Precategorical acoustic storage (PAS)[1]

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A system for precategorical storage of acoustic information is described. Material in this store is subject to overwriting and to decay with time. Precategorical Acoustic Storage (PAS) receives information only from the ears; it is not affected by silent rehearsal or by visual stimulation, and is explicitly distinguished from storage in terms of articulation. Two experiments are reported in which these properties of PAS are tested. Postulation of PAS permits an account of serial position functions for visual and auditory presentation in immediate memory, a distinction between "recency" and "finality" effects, the differential effects of a redundant prefix and a redundant suffix, effects of vocalization at presentation and at recall, and the relation between memory confusions and speech perception. Implications for a general theory of human memory are discussed.

Traditional analyses of human memory have carried, until recent years, the implicit assumption that the nominal stimulus (e.g., the letter, digit, or word) is the functionally significant theoretical commodity and that theory should therefore deal with processes by which such idealized elements become combined and ordered. It follows from this type of approach that any attempt to distinguish alternative forms of coding for stimulus information (i.e., the attempt to discover what Ss learn *about* a digit) would be considered an irrelevant, if not mystical, undertaking. Probably starting with Miller's (1956) discussion of recoding in memory experiments, however, a variety of data have made it necessary to recognize that the conditions of stimulus presentation (including especially Ss' behavior during presentation) affect materially what aspects of the nominal stimulus are acquired and therefore may be said to dictate the appropriate theoretical units of analysis (see also, Posner, 1967). Glanzer and Clark (1963) have, for example, argued that Ss in their study literally did not remember the strings of binary digits they were given, but rather remembered their description of the patterns they perceived in the strings. In the free recall situation, distinguishing what S learns from what is presented to him has led to the postulation of higher-order, supraverbal dimensions of analysis (Garner & Degerman, 1967; Mandler, 1968; Tulving, 1968). It is of critical importance to note that the question of the *product* of learning (interitem associations, categories, mediators, etc.) can be to a large degree independent of the question as to what *processes* underlie such acquisition. For example, both organizational (Mandler, 1968) and strictly associative (Hebb, 1949) theories predict categorical and subjective clustering in free recall.

Although the standard digit-span task is unlikely to involve just the same processes as free recall, the parallel issue concerning the product of learning in immediate memory is demonstrably a central issue for all memory theory. In the present paper we intend to identify a source of stimulus information deriving exclusively from auditory presentation. Being specifically auditory and specifically precategorical, this Precategorical Acoustic Storage (PAS) does not resemble the "primary memory" of Waugh and Norman (1965).[4] Atkinson and Shiffrin (1968) have suggested; that such a "sensory register" may exist for audition, but concluded that there is little evidence for it and that its properties would not necessarily resemble those of other sensory stores. Our argument is, on the contrary, that PAS bears important qualitative similarities to the comparable precategorical storage system in vision (Sperling, 1963) though the relevant time parameters appear to be of different order of magnitude. While other writers (e.g., Mackworth, 1965; Neisser, 1967) have previously considered the existence of an acoustic equivalent to the visual sensory store (and have suggested longer duration in the case of audition than in vision) there has been no comprehensive attempt to make explicit the properties of such a store. In considering these properties, our main objective has been to give an explanation for various serial position data which have been reported in immediate memory. Although the system is in this sense ad hoc it leads readily to a number of testable implications, two of which were confirmed in the experiments reported herein. We shall first describe the PAS system and its properties; second, review the evidence in its favor from both our laboratory and others'; and finally, suggest the relation of the model to a general approach to memory theory.

PRELIMINARY DESCRIPTION OF THE MODEL

The overall schema in which we are operating is given in Fig. 1. Our preliminary assumptions are based on a clear distinction between information which has been categorized (i.e., identified or perceived) and information which has not been categorized. Like Tulving (1968) we see no defensible reason for distinguishing between perception and learning, with respect to individual elements. Once categorization has

