning, attempted to demonstrate that an STM list is gradually better retained if it is repeatedly presented (Melton, 1963). In the next section, however, it will appear that the supposed formation and strengthening of associations between successive items that are implied, do not occur automatically, not even during the repeated presentation of the same item sequence, but that any improvement in recall depends on the structure of the list as a whole. Rhythmic or grouping structures possibly provide anchoring points to certain positions in the list to which (by associations of a different type) items may be connected.

This is in fact a flexible version of the classic alternative interpretation of correct serial recall. In its original form, this interpretation assumes that during their presentation the items of an STM list are localized successively in a permanent row of cells ('slots') which belong to the serial positions. The size of the row is supposed to be equal to memory span. Read-out of the cells is always done in the same direction and will be performed without any error if the time interval following the deposit of the items in their cells is not too long (see fig. 6b). Interaction between the cells is, according to this 'slot' model, not possible. From the data of Conrad (1960) it appears that subjects show a tendency to respond in recall with an item that, in the preceding list, would have been correct for the serial position in which it now appears erroneously. Such a 'serial position intrusion' would reflect the residue of the previous occupation of the cell involved. This phenomenon will be particularly difficult to explain according to an inter-item association model; associative intrusions in turn provide great difficulty for a 'slot' interpretation of STM. The obvious conclusion is that probably both explanations are valid, i.e., that it is possible that items or their internal representations are connected through associations so that retrieval of each item is facilitated by the preceding item and that certain items are connected through associations of a different type to specific positions in the sequence; among the latter are at least the most conspicuous positions in the list. The prevalence of one type of connection over the other will be determined by the material as well as by the mode of presentation. Thus, connection to serial positions, and therefore the occurrence of serial position intrusions, will be brought about by the presentation of a large number of lists all having the same length and the same structure; it will be counteracted by a greatly varied presentation.

Visual STM code

The findings regarding coding in terms of speech as discussed above are, in general, equally representative for visual and auditory material. As far as the visual modality is concerned, however, there appear to be other STM coding possibilities as well for verbal material. Thus Kolers and Katzman (1966) showed that subjects are able to recall verbal items, albeit not in the correct order, that are presented so fast (12 per second) that their implicit verbal coding or rehearsal was ruled out. (Presentation of all these items was at the same spot so that, as a result of masking, no SR information was available either.) The result obtained by Sternberg (1969), that an indistinctly presented visual test item delays the search for that item in memory, similarly indicates the presence of visual characteristics in memory storage. In some cases, a nonverbal code is even amenable to rehearsal. Posner et al. (1969) were successful in their instruction to let the subject rehearse visually a single visual verbal symbol. The memory data show that with this strategy the memory material was highly resistant to the effect of a verbal filler task. An interesting modality difference related to this phenomenon was found by Kroll et al. (1970). They had a shadowing task performed during the retention of a single letter. The subjects were better able to perform the task if the letter was visually presented that when it was spoken.

Experiments by Scarborough (1972) demonstrate that the retention of an auditorily presented STM list is not severely hampered by the retention of a visual list presented in the meantime by means of a tachistoscopic exposition; nor does the auditory presentation affect performance in the visual task. Rehearsal of an auditory list that contained six to nine items must have occupied the verbal STM capacity to a considerable extent. One may therefore assume that there was hardly any verbalization of the visual list. The retention of the latter may accordingly depend on a visual form of storage which, as is shown by the results of Scarborough, is maintained for several seconds, thus surpassing the much shorter duration of visual sensory registration. Taken together, the data indicates that it is possible, under circumstances which are unfavorable for verbal coding and rehearsal, to hold the visually presented verbal symbols in their original modality. Apparently the subject can adopt this strategy in order to avoid, for example, intrusions between items from the memory material and the filler task. At present no data is available to decide on the efficiency of the discussed coding modalities for different types of material, but it may be expected that the verbal code will prove to be superior for storing and retaining order information.

Serial position phenomena

If a subject is presented with a list of words that exceeds his memory span and if he is given a free recall instruction for the whole list, he will generally start recalling the last words first and subsequently attempt the recall of any earlier items he remembers. The results (see, e.g., Glanzer, 1972) show that the last (most recent) six to eight items are recalled much better than the earlier items. This *recency effect* (see fig. 7a) must be seen as an STM phenomenon in contrast to the LTM processes that are responsible for the (much less successful) retention of the earlier items. A filler task of 30 sec following the presentation of the list results in a complete disappearance of the recency advantage, whereas the recall level of the earlier items hardly shows any decline (see fig. 7b). It may be noted here in passing that there is a distinction between the modality effect and the recency effect. Stressing this distinction is desirable because for ASR, upon which the modality effect rests, the term 'echoic storage' (Neisser, 1967) is used, whereas the term 'echo box' has become popular in connection with the retention of the most recent items in free recall tasks. Both these end effects are concerned with an advantage of the final items in a memory list; an advantage that may be easily be disturbed. The modality effect, however, is confined to auditory presentation and has an effective duration of several seconds, whereas the recency effect also appears after visual presentation and has an estimated duration of about 20 to 30 sec. A combination of the two, to be expected after the auditory presentation of a

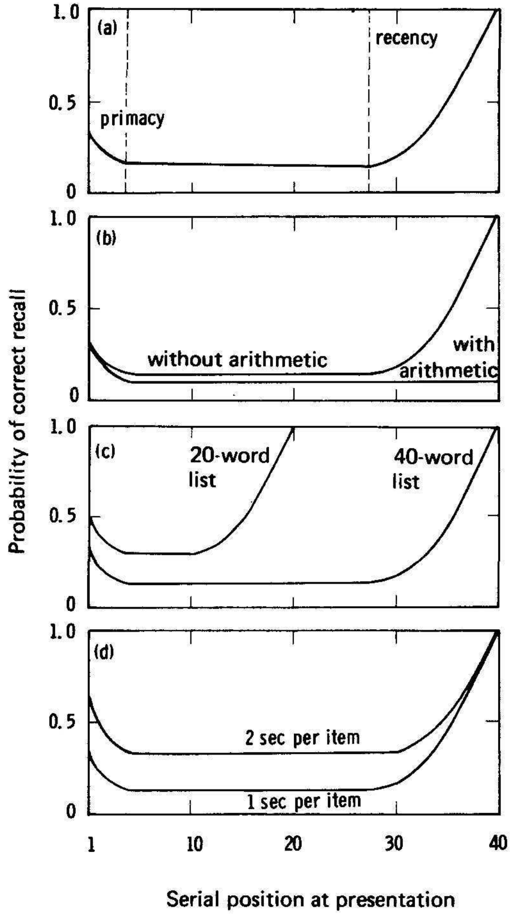

Fig. 7. Serial position curves for free recall of long lists of unconnected words. (a) Primacy effect, asymptote and recency effect. (b) If recall is delayed by an interval of 30 sec, during which an arithmetic filler task is performed, the recency effect is selectively affected. A number of other variables such as (c) list length and (d) rate of presentation have an effect on primacy and asymptote value exclusively. The curves are idealized (after Atkinson and Shiffrin, 1971).

list for free recall, will be reflected by a somewhat S-shaped recency curve. All items preceding the final items in a free recall task (and thus preceding the items that show the recency effect) are recalled less well. Among these items, however, the first one to three from the list are distinguished from the remaining items which all have an equal probability of correct recall (asymptote). The initial advantage of the very first items, called the *primacy effect* (see fig. 7a), is probably due to the fact that these items can still be rehearsed adequately, and thus be learned fairly well, because at their arrival there are no other items present in STM; the first items therefore do not yet have to share rehearsal capacity with any other items. The assumption that the primacy effect is indeed related to rehearsal is due to the fact that a second task to be performed during presentation in order to suppress rehearsal mainly affects the primacy effect in the serial position curve (Baddeley, 1968). The results of Bernbach (1967), who had children remember sequences of colors, point in the same direction. Only after he had given them a great deal of practice in the naming of the colors, so that implicit rehearsal became possible, could a primacy effect be discerned.

With the continued presentation of new items the system soon reaches a 'steady state', in which only a much reduced amount of the total available capacity can be devoted to each new item. Yet, the items are retained to some extent even after a filler task of half a minute. The same applies to the most recent items. Although in immediate recall these predominantly show their presence in STM, they are not exclusively represented there: to some extent they are – after a delay – available in LTM. The number of items present in STM during a free recall task can be taken as a measure of the capacity of STM. It can accordingly be determined from the recency part of the serial position curve, with a correction for the asymptote value which represents the presence of these items in LTM. The calculation per serial position is – in analogy[2] to the formula by Waugh and Norman (1965) – as follows:

$$P_i(\text{STM}) = \frac{P_i(\text{REP}) - P_i(\text{LTM})}{1 - P_i(\text{LTM})}$$

---

[2] Waugh and Norman (1965) state that recall of an item *i* may depend on information in STM (or *primary* memory) as well as in LTM (or *secondary* memory) as follows: $R_{(i)} = P_{(i)} + S_{(i)} - P_{(i)}S_{(i)}$, in which $R_{(i)}$ equals the probability of correct recall of item *i* and $P_{(i)}$ and $S_{(i)}$ the probability of the presence of item *i* in primary or secondary memory, respectively, during the time of recall. Thus a standard correction is presented to separate the STM component from the LTM component in probe word data. This 'correction for asymptote' implies an estimation of $S_{(i)}$ based on the mean recall level of the items preceding the last six or seven items of the list and it is worked out according to the formula $P_{(i)} = (R_{(i)} - S_{(i)})/(1 - S_{(i)})$.

in which P_i(STM) is the probability that item i is available in STM, P_i(REP) the probability of correct recall of item i, and P_i(LTM) the probability (estimated from the asymptote value) that item i is represented in LTM. The capacity is the sum of all P(STM) values for the last items. The STM capacity calculated by various authors by means of this method has been estimated at values between 2.5 and 3.5 items.

A minor inaccuracy in the present calculation is a slight overestimation of the asymptote value due to an effect of 'negative recency' (Craik, 1970). If after a session a subject is asked to recall once more all the items he has memorized, it appears that he will have slightly greater difficulty in recalling exactly those items that were, at first, on the basis of their availability in STM, relatively easy to recall. This need not be surprising because the items have been less well rehearsed since they were directly available in STM; moreover, the subject has had less practice in retrieving these items from LTM for exactly the same reason.

In contrast to recall delay, which affects the recency effect exclusively, there are other variables that have a selective effect on the primacy and asymptote portions of the curve without any effect on the recency part. Among these variables are, for example, length of the list, rate of presentation, number of presentations per word, word frequency and concreteness of the words. In brief, for all kinds of variables that affect the learning of the list, STM is relatively insensitive as far as it is reflected by the recency effect under free recall conditions (see fig. 7c, d).

These selective effects are regarded as arguments for the mutual independence of STM and LTM. The phenomenon of negative recency furthermore indicates that representation in STM does not imply an equal probability of transfer to LTM for all items, but rather that there are certain control strategies (such as rehearsal and organization) that bring about more permanent (LTM) storage. The latter conclusion must also be drawn from the results obtained by Restle (1970). He had his subjects learn paired associates in a continuous task in which learning and test trials alternated. One group of subjects was given the impression that the pairs would be tested soon (after two or four subsequent pairs); other subjects were led to expect testing somewhat later (after seven or nine subsequent pairs). An unannounced delay of testing of pairs was much more detrimental to the first group than to the second, who apparently had followed a 'permanence' strategy.

The measure for the capacity of STM given above is far below the *memory span* for which six to nine items are observed. The reason may be that, in span task more than in a free recall task with long lists, rehearsal can be applied profitably. In conditions where the lists hardly exceed or do not exceed the size of the memory span – especially under moderate presentation rates and with known list lengths – the subject will be more successful in applying strategic rehearsal and grouping than when the input of new items just keeps on flowing. Indeed, the primacy effect in serially recalled lists containing six to nine items usually is somewhat larger than that observed under free recall conditions for longer lists (cf. figs. 4 and 7). The above line of thought implies that even memory span performance partly depends on certain LTM mechanisms, which, in turn, is in agreement with results that sources of interference that are known to work in LTM are also effective in, for example, span-type performance (e.g., Melton, 1963) and with findings, such as those of Craik (1970), that memory span shows a lower correlation with STM than with LTM performance.

The question regarding the capacity of STM must be related directly to the form and the extent of the functional units that are coded, grouped and rehearsed by the subject. Of course, the existing LTM structures, especially those for linguistic processing, play the main role here. As far as the recording of larger linguistic units in STM is concerned, there appears to exist a very flexible capacity (for example, in terms of words in STM) not only if well-known verbal expressions of several words are to be retained, but also if new grammatical expressions, containing numerous words, are involved. The manner in which the appropriate linguistic analysis and coding are achieved – and especially in which these differ from the grouping of unconnected words – is, however, outside the scope of the present chapter (see chapter 8).

2.3. Storage of information in LTM

Verbal LTM comprises, firstly, a network in which the nodes correspond to concepts and the connections to associations among concepts, and, secondly, a network of connections between the lexical words of the language – specified both in terms of audition and articulation – and the concepts to which the words refer. The need to distinguish between these two networks is merely to account for the existence of homonyms (one word indicating more than one concept) and synonyms (more than one word indicating a single concept). Storage of information in LTM, more commonly referred to as *learning*, can therefore be considered an extension of the network: new words or concepts may be added and new associative word-concept or concept-concept connections may be made. For a very detailed network model, see Anderson and Bower (1973).

Little or nothing is known about the formation of new words and concepts (or, in other words, about the nodes and their labels). The only statement on this issue that can be made since Lashley's (1951) analysis is that learning a new word (e.g., *ooyep*) cannot simply be conceived of as making associative connections between the successive phonemes (*oo-y-e-p*). Regarding the origin of associations, two different notions are currently held. According to one theory, an association is gradually formed if the subject studies the material to be learned by sufficiently repeating it. The other theory pictures the formation of an association as a process which, once set into operation by the presentation of the learning material, delivers the ready-made association at once. The latter notion does not conflict with the gradual progress that is generally observed in learning curves if one takes into account that a learning curve usually represents the establishment of more than one association. Even when a single pair of words is learned, several associations are formed: beside an inter-word association there is also a connection with a marker, i.e., with a concept node representing the situational context during the learning session. Connections of this type are essential for expressing the conditions under which the two words belong together. Both theories have been worked out to a highly formal degree in the form of statistical learning theories. A detailed survey may be found in Coombs, Dawes and Tversky (1970). Kintsch (1970) shows that it is indeed often possible to dissect learning processes into a number of discrete meaningful components. It is impossible to deal with the very extensive literature on 'verbal learning' in a representative fashion. Parallel to section 2.2 we shall here continue to concentrate particularly on the coding problem. When someone is memorizing a list of words or word pairs, what kind of information enters LTM?