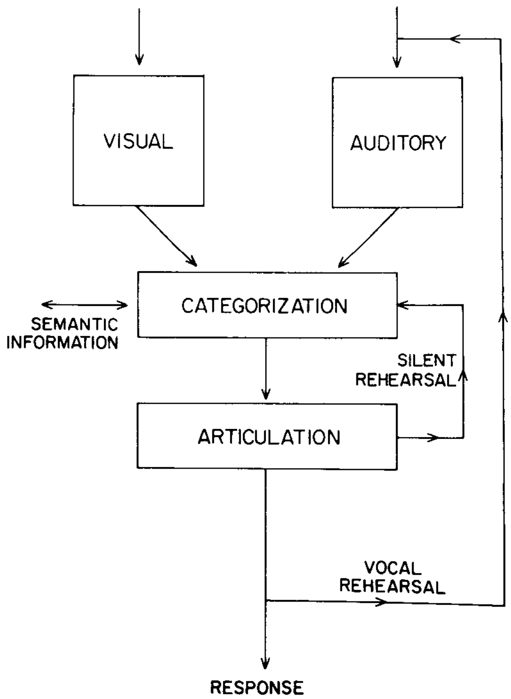

Fig. 1. An incomplete conceptual diagram of information flow in immediate memory tasks. No reference whatever to locations or pathways in the nervous system is implied.

occurred, there is assumed to be little or no distinction among the original modalities of presentation;[5] however, prior (in the logical sense) to categorization information is held briefly in a form appropriate to the input mode, in virtually all cases either vision or audition. The visual precategorical store has been studied extensively elsewhere (Averbach & Coriell, 1961; Sperling, 1963, 1967) and is believed to be of such short duration (a fraction of a second) as to be ignored in immediate memory experiments with conventional rates of presentation. What we are proposing is that there is an acoustic store, PAS, with similar properties and substantially longer storage time. The consequences of PAS for immediate memory will be identified after the general system of Fig. 1 is described in somewhat more detail.

At the precategorical level, we suppose that there is no effective connection between the visual and auditory stores and that performance failures deriving from the limitations of these stores will be describable in terms of purely "sensory" psychology. Of course, it is inevitable that within these preperceptual stores there will be some information reduction with respect to the original stimulus, *at least* information reduction deriving from the limited resolving power of the receptor (Neisser, 1967, p. 200). *At most*, information in PAS could be processed and coded to the level of feature analysis. Although this would logically qualify as a form of categorization (as would all information reduction), the important points are that (a) the model is indifferent to the amount of processing, within the bounds stated, occurring before identification, and (b) we believe it more useful to restrict the term "categorization" to a level at which there becomes the potential for a direct linguistic response. Thus, information stored precategorically is raw in the sense of not yet having made contact with S's overlearned linguistic repertoire; however, it may well not be completely unprocessed information.

Apart from possible reservations concerning the problem of selective attention, which problem, at the level of sophistication of our present concern remains largely opaque (Norman, 1968), the categorization of raw information proceeds in a passive or autonomous fashion (Morton & Broadbent, 1967). The outcome of this categorization process is identical regardless of the original source of stimulation. That is, the informational content of a symbol, once extracted from preperceptual input, is not different when that input was auditory from when it was visual. In the broad context of language recognition two kinds of outcome appear to be necessary. One of these is coded in an *articulatory* mode and could (but need not) lead directly to speech. The other outcome of categorization is in a form suitable for long-term processing. With language the latter type of code would be termed "semantic"; with simple alpha-numeric elements such a term may not seem appropriate, but the existence of strategic and mnemonic processes argue that some comparable mode must be present. We assume that only material which has been categorized is available for rehearsal, association, or participation in such organizational strategies as may be available to S. Further, as Fig. 1 shows, what is customarily known as rehearsal takes place in the articulatory mode whereas organizational and strategic storage features are related to the quasi-semantic mode.

Within the system, the "perception" of the immediate stimulus is characterized by a response becoming available, i.e., by a potential output coded in articulatory form (together with general information that the sensory analyzers have been active). A more detailed description of the properties of this recognition system, per se, may be found in Morton (1964, 1968a, 1969). For the present purposes the important point is that one central consequence of stimulus identification is postulated to be an articulatory event, preceded by an acoustic or other precategorical store.

Evidence of correlations between listening errors and memory errors across the alphabet (Conrad, 1964) was originally interpreted as implying a recoding of visual information into an "acoustic" mode of storage. According to the present position, however, acoustic features are relevant only prior to categorization. "Acoustic confusions" would then be more properly termed "articulatory confusions," the correlation between acoustic and articulatory descriptions accounting for Conrad's results (Murray, 1967; Wickelgren, 1966). Such errors could take place during rehearsal or during output. For this reason, we do not at the moment feel it necessary to suppose that there is any *store* in which information is coded in an articulatory form. Supporting evidence for our contention that errors in memory of visual stimuli are articulatory in nature comes from Hintzman (1965, 1967) who showed that visual memory errors, unlike auditory perceptual errors, are related to place of articulation as well as to voicing. We are, however, aware that the validity of such comparisons of error matrices requires assumptions about the nature of the acoustic noise which is appropriate in obtaining the acoustic confusion matrix.