First of all we note context marking. Subjects know under which circumstances (e.g., in which room, with which experimenter, by means of which apparatus and at which point in time) they studied the material to be learned. In fact, the experimenter presupposes context marking when he asks for the word list 'that you learned yesterday morning' to be recited. By way of the association between the time marker and the word list, the subject gains access to the items to be recalled. If several lists have to be learned in succession, the danger of a failing list-differentiation crops up: the context markings of the several lists overlap so that the subjects have an insufficient basis for distinguishing between the list items from the different lists (see also 3.2).

As regards the LTM coding of the items themselves, in verbal learning tasks this appears to be a predominantly semantic matter. Context marking does not, or hardly, appear to become connected to the visual, auditory or articulatory specification of the list items, but to their meaning instead, i.e., to the concepts with which they are associated (see also 2.2.2). A convincing demonstration of this is provided by a study by Elias and Perfetti (1973). They presented to four groups of subjects a list of 80 words at a rate of 10 sec per word. The groups were each given a different task. Only Group 1 was required to learn the list. Group 2 had to name as many words rhyming with the stimulus word as possible in the 10 sec available: their attention thus was directed chiefly to the auditory specification of the stimulus word. Groups 3 and 4 received tasks focussing on the meaning of the words presented: naming synonyms and free association words, respectively. Retention was measured in all groups by means of a recognition test which, apart from 'old' words (list items), included both auditory and semantic 'distractors'. (These distractors are items which do not appear in the list but which do bear resemblance to the list items with respect to their sound or to their meaning.) It appeared that Groups 3 and 4 (whose attention was concentrated on meaning) performed better than Group 1 (who were instructed to learn); the auditory Group 2 had the lowest score. Furthermore, Group 1 gave many false alarms ('old' judgments to items that had not occurred in the list) for semantic distractors, but hardly any for auditory distractors. Both these results indicate that verbal LTM has a marked bias towards recording semantic information.

The semantic preference of LTM and the articulatory-auditory preference of STM (see 2.2.2) emanates from the function that these memories fulfil during the most important form of human communication, namely the use of spoken language. STM provides the possibility of retaining literal utterances over a short time interval in order to make syntactic analysis possible; LTM retains the meaning of the utterances for a long period of time.

3. Theories of forgetting

In view of the preceding discussion on coding and rehearsal in relation to retention, it is obvious that if we are to assume a number of stores, each with its own forgetting characteristic, this would be an extreme simplification. Rather, the forgetting process is determined by the degree of perceptual processing and by the level of the code resulting from it. In the majority of cases, moreover, forgetting is not so much due to a complete disappearance of all information on the items thus coded, but rather to the diminishing possibility of retrieving the items; this decline is caused by a decreased discriminability between the items themselves, between the classes to which they belong (at the level of coding) or between the lists in which they appeared during learning. In the present section we shall consider the theories of forgetting that have been developed over the past 30 years. When discussing forgetting in LTM we shall deal more explicitly with interference theory; when discussing forgetting in STM, with which we shall start below, some properties of the decay theory will be reported.

3.1. Forgetting in STM

In our discussion of the technical data concerning STM, we have already mentioned two factors held responsible for the forgetting of verbal items in STM. These are, on the one hand, the lapse of time between the presentation of items and the testing of retention, which leads to decay, and, on the other, the interruptive interaction of other items presented before or during the retention interval, which results in interference. For the very reason that, during the forties and fifties, the interference theory of forgetting in LTM was substantiated by a large quantity of empirical evidence (see Postman, 1961; see also 3.2), there were many who showed a marked preference for a similar interpretation of STM forgetting.

A remarkable result of the data from STM experiments was, however, that the interpolated (filler) task need not imply any new learning for it to result in a drastic loss in the memory of the original material. This meant that the but recently explained cause of forgetting – viz., certain relations of similarity between original and interpolated learning – could not simply be transferred to STM experiments. Mainly for this reason, other investigators adhered to a decay interpretation of forgetting over short time intervals. Broadbent's notions (1958), already mentioned above, which took a central position in the argumentation of decay adherents, held that the processing of new information (the interpolated filler task) takes up part of the capacity of the processing unit, so that rehearsal of the original material is endangered, with the result that it is subjected to the wear and tear of time. The interpretation given by decay theorists to rehearsal is that the trace is only renewed by rehearsal, not strengthened. Decay can therefore only be delayed for as long as rehearsal lasts; the trace itself will not be able to better resist autonomous decay with time. The study of pure decay is impossible, however, because, on the one hand, the processing unit (the 'central channel') starts rehearsal as soon as the supply of new information stops and, on the other hand, there is in principle always a possibility of a certain interaction with the memory material whilst one is trying to keep the processing unit occupied in a 'neutral' fashion with a filler task, even if this differs greatly from the memory task. The question therefore is whether decay can be demonstrated to be a factor in forgetting, separate from interference. It appeared (2.2.2) that loss of retention in STM can be shown to be a function of similarity relations, with the condition that these are defined at the level of 'acoustic' or phoneme similarity. One may then rightly speak of interference between the items of a series, and wholly analogous to LTM, of retroactive and proactive inhibition in STM. (The experimental paradigm proper to the latter form of interference, in which the interfering list precedes the list to be memorized, naturally is suited best to studies in which a decay interpretation must be ruled out, since testing can be conducted immediately after presentation.)

It may be noted that it is especially memory for item order on which such interference acts. If the requirement of serial recall is substituted by one of free recall then the effect of acoustic similarity is already diminished considerably. According to an item recall criterion, independent of the recall order, Wickelgren (1965a) has even observed a small advantageous effect of acoustic similarity. It is also specifically the sequential order of the items that is remembered better if there is opportunity for rehearsal. Rehearsal under not too rapid presentation rates often is, as we saw, of a cumulative kind. This implies that rehearsal strongly benefits the correct serial recall of the first items of a series.

A noteworthy phenomenon which clearly illustrates that STM retention is affected by interference and its accompanying principles of 'similarity' (this time not in terms of phoneme similarity but of category membership) can be observed in the following way. A subject is repeatedly required to memorize a trigram with a filler task in the retention interval, for example, naming colors. The first trigram is remembered quite well, but the second and third already less well; at the fourth successive presentation of a trigram, memory performance has drastically declined (e.g. from 70% to 10% correct), after which this low level of recall remains more or less constant. If the experimenter now changes over from trigrams to three-digit numbers, the first number is again well recalled, the second, third and fourth gradually worse, and so on. Apparently, proactive inhibition, which is involved here, is built up to its maximum strength in approximately four trials and is suddenly released completely upon transition to a different type of material (see also Wickens, 1972). If one is aware that in the majority of STM experiments many similar lists are presented in succession in order to obtain a great number of observations, one will conclude from these findings that the retention data concerned usually contains a maximum amount of proactive inhibition.

The experiment that is no doubt most often quoted in connection with the question of whether interference or decay provides the best explanation for forgetting in STM, is that by Waugh and Norman (1965). They used the probe word technique (2.2.1) in measuring the STM retention of the members of a 16-item list. The presentation rate was one or four digits per second. The subjects were permitted to rehearse an item only during its presentation. According to the decay interpretation one would expect more rapid forgetting of the slowly presented items because they were subject to a decay process lasting four times as long, whereas the interference interpretation predicts mainly an effect of retroactive inhibition as a function of the number of ('interpolated') items presented after the item to be tested. The results strongly support the latter interpretation (see fig. 8).

If the results are carefully examined, however, a systematic interaction appears, indicating a negative effect of time. In accordance with the association principles of interference theory (but not according to the decay theory), a slow rate ought to result in better learning and therefore better retention, which is indeed found in the most recent items. But the items presented earlier at the same slow rate are the very items that are recalled less well than the corresponding, rapidly presented items (that were followed by just as many interpolated items). The shape of the net retention curve of STM information may apparently be ascribed here to both interference and decay.

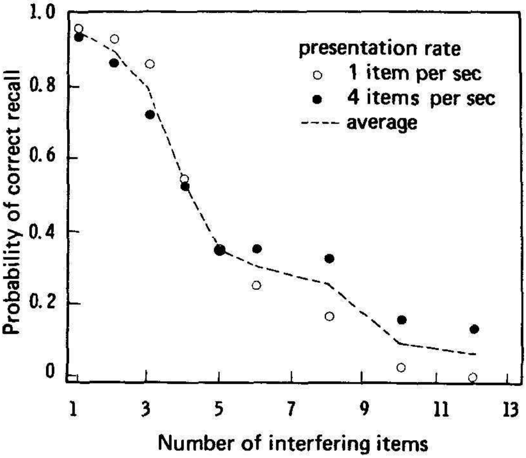

Fig. 8. Retention curve obtained by means of the probe technique. The number of retroactively interfering items is a stronger determinant of forgetting than the passage of time. The latter factor, however, also has an effect. On the abscissa of this figure the serial positions run from right to left (after Waugh and Norman, 1965).

We shall not pursue further the historical series of publications concerning the question whether memory relies on a single trace or on two separate traces (STM and LTM) each with their specific cause of forgetting. We will, however, draw attention to a recent, commendable attempt to accommodate all the important data concerning STM – also those of the modality effect and of the organization principles – into one theory. It is a modern single-trace theory in which particularly the study of interference principles is given a new incentive (Sanders, 1974).

Unconnected with the question as to the cause of STM forgetting are numerous studies devoted to quantitative aspects of forgetting. The most important contribution to these studies has been made by Wickelgren. Recently he established that, during learning, two traces are formed, an STM and an LTM trace. Consolidation of the LTM trace begins later and continues longer than that of the STM trace. During an interval of several minutes, in which arithmetic serves as a filler task, the strength of the two traces appears to decrease exponentially over time, but each with its own forgetting parameter (Wickelgren and Berian, 1971).

It is important to emphasize again at this point that STM forgetting in particular is connected with the degree of coding. In the one extreme case, e.g., very rapid presentation of utterly meaningless verbal information for immediate recall, no other strategy is possible than to rely on purely temporal and acoustic retrieval cues. These may – in agreement with our discussion of STM associations above (2.2.2) – be conceived of, for example, as being related to 'cells' with position features as well as of connections between the successive items. At recall, the subject uses these to reconstruct the best fitting reproduction of what was presented. From the viewpoint of the retention of linguistic verbal information, as such, one really confronts the subject with a task that, under this condition, is impossible. He merely codes a labile phoneme sequence, and his forgetting it must, of course, rather be blamed on autonomous decay than if it had been a question of retaining a slowly presented STM list made up of larger verbal units that are completely anchored in LTM. The latter constitutes the other extreme. Thus, as has been indicated above (2.2.2) there may appear to be in STM mechanisms of storage and retrieval that are more typical of LTM. Observed phenomena of forgetting will, in these cases, have to be ascribed in the first place to the various interference factors that are known to govern LTM and which we shall discuss in more detail in the following section.

3.2. Forgetting in LTM

As in the case of STM, we shall also distinguish between two types of theory explaining LTM forgetting. In the first class of theories, forgetting is wholly attributed to some physiological process affecting memory traces and causing their disintegration (decay). The speed at which this process takes place is supposed to be independent of earlier or later cognitive activity. In the second class of theories it is, in contrast, assumed that all forgetting does depend on the information processing activities that take place before or after the moment that a certain content has been stored in LTM.

The latter principle has been worked out in interference theory and in consolidation theory. According to interference theory, later cognitive processes, in particular new learning tasks, will have a disturbing influence (to be further specified) on the already stored contents, which is retroactive inhibition. Furthermore, already existing LTM contents can also disturb the retention of new learning material, which is proactive inhibition. Consolidation theory sets out from the notion that, after the termination of the learning task proper, a kind of neural activity takes place in the brain such that the material learned is fixated. This consolidation process has a relatively short duration, say a few minutes, and it makes the material learned resistant to forgetting over a long period of time. Cognitive activities that are conducted within the consolidation period disrupt the process of consolidation and thus shorten the stay in LTM of the material learned. To a drastic degree, this is also the case with neurophysiologically radical experiences, such as electro-convulsive shocks, hypothermia, concussion, or the injection of pyromycin.

The first type of theory, decay, is not tenable as the sole explanation, because there is varied evidence that the forgetting process is affected both retroactively and proactively. Consolidation theory has the inherent disadvantage of a limited scope: it is not able to account for any proactive effects or for retroactive effects occurring beyond the critical consolidation period. Moreover, it is inadequate from an empirical point of view (see Postman, 1971). The neural activity resulting in consolidation is presumed to come to a halt gradually and to decline faster the more strenuous any cognitive activity is that is performed simultaneously. Both assumptions give rise to incorrect predictions. If the task interpolated between the original learning task and the retention test varies in difficulty, the degree of forgetting remains constant nevertheless. A factor that does, in contrast, cause the rate of forgetting to increase strongly – although this is not predicted by the consolidation theory – is the similarity between the interpolated task and the original learning task. From the assumption of gradually reduced consolidation activity it follows that, with a constant retention interval, the degree of forgetting must be greater if the time between the original and the interpolated task is shorter. Such a connection does not appear to exist; rather, the converse relation is the case (Postman and Warren, 1972). A new, appealing interpretation of the consolidation concept in the context of research into amnesia may be found in Miller and Springer (1973) and Spear (1973).

Interference theory, in which interaction among memory contents takes a central position, is – at least in its modern version – in agreement with a wide range of forgetting phenomena. We shall discuss in turn the two chief manifestations of interference, viz., retroactive and proactive inhibition.

Retroactive inhibition

In the A-B, A-C paradigm, the subject learns two responses to one stimulus.[3] When during the retention test he is confronted with the A terms, the most recent C terms will frequently be elicited as (incorrect) responses. This hampers the recall of B terms which the experimenter requires in the retention test. This notion, that was already current in the thirties, is known as the response competition theory.

An important assumption of the theory is that learning A-C in itself does not affect the availability of the A-B pairs. This presupposition, often called 'independence hypothesis' was, however, soon contested. Indeed, no high correlation was found between the amount of response competition (measured as the number of C responses during A-B recall) and the amount of interference. Particularly when the subjects had thoroughly learned the A-C list interference proved large but response competition remained small. This suggested the activity of a second factor alongside response competition: unlearning of A-B associations during A-C larning. The mechanism held responsible for this unlearning is extinction: first-list responses elicited during the interpolated learning task ('elicitations') are not reinforced, so that the strength of the A-B association is decreased.

A direct demonstration of the inadequacy of response competition theory may be provided by means of a modified retention test. Subjects who learned two lists according to the A-B, A-C paradigm, are presented with the A terms under the instruction to respond to these with both the B and the C terms, in the order in which they come to mind. If, moreover, there is ample time for recall, the B and C terms no longer stand in a

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[3] We shall adhere to the following conventions. If the learning materials (generally two) are lists of paired associates, the stimulus terms and response terms will be indicated by a capital letter. For example, A-B, A-C stands for an experiment in which the stimulus terms of the two lists are identical and the responses unrelated. In a retroaction experiment it would be determined how good retention is for the B terms; in a proaction study, the memory score for the C terms would be measured after a retention interval. The relevant data always concerns a difference in the retention score between the experimental group and the control group that has not been subjected to the interfering learning task. In a retroaction experiment, the second learning task may also be referred to as 'interpolated learning task'.

competitive relationship. Nevertheless, it appears that the number of correct B responses decreases steadily with the number of trials on the A-C list. At first, this was taken as supporting unlearning theory, but we shall see that other interpretations are also possible.