In discussing the system represented in Fig. 1, (a) we have suggested parallel auditory and visual preperceptual stores, with longer persistence in the former than in the latter, (b) we have proposed a passive process for the involvement of precategorical information in the event of categorization, (c) we have asserted that categorization eventuates in a potential output coded according to articulation, and finally, (d) we have proposed that an additional consequence of categorization can be access to systems of semantic information accumulated during S's lifetime. Rather than treating this general schema, our main concern will hereafter be with PAS and its effects on immediate memory performance.

The main feature of PAS is that it is capable of holding information sufficiently long enough to affect the immediate memory task, at least on the order of a few seconds. As limitations to this persistence, we suggest that information in PAS is lost for either or both of two reasons, (a) overwriting or displacement by subsequent auditory events, and (b) decay with the passage of time. The critical behavioral consequence of these properties may be summarized in a pair of theoretical serial position functions representing visual and auditory presentation of digit or letter series. Figure 2 displays these idealized functions for serial recall. Auditory presentation (represented by the "Auditory Curve" in Fig. 2) supplies S with extra information as opposed to visual presentation due to the persistence characteristics of PAS. The extra information leading to the superiority of auditory presentation

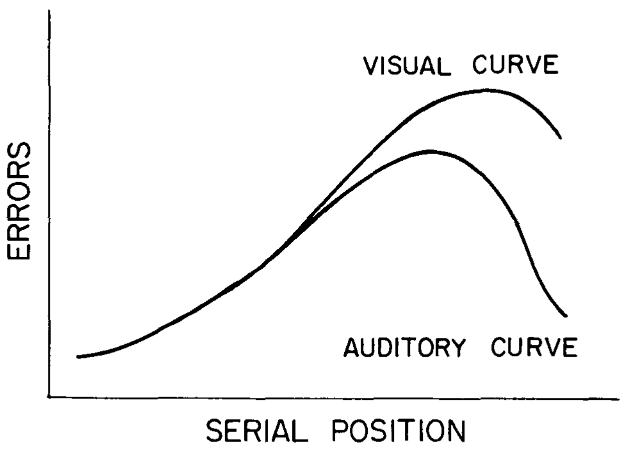

Fig. 2. Idealized serial position functions for visual and auditory presentation. These theoretical curves refer to conditions where approximately span-length series are serially recalled.

is restricted to the last few serial positions in Fig. 2. This follows from the assumed system because early serial elements have decayed from PAS by the time recall is initiated and/or because presentation of the last few elements displaces information in PAS about the first portion of the series. Thus the auditory and visual curves are identical initially, but diverge towards the end of the list.

The system summarized in Figs. 1 and 2 was suggested by data on the effects of redundant elements in immediate memory. We shall now review these effects, then describe two new experiments of our own which were designed to test the PAS assumptions directly.

EFFECTS OF REDUNDANT ELEMENTS IN IMMEDIATE MEMORY

Immediate memory experiments contain redundant elements when, over a substantial block of trials, the series S receives or his reproduction of it contains some predictable element. By predictable is meant that the location and identity of the extra element are known to S in advance of the trial. The digit "zero" has often been used in this kind of experiment, with the restriction that zero can never be a member of the nonredundant memory series. We shall be concerned here with conditions in which the redundant element occurs between presentation of the last nonredundant element and reproduction of the beginning of the series. In studies of the Stimulus Suffix Effect, E presents the redundant element himself, as if it were the n + 1th element of series of n elements. In studies of the Response Prefix Effect, S, following previous instructions, emits the redundant element just before initiating serial reproduction of the memory series. In both cases, the redundant element has been found to produce impressive decrements in recall (Crowder, 1967); the reason for citing this literature here, however, is that the prefix and suffix have quite different effects on the serial position function.

Stimulus Suffix

Serial position data from the Stimulus Suffix Effect are the best illustration of how information stores in PAS can be displaced by subsequent auditory events. Experiments by Dallett (1965) and Crowder (1967) may serve as reference demonstrations. Dallett found that recall for seven-digit series was the same whether an eighth digit presented was (a) redundant and not to be recalled (the digit "zero"), or (b) nonredundant and recalled. The specific effects of the

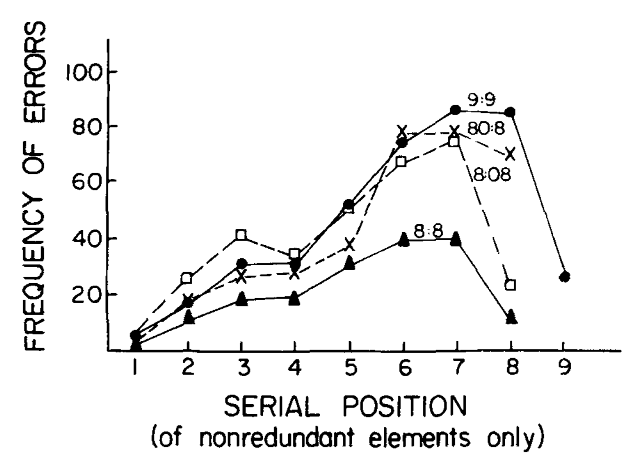

Fig. 3. The relation between serial position and error frequency with vocal presentation for eight- and nine-digit controls (8:8), a stimulus suffix condition (80:8), and a response prefix condition (8:08) [from Crowder (1967, Experiment 3)].

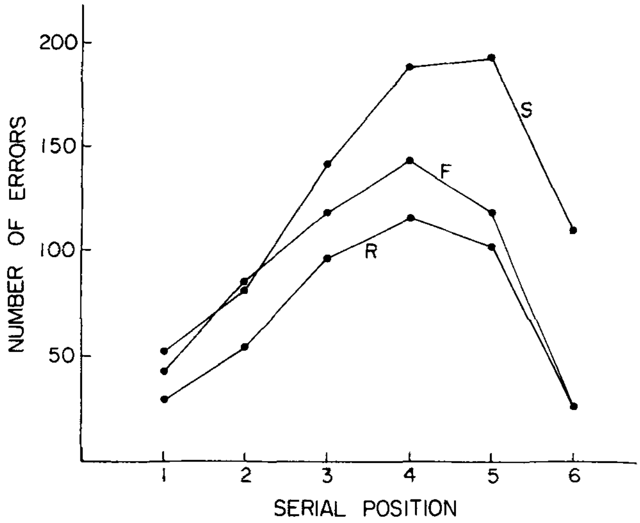

Fig. 4. The relation between serial position and error frequency with vocal presentation for six-letter series, with irrelevant digits interleaved in presentation (Conditions S and F) or each letter presented twice (Condition R) [from Morton (in press)].

stimulus suffix have been shown also by Crowder (1967, Experiment 3) a portion of whose data are given in Fig. 3. The figure displays performance of Ss recalling vocally-presented lists of eight digits, under stimulus suffix conditions (80:8), response prefix conditions (8:08), and both eight- and nine-digit control conditions (8:8 and 9:9, respectively). The main point for the present is that the Stimulus Suffix Effect increased directly with serial position, the greatest effect occurring at the terminal digit. Morton (1968b) has obtained comparable results with presentation of a nonredundant but irrelevant item. In his experiment six consonant letters were recalled under three conditions following auditory presentation. In Condition R, each letter was presented twice (LLZZRRXXNNHH); in Condition F, the letters were interleaved with digits, the letters following the digits (4L5Z3R9X2N7H); and in Condition S, the letters were again interleaved with digits, but the digits followed the letters (L4Z5R3X9N2H7). In all three conditions, S was responsible for reproducing *only the letters* (LZRXNH). Condition S is most relevant here because the terminal digit can be considered a suffix. Morton's data, shown in Fig. 4, indicate that the effect of this terminal digit is primarily upon the last relevant element (the last letter). There were, however, greater differences between Conditions S and F on each of the last three positions than on the first three positions. Furthermore, although Condition F was elsewhere poorer than Condition R, these two conditions were not noticeably different on the terminal position.

These findings are consistent with the position that information about vocal stimuli is held in PAS for some brief time and subject to displacement by subsequent items. Normally (i.e., without a suffix), this means that the terminal position(s), by virtue of having few or no subsequent elements, are represented in PAS longer than early elements in the list, and therefore can be more readily perceived or categorized (Aaronson, 1968). The effect of the stimulus suffix is then to reduce the availability of these last elements in PAS and limit the normally generous readout time they enjoy. At this point the foregoing interpretation is only one of several permitted by the data; we shall show it below to be a necessary interpretation, particularly in Experiment 2.