The extinction mechanism outlined implies the prediction that in learning conditions where, during the interpolation task, few first list answers are elicited, interference will be slight. One can create such a situation by choosing the B terms and the C terms in the A-B, A-C paradigm from response categories that are unlikely to be confused, such as adjectives and letters. Indeed, retroactive inhibition disappeared almost completely in a paradigm of 'digits-adjectives, digits-letters' (Postman, Keppel and Stark, 1965). In more general terms it can be said that the number of elicitations is a negative function of the degree of list differentiation, i.e., of the ease with which a subject can judge to which list the response terms belong. The degree of list differentiation will be higher the more distinctive features the different learning tasks performed possess. These do not necessarily have to be features of the learning material itself: each discriminating feature of the learning task can enhance list differentiation. If, for instance, the first list is learned under a distributed practice schedule, whereas the second is learned under a massed practice schedule, then the amount of retroactive inhibition is considerably less than if both lists are studied under the same schedule (Houston and Reynolds, 1965).

An important further development was the reinterpretation of the notion of response competition. Whilst this concept had hitherto only applied to individual B and C responses, it gradually became clear that the response repertoire of the one list as a whole entered into competition with the repertoire of the other. Already in 1956 Newton and Wickens drew attention to this phenomenon of 'general' response competition: while being tested for retention of the original list, their subjects showed a tendency to persist in giving response terms from the interpolated list, especially if the retention test was conducted immediately after the interpolated task. The response terms of the material just learned were apparently better available and more easily accessible than the response terms of material learned longer ago.

Analogous to this shift from 'specific' to 'general' response competition, Postman in particular (see Postman and Stark, 1969) proposed that unlearning should not be regarded as a process that weakens specific A-B associations but as one that suppresses entire response repertoires.

Each time that a B response is elicited during the learning of an A-C list, a mechanism is assumed to come into operation that makes the B repertoire less accessible. Retroactive inhibition would thus be the result of two 'general' factors: first, response competition between the B and the C repertoires and, second, suppression of the B repertoire. Experimental evidence for the existence of a suppression mechanism of this kind has up till now been only slight but, even if it were to gain a stronger empirical basis, theory construction would still allow room for 'specific' unlearning. Thus there are the results obtained in the A-B, A-Br paradigm, where the second list contains the same response terms as the first, but paired to other A terms. In spite of the fact that the two general factors cannot operate here, a very strong retroactive inhibition appears, an effect that is attributed to specific unlearning. However, in the A-B, A-C paradigm also specific unlearning is demonstrable. This requires an experimental procedure in which the interpolated list does not only include A-C items, but also D-E items (completely unrelated to the A-B list). For example, the A_1-B_1 pair corresponds to a pair A_1-C_1 in the interpolated list, but A_2-B_2 has no direct parallel there; instead, there is D_2-E_2 in the interpolated list. On the ground of the two general interference factors one would not expect any difference in retroactive inhibition between items of the A_1-B_1 type and those of the A_2-B_2 type. Nevertheless, a distinct difference was found; as was predictable from the principle of specific unlearning, the difference was to the disadvantage of the A_1-B_1 items (e.g., Weaver, Duncan and Bird, 1972).

Proactive inhibition

One may make the obvious assumption that proactive inhibition – the phenomenon that learning material is forgotten more quickly if, at an earlier point in time, more or less related learning material has been acquired – can be interpreted by the same type of factors as retroactive inhibition. Probably, such an assumption is to a large extent warranted; in any case we see a recurrence of the theoretical developments that occurred with respect to retroaction. This is particularly true of the concept of competition between response repertoires. It has long been known (Koppenaal, 1963; Houston, 1967) that proactive inhibition cannot result from specific response competition only, for interference also occurs in the above-mentioned modified retention test which is free from specific competition since, for each stimulus term, both response terms may be given. This does not, however, rule out the possibility of general response competition. If we assume that in the long run any differences in the degree of accessibility of response repertoires decrease, the most recent test list will gradually lose its lead over the previously learned list. During the retention test, two response repertoires become activated, which implies a disadvantage in comparison with the control group, that is only concerned with one response repertoire. Furthermore, in the case of several learning tasks, there is always the possibility that the subject first activates the inappropriate response repertoire and subsequently has great difficulty in switching over to the correct repertoire (Postman and Hasher, 1972).

Just now we had to assume that any difference in accessibility between response repertoires would decrease with time. This assumption, which had a somewhat gratuitous character, is to a certain degree substantiated by findings by Houston (1971). He made the surprising discovery that only those subjects were prone to proactive inhibition (A-B, A-C paradigm) who expected a retention test. Subjects who were given the impression that the experiment had ended after learning the A-C list (but who were subjected to the subsequent A-B test all the same) showed hardly any proactive inhibition. This suggests that the subjects liable to proaction were themselves responsible for making the two response repertoires equally accessible by rehearsing both lists during the retention interval.

4. Organization

Thus far we have been looking at the fate of individual verbal items and of isolated associations during their passage through the different memory stores. In fact, this was an abstraction because in STM the items do not lead an isolated existence and in LTM the items and their interconnections are taken up into vast association complexes. The present section attempts to describe the structure and the properties of some of the resulting wholes. The text under the first two headings is devoted to grouping phenomena in STM and in LTM, respectively. The section is closed with a discussion of a very frequently occurring organization process, the properties of which give rise to the assumption that it is not ruled in the same manner by the laws of grouping and association: the organization principle of imagery.

4.1. Organization in STM

If an experimenter determines a subject's memory span, just as in the majority of the other STM conditions, the presentation of the memory lists is done carefully in as monotonous a fashion as possible. The oral recall of such a monotonous list, however, often betrays spontaneous grouping on the part of the subject, as revealed by his pattern of intonation and pausing. It seems as if the experimenter could as well have saved himself the trouble of preparing his material in such an unnatural way. Generally speaking, a series of items that are grouped through intonation or pausing will be retained better than a homogeneous list under both written and oral recall conditions. A frequent cause of 'spontaneously' structured recall is rehearsal in groups during presentation. In that case the subject often repeats the items within each group in a cumulative fashion – for example, (6) (6, 2) (6, 2, 5) (6, 2, 5 – 9) (6, 2, 5 – 9, 3) (6, 2, 5 – 9, 3, 1), – holding several items together in a rehearsal group. Wickelgren (1967) gave his subjects the explicit instruction to follow a similar strategy. For various list lengths he observed that rehearsal groups containing three items led to the best performance, especially with respect to recall of the correct order. The items themselves are also well recalled if rehearsal groups of four or five items are used. Some further important findings in these experiments were the following. Firstly, order errors appeared to have a preference for occurring within rehearsal groups, this preference becoming greater in larger rehearsal groups, list length being held constant; and secondly, a kind of serial position intrusion tends to occur, involving the exchange of places between items within the same list, where they occupy corresponding positions in different rehearsal groups. The first observation is not in agreement with a straightforward inter-item association model because in this experiment a larger rehearsal group would have entailed a more frequent repetition of the items in their correct order. The second finding seems to provide evidence for an indirect form of localization of items in their successive list positions, probably via a hierarchy involving rehearsal groups.