Response Prefix

Superficially, the response prefix condition is similar to the stimulus suffix condition in that the same sound "zero" is made in approximately the same temporal relationship to the nonredundant events of the trial. Conrad (1958) was the first to report data on the Response Prefix Effect, in an experiment where Ss were compared for prefix and nonprefixed recall of eight-digit numbers. Under both dialing and keypressing recall methods there was a large and significant difference favoring nonprefixed lists. This basic finding has been replicated numerous times since Conrad's first article (Conrad, 1960; Crowder, 1967, in press; Crowder & Erdman, 1968; Crowder & Hoenig, in press; Dallett, 1964a, b; Mortenson & Loess, 1964; Whimbey & Leiblum, 1967). In these studies the Response Prefix Effect has proven refractory to interpretations based on (a) time delay (Conrad, 1960), (b) formal similarity between the prefix element and the memory series (Crowder, 1967, Experiment 2) (c) the memory load imposed by the prefix instruction (Crowder, 1967, Experiment 3), (d) recall modality (Crowder & Erdman, 1968), (e) mode of prefix emission (Crowder & Erdman, 1968) and (f) interseries competition at recall (Crowder & Hoenig, in press). For the moment the only critical point about the Response Prefix Effect is that although it and the Stimulus Suffix Effect are of comparable magnitude, they interact differently with serial position. This is shown in Fig. 3 where it is evident that the suffix (80:8) reduces facilitation at the end of the list (producing the visual curve of Fig. 2). On the other hand, the prefix (8:08) does not apparently change the form of the serial position function, only its elevation; the prefix curve remains an auditory curve. (The comparison of prefix and suffix conditions on the eighth serial position makes this point most forcefully.[6]) Since it is precisely this generalization that is central to much of the discussion below (i.e., the generalization that the prefix and suffix affect serial position functions differently and as stated) we decided to test it under somewhat different circumstances.

EXPERIMENT 1

Among the studies discussed so far, a common procedural detail was that all series were the same length within a session. With constancy of list length, it is reasonable that whatever grouping or organizational strategies Ss apply are facilitated as compared with the conditions where S is ignorant of list length during presentation. In fact, perfectly reasonable interpretations of the Stimulus Suffix Effect and Response Prefix Effect could be based on the higher-order coding and decoding problems engendered by the presence of redundant elements. To rule out such interpretations, and thereby to strengthen the ones being formulated here, we wished to test for the Stimulus Suffix Effect and Response Prefix Effect under conditions where such strategic organization would be minimized. Simply asking Ss not to rehearse is one possibility (Waugh & Norman, 1965); however, such a request presupposes extremely powerful assumptions about the voluntary nature of rehearsal. Another way to minimize rehearsal and organization is provided by the running-memory-span technique of Pollack, Johnson, and Knaff (1959). With this procedure, the S is told to report as many elements from the *end* of the list as possible and the lists used are both variable in length and too long for complete report. When a list is liable to contain as many as 30 letters or digits, it is maladaptive for S to organize the elements as presented, at least if the rate of presentation is fast, for he never knows until too late which ones he will be reporting. A comparison of the gross aspects of the serial position curves from the running memory situation (see Fig. 5) with those from the standard fixed-length task, such as in Figs. 3 and 4, makes it obvious that there are enormous differences in the qualitative nature of the position functions. We assume that these differences lie in the greater use of rehearsal, grouping, etc., in the fixed-length case, whose effect is relative overlearning of the early list members (Welch & Burnett, 1924). PAS would by comparison be unaffected, since, as Fig. 1 shows, PAS has no access to "semantic" information. Thus, one purpose of Experiment 1 was to replicate the Stimulus Suffix Effect and Response Prefix Effect in the running memory task.

The second purpose of Experiment 1 was to determine the dependence of prefix and suffix effects upon rate of presentation. If the Stimulus Suffix Effect degrades performance by reducing availability of information in PAS, then the more information is stored in PAS at the time the suffix is presented the larger the effect ought to be. From the decay properties of PAS, it follows that the faster the rate of presentation, the more information there should be in PAS when the suffix is given. Therefore, the Stimulus Suffix Effect should be larger the faster the presentation rate. If the Response Prefix Effect is, as we have claimed, based on a different mechanism, then there is no reason to expect it to be related to presentation rate.