Let us return for a while to the main result discussed above, namely the unique effectiveness of rehearsal groups with a size of three items, where recall is required not only of the items but also of their order. This result is highly compatible with a model for the retention of unconnected items that has been proposed by Estes (1972). Structural coding is a cardinal feature of this model. According to Estes, associations are not formed between successive elements (items) of a list, but rather between the individual elements and a control element which represents a set of elements at a higher level. A new control element is involved at every discontinuity in the presentation of the list or in the rehearsal of its elements. Also at high hierarchical levels control elements govern retention, so that ultimately there is one control element representing the entire list. Retention of the items belonging to one control element for more than a few seconds is possible only through rehearsal. The rehearsed order of the items of the last control element may be tested against still available STM information regarding this order. In a rehearsal cycle, however, order errors may crop up due to the fact that one control element activates the internal representations of all its elements simultaneously while, moreover, certain items may be more easily aroused than others. In order to prevent later items from prematurely entering the rehearsal cycle (or the recall output sequence), a suppression mechanism exerting an inhibitory effect between the simultaneously activated items of a control element is required. It is assumed in the model that, alongside the associative relations between hierarchically ordered control elements and between the control elements and their individual items, there are inhibitory relations fulfilling the necessary suppression task (see fig. 9). For a whole list the sum of the associative and the inhibitory relations predicts the difficulty of the recall of any list having a given number of items and a given grouping structure. For widely varying lists, the minimum value is often

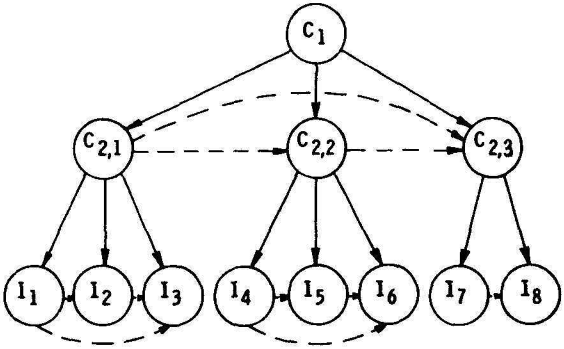

Fig. 9. Associative relations (solid arrows) and inhibitory relations (dotted arrows) in a structured list in memory (after Estes, 1972). The total number of relations for the pictured hierarchy ((1, 2, 3)(4, 5, 6)(7, 8)) equals 11 + 10 = 21.

obtained for grouping in threes. Apart from the results, discussed above, obtained by Wickelgren (1967), which are in complete agreement with this prediction, there are several other authors (e.g. Mandler, 1967; Ryan, 1969) reporting an optimal group size of three items.

A special effect of different grouping structures within the same list of items was studied by Bower and Winzenz (1969). These authors, who required recall and recognition of digit lists, discovered that a sequence presented with a certain structure – for example (1, 2, 3) (4, 5) (6, 7, 8) (9, 0) – is not recognized at a second presentation if the structure is changed, for example, into (1, 2) (3, 4, 5) (6, 7) (8, 9, 0). Similarly, the Hebb effect (the phenomenon that an STM list, which is presented several times hidden among other interpolated lists, is gradually recalled better; Hebb, 1961) appears to depend on the grouping structure of the list. Any improvement occurs only if this structure is held constant. If grouping is different for each presentation, the level of recall remains the same as that for the interpolated 'noise' lists, which are always new for the subjects (see fig. 10). This fact clearly illustrates the predominant role of the group, functioning as a coding (and re-

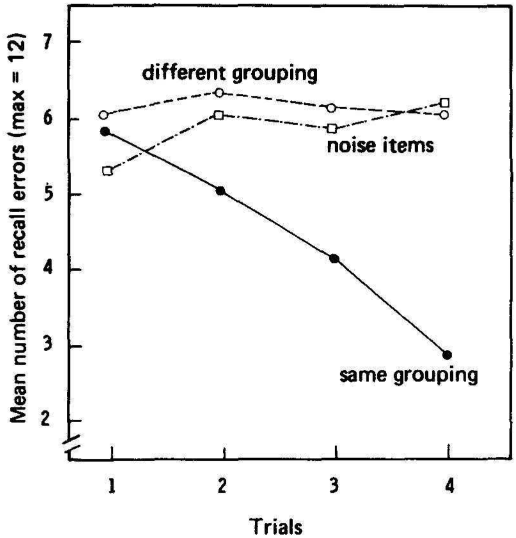

Fig. 10. Mean number of errors in the STM recall of grouped lists containing 12 items during four successive trials, occurring among a large number of distractor (noise) lists (after Bower and Winzenz, 1969).

hearsal) unit at a higher level. The finding, it may be noted, is once more in conflict with a simple inter-item association interpretation. The latter would predict, for example, an increasing association strength between any two adjacent items with every further trial on the same list. According to the associative interpretation, the increase in strength may perhaps be expected to be slightly less if with different grouping a short pause is introduced between two adjacent items, but it still ought to be there. Two further results confirm the functional significance of grouping in STM tasks. In the first place, it was found that lists that were presented only once, display a distribution of sequential dependencies according to the pattern of grouping. The transition probability of going from a correctly recalled item *i* to a recall error at the subsequent item *j* is relatively small within the same group, and large if *j* is the first item of a group. Even at one presentation, therefore, the group is a fairly well integrated whole. Below we shall return to similar effects, in the context of organization in LTM (4.2.1). Secondly, it appeared that the Hebb effect, which as we saw occurs upon repeated presentation of a list following the same grouping structure, is often due to an increasing ease in crossing group boundaries; over the subsequent trials this was evidenced by a declining transitional error probability between groups, whereas this probability remained constant within groups.

In the present context we shall only briefly mention the 'reallocation' theory developed by Bower in order to account for the above data. A 'perceptual coder' is assumed to decide, on the evidence of the first one or two groups of a list, whether or not the list is familiar. If it is, the list is referred to the same memory location as where it was stored upon its first occurrence; the old trace present there is reinforced by this process. If it is decided that the list is not familiar, it is stored in a new location as an entirely new trace. It therefore depends on the very first group(s) whether or not a list is dealt with as completely new information.

The grouping phenomena in recall discussed above are associated with the application of a different structure in a list in which, however, the order of the items is left unchanged. It is indeed typical of most STM recall tasks that, in general, the item order is maintained. The reorganization of memory material in experiments that generally employ longer lists to be retained over longer intervals will receive ample attention in a later section (4.2.2). In principle, effective order changes among list items in typical STM conditions are possible, but in every task it remains to be seen whether in STM the disadvantage of the extra amount of time needed for categorizing and grouping during retention is not greater than the advantage in recall: in tasks that involve mainly STM there is seldom a requirement of 'higher' organization, because the number of items to be recalled is never very large and they are usually 'directly' accessible.

An experimental situation, in which the presentation order is often changed when grouping occurs, is dichotic presentation. If the subject is asked to recall two simultaneously spoken sets of digits (e.g., 6, 8, 3 to one ear and 2, 5, 1 to the other) he will in his recall frequently deviate substantially from the temporal order of presentation of the six digits. He will show a tendency to recall, for example, 2, 5, 1, 6, 8, 3 rather than, for example, 6, 2, 5, 8, 3, 1, which is more like the presentation order. It is possible that the order recalled results from the fact that the information presented to one ear was transmitted earlier because that ear happened to be dominant or to receive most attention. In that case the order of recall would reflect the order of processing. It is also possible, however, that the order of recall results from a retrieval strategy in which direction cues guide the searching process.

The recall of items in any order that differs from the order of presentation is sometimes also possible if the items belonging to one class are retrieved and recalled first, and subsequently those belonging to the other class. Thus, it was reported by Gray and Wedderburn (1960) that the same level of performance was obtained when their subjects recalled three dichotic letter-digit pairs ear-by-ear as when they recalled them class-by-class. This result seems to indicate an *a posteriori* search; it may be asked, however, whether total memory span, which in this kind of task is not large, has perhaps decreased rather than increased as a result of grouping. Sanders and Schroots (1968) have shown that a single (binaural) list of the type ABABAB, composed of members from class A and class B, is better recalled in the order of presentation when the similarity between the categories is high (e.g., even and odd digits), and that recall by category (AAABBB) is better when they are more different (e.g., letters and tones) and the associative connections between the items of the different classes weaker (see also Sanders, 1974).

4.2. *Organization in LTM*

4.2.1. *Grouping in serial recall*

If in a number of trials a long list of words, syllables, digits or letters is learned, taking into account the ordered position of the items (serial recall), the errors made in recall are not evenly distributed over the serial positions. However, most of the errors tend to occur around the middle of the list, which graphically results in a serial position curve with the shape of an inverted U. Moreover, transition error probabilities (TEPs, see 4.1) may be high at certain item-to-item transitions, resulting in spikes on the TEP curve. The experimenter can control the location of the spikes by suggesting groups of items, for example, by spacing or coloring. As was discussed above for STM, we see here too that transition errors tend to be more frequent between items belonging to different groups than between items of the same group.

To account for the different TEP profiles in lists with various grouping structures a reasonably successful theory has been formulated by Johnson (1970). In his experiments he always employs letter sequences with low associative values between adjacent letters. The main idea is that such a list, e.g., *SBJ FQL ZNG*, is stored in LTM as a hierarchical structure of 'chunks'. Every chunk contains information that can be decoded further into one or more chunks in a specific order; chunks at the lowest level contain the specifications of the individual members of the list. The list of our example is, accordingly, represented in LTM as chunk *A* with the content *EOU*; *E* contains the subchunks *SBJ* that correspond to the output letters *S*, *B* and *J* in this order, etc. (the names of the chunks are arbitrary).

For the transformation of chunks into letters, use is made of a temporary pile-up memory store. The decoding process starts upon retrieval of a chunk from LTM by the subject. This chunk is placed on a pile that was thus far empty. Decoding is subsequently performed by the recursive application of the following rule: replace the chunk on the top of the pile by its subchunks so that the first subchunk is now on top, the second one immediately below, etc.; if the uppermost chunk contains only one letter, call it out and remove it from the pile. For making predictions on transition errors, Johnson makes the following two assumptions. First, the probability of an erroneous response increases with the number of decoding operations required since the production of the last response. Second, the subject suppresses all the responses belonging to a chunk if he is not confident that he can perform all the required decoding operations without a mistake.

The model is, among other things, able to predict correctly that in, for example, the four lists *NG V*, *NG VH*, *NG VHS*, and *NG VHSB*, the *G-V* transition is more difficult with increasing size of the second group, whereas the number of errors at the within-group transitions remains constant. A different type of prediction is concerned with changes within groups. After the subjects have learned a list, composed of, say, three groups, they subsequently start to learn an interpolated list which, with the exception of a few letters, is identical to the first list (in two of the groups only one letter is changed). How rapid will forgetting of the unchanged letters be in the changed and unchanged groups? The theory states that the subjects can only observe the result of the decoding process; the decoding operations themselves are 'opaque containers'. If during the learning stage of the second list the subjects notice that something is changed in a group, all they can do is replace the old chunk representing that group by a new one. This means that the information stored in altered chunks is no longer used, even if (to the extent that it is unchanged) it is still partly valid. Irrespective of the particular interference theory one adheres to, this leads to the prediction that unchanged letters in changed groups are less well retained than in unchanged groups. This prediction is indeed strongly supported. Similar results are obtained if the order of the items in a group, or (as was also discussed above in the context of STM; see 4.1) if the grouping structure itself is changed, altering, for example, the list *SBJ FQLZ* into *SB JFQ LZ*. In brief, the results show that subjects react to a change of part of a group as if they meet an entirely new group. This constitutes clear evidence for the role of groups as processing units also in LTM. We shall encounter similar phenomena when discussing learning under conditions of free recall.

4.2.2. Grouping in free recall

In 1952 Jenkins and Russell observed the occurrence of 'associative clustering' cases where two list words having a high mutual associative value are recalled in immediate succession, whereas at presentation they were separated from each other. A year later, Bousfield (1953) described the phenomenon of 'category clustering'. His subjects were presented with a list of 60 words, presented one by one at a rate of three seconds per word. After this presentation they were allowed unlimited time for recalling as many items from the list as possible in any order they might prefer (free recall). The list was composed of 15 instances of each of four categories (animals, proper names, foodstuffs, and professions); the word order was completely random, the categories being mixed in an irregular fashion. Bousfield observed that the number of times that two words from the same category were recalled in immediate succession was much larger than expected on the basis of chance. The free recall paradigm thus provided the opening to an intensively practised approach in the research on organization phenomena in LTM. Detailed surveys may be found in Tulving and Donaldson (1972).

To the above kind of grouping on the basis of 'objectively' present categories, the phenomenon of 'subjective organization' was added by Tulving (1962). If one studies, in several successive trials, a list composed of words having minimal semantic relations between them, and if the word order is different with every presentation of the list, there is a tendency to recall the words in a consistent stereotyped order on these successive trials. Furthermore, it appears that the degree of such subjective organization (as determined by means of the sequential dependencies present in successive recall lists) shows a high positive correlation with the recall score.

Better insight into the nature of the subjective organization applied by the subjects on the material is provided by the method of Mandler (1967). In one representative experiment, 100 words were presented to the subjects, each word typed on a separate card. The instruction was to sort the cards into a number of freely adopted categories. In one condition the number of categories to be employed was the subjects' own choice; in the other condition the experimenter imposed the number of sorting categories, varying it from two to seven. Sorting continued until a stable classification was attained with 95 words into identical categories on two successive sortings. Following this, the subjects were asked for a free recall of the words (unlimited time). Fig. 11 shows that the recall score increases linearly with the number of categories employed during the sorting task. From the slope of the best fitting straight lines it appears that the addition of one category results in a recall increase of approximately seven words.

The latter findings, as well as various other observations, suggest that the subjects may adopt a specific strategy when memorizing word lists for free recall. During the first trials they arrive at a general knowledge concerning the different classes of words that occur in the list. At first,

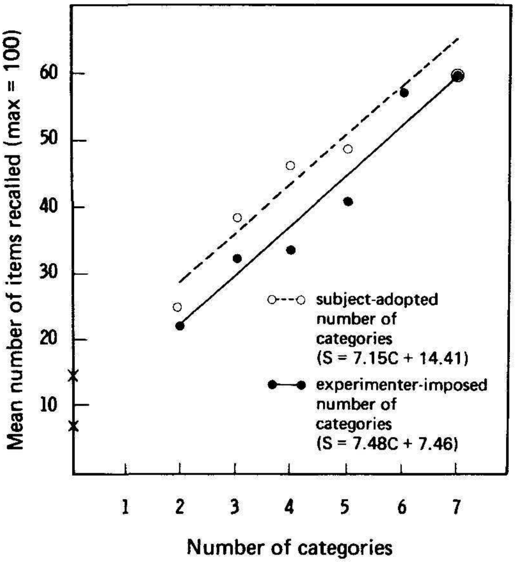

Fig. 11. Mean number of items correct in recall as a function of the (adopted or imposed) number of sorting categories. Equations shown are for the lines of best fit (after Mandler, 1967).

these categories may as yet have very few instances, but they provide the basis for an organization scheme. During subsequent presentations, the list words are supplied as much as possible with markers indicating the category to which they belong. If it later appears that a category contains more than the maximum seven elements, a further subdivision must be made, etc. Thus, a hierarchy of groups (chunks) originates in LTM which may be employed systematically by the subject as a retrieval plan during recall. The growth of the latter retrieval plan, through which more and more words can be reached and consequently recalled, explains the increasing score at successive trials. The final level attained by the subject depends on the number of groups in the hierarchy, because one group allows space to at most seven items. Order consistency in the recall lists is due to the systematic pursuit of the retrieval plan and the immediate recall of the words retrieved.

Mandler's theory is not the only one that has been proposed within the research field under discussion; the alternatives have the same basic pattern, however. Disagreement exists mainly on the build-up of the retrieval plan: does it have a hierarchical structure or is it of an associative nature? In Anderson's (1972) computer model for free recall, the retrieval plan operates on the basis of an associative network. When the program learns a word list, it tags the nodes corresponding to the list words with list markers and it searches for (direct or indirect) associative relations between a presented word and a tagged node. The associations involved are tagged likewise. Recall is achieved by beginning from starter words (words that take a central position in the marked subnet), by subsequently following the marked associations and, finally, upon arrival at a tagged node, by denoting its label as a response word.

The latter associative retrieval plan also appears to be in agreement with a large variety of free recall data. There are, however, some significant exceptions. Thus, the model may indeed show 'category clustering' (see above) but it does so to a much lesser extent than is the case with subjects. The cause of this difference is obvious: the model is able to tag the associative relations between the members of a category and even between members and category name, but it is not equipped with the ability to use the category name, which does not occur in the list, as a starter word from which the members of the list can be reached directly, without detours via other words. The latter finding indicates that 'category clustering' cannot be completely reduced to 'associative clustering'. It does not mean, however, that associative principles would fail in accounting for organization phenomena such as category clustering. It is possible, for example, to consider a hierarchy of groups (chunks) as a special configuration of associations. But a statement of the latter type has no informational value in the present context where we are concerned exactly with the nature of the configuration and not with the parts of which it is composed. Very little is gained by regarding organization and association principles as being opposed to one another.

A last observation that we shall discuss here is not a well-understood one. It is concerned with the transfer that occurs if, following the learning of one list in a free recall experiment, a second word list is learned that partially or completely overlaps with the first list. From several studies it appears that the common words are a source of negative rather than of positive transfer. Tulving (1966) asked two groups of subjects to learn a list containing nine words. Subsequently, both groups started to learn a second list containing 18 words. For one group, these were all new words, for the other group the list was made up of the nine items from the first list and nine new words. The latter group of subjects did not show any advantage of knowledge of the old words. These subjects even made slightly more errors than the subjects who received 18 new words. This phenomenon of negative part-to-whole transfer is complemented by negative whole-to-part transfer (Tulving and Osler, 1967). Related findings under conditions of serial recall have been mentioned above when we discussed the rapid forgetting of unchanged letters in changed groups as observed in Johnson's (1970) experiments.

The direction of transfer (positive or negative) depends on the subjects' prior knowledge of the manner in which the word material is put together to form the two lists. Thus, the above negative part-to-whole transfer is reversed into positive transfer if the subjects are informed. Similarly, the 'positive transfer', which occurs if one 'proceeds' from learning one list to learning the same list, is changed into negative if one is made to believe that certain words will be changed (Anderson and Bower, 1972). These findings suggest that subjects who may become uncertain as to which words or groups of words belong to which list, would rather avoid the former organization altogether than check carefully which elements of it can still be used. For a different interpretation of the part-to-whole effect we may refer to a paper by Novinsky (1972).

4.2.3. Imagination and mental images in LTM

LTM contains information allowing the construction of percept-like scenes that are mainly of a visual nature, although they may also carry features of different sensory modalities. It was known already in antiquity that mental images of this kind may be important as a mnemonic device (Yates, 1966). Experimental research on the role played by imagery in a memory task has, however, not been undertaken until recently. The majority of the first studies were performed by Paivio and his coworkers. (For a thorough and detailed survey, see Paivio, 1971.) The most important and most general result of these studies is the fact that memory performance in both STM and LTM tasks may be strongly enhanced by the use of images. We shall elaborate on the evidence obtained by means of the paired-associate paradigm.

For these studies, stimulus and response words may be selected so that they vary in the degree to which they evoke mental images. An indispensable aid here are imagination norms based on the intuitive judgments made by subjects on the speed and the ease with which specific words evoke images. Norms of this kind have been collected for various languages. For the Dutch language they were made available by Janssen (1973). The imagination value of words is almost perfectly correlated with their concreteness value obtained by means of 'concrete-abstract' rating scales. Paivio (1965) required the learning of 16 word pairs, evenly distributed over the four classes 'concrete-concrete' (i.e., both the stimulus and the response item are concrete words), 'concrete-abstract', 'abstract-concrete', and 'abstract-abstract'. In a retention test, confronting the subjects with the stimuli and asking them for the appropriate responses, the recall scores appeared to decline over the four conditions in the order mentioned. This means, in the first place, that concreteness results in better retention and, secondly, that this effect occurs more strongly at the stimulus side than at the response side. For an interpretation of the first finding, two possible functions of imagination and concreteness have been mentioned. On the one hand, mental images which are more easily evoked in the case of concrete words, may enhance the discriminability of these words and thus reduce the chance of their being confused with other words in the list. On the other hand, with increasing concreteness of stimulus *and* response members, it becomes easier to use compound images as mediators, i.e., scenes in which images corresponding to the stimulus and the response terms are present together. The advantage of the latter combination may itself be twofold. Either imagery mediators might exist alongside and independent of language mediators, so that the subjects have more than one route to gain access to the response word, starting from the stimulus word, or images may intrinsically be more effective as mediators than language mediators. The latter is, however, an unproved statement which has been challenged especially by Pylyshin (1973). In order to account for the second aspect of the above results, namely that 'concrete-abstract' word pairs lead to fewer errors than 'abstract-concrete' pairs, Paivio has made the following suggestions. He assumes that during learning trials an image may be adopted as a mediator with equal probability in both cases. However, the mediator is supposed to be retrieved more easily if its search starts with the concrete than with the abstract word, since the concrete word allows direct access to its image and thereby to the mediator in which it figures.

An intriguing phenomenon of image mediation is the outstanding effectiveness of images in which the imaged parts are in some way or other in *interaction*. An illustration of this is an experiment by Neisser

(1972), who asked his subjects to visualize a number of scenes and to rate the resulting images as to their vividness. In some scenes the visualized parts were kept separate as much as possible (e.g., two rooms, in one of them a *daffodil*, in the other *Napoleon*); in other scenes a form of interaction was suggested (e.g., a *daffodil* sticking out of *Napoleon's* coat pocket). This was followed by an unexpected retention test in which the subjects, who heard one member of each word pair spoken, had to complete the pairs by giving the second member. Scores for the interactive condition were about 20% higher than in the separation condition, whereas a corresponding difference in the vividness rated between the two types of images was not observed. In a similar experiment, Bower (1972) even obtained a performance improvement of 50% due to interaction. Earlier, analogous results had been reported by Epstein, Rock and Zuckerman (1960). Their subjects were engaged in the learning of pairs of actual pictures. Combinations of schematically drawn pictures, such as of a *hand* and a *bowl*, were easier to learn if their juxtaposition (e.g., hand *beside* bowl) was replaced by an interaction (e.g., hand *in* bowl). The explanation of this phenomenon has hardly been attempted.

The experimental results discussed in the present section are by no means an exhaustive account of the different functions fulfilled by imagery in memory tasks. For further hypotheses on this issue we may refer to the contributions of Neisser (1972) and Collins and Quillian (1972) and – hopefully with equal effectiveness after his reading of our survey – to the reader's own imagination.

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