Method

Each of 36 paid undergraduate Ss heard 45 tape-recorded lists of digits, the lists varying randomly in length from 10 to 30 digits. The main task was to write down as many of the digits from the end of each list as possible, in order, as soon as the presentation series ended. The stimulus lists were concatenated permutations of the nine digits in random order, arranged so that the last nine elements presented included no repetitions. Every S had one block of 15 trials under control conditions, one block in which a stimulus suffix ("zero") was presented as the last element of the list, and one block with the requirement to say "Zero" before initiating recall. The digit zero never occurred in the to-be-remembered series. Detailed instructions preceded each block of 15 trials, so as to ensure that Ss understood the role of the redundant elements. Independent groups of 12 Ss heard all 45 lists at fast (4/sec), medium (2/sec), or slow (1/2 sec) rates of presentation. Recall conditions were appropriately counterbalanced across stage of practice as was the assignment of Ss to rates across stages of data collection. The Ss were run individually and recalled the series on 3 x 5 in. cards. They were instructed that the temporal order of recall did not matter so long as the ultimate positions of the digits they wrote corresponded to the order of presentation. Only the last eight positions in each series were actually scored.

Results and Discussion

The results were analyzed in a 3 (rates of presentation) by 3 (recall conditions) by 8 (serial positions) factorial design with repeated observations on recall conditions and positions. The main effect of serial position [$F(7,231) = 476.6$, $p < .01$] is apparent in Fig. 5. This serial position function is in a sense a more fundamental representation of human immediate memory capacity than the famous bow-shaped curve so widely reported, for it (the function of Fig. 5) is relatively uncontaminated by factors introduced by the S during presentation. It is furthermore interesting that if the appropriate psychophysical methods were applied so as to permit calculation of a "memory span" from these data, the limitation on immediate memory would appear very much more severe than the seven-plus-or-minus-two usually quoted (Miller, 1956). For present purposes, however, the position data were of primary interest as participants in interactions with other variables.

The most important findings were the significant interaction of recall condition with serial position [$F(14,462 = 4.18$, $p < .01$] and the three-way interaction [$F(28,462) = 1.6$, $p < .05$]. The former is shown in Fig. 5, giving errors as a function of serial position, collapsed over presentation rates,

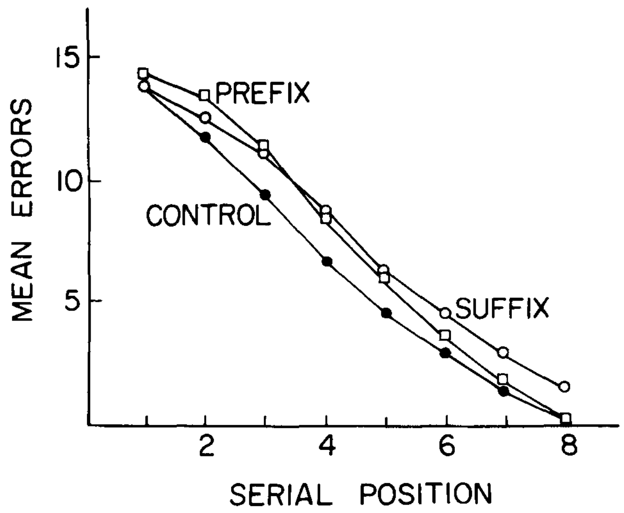

Fig. 5. Serial position data for Running Memory Span, vocal presentation, combined over presentation rates (Experiment 1).

with recall condition the parameter. The data of Fig. 5 firmly established the replicability of the Stimulus Suffix Effect and the Response Prefix Effect in the running memory situation, with respect both to the selectivity of the suffix late in the list and to the relative nonselectivity of the prefix across serial positions. Thus, either these influences of redundant elements on immediate recall do not depend upon organizational factors, or such organizational factors are just as prevalent in running memory as in fixed-length studies.

The main effect of presentation rate was not significant [$F(2,33) = 2.02$], but that of recall condition was [$F(2,66) = 17.9$, $p < .01$]; both factors, and their interactions with each other [$F(4,66) = 2.85$, $p < .05$] may be seen in Fig. 6. These data indicate that as predicted presentation rate was more strongly related to performance in the stimulus suffix condition than in the other two conditions. Furthermore, the magnitude of the Stimulus Suffix Effect was greater the more rapidly the digits were presented. The data from the control condition certainly do not support the decay-theory prediction that under conditions of attenuated organization fast rates should lead to better performance (Posner, 1963). As we shall show below, however, the reduction of the Stimulus Suffix Effect with slow presentation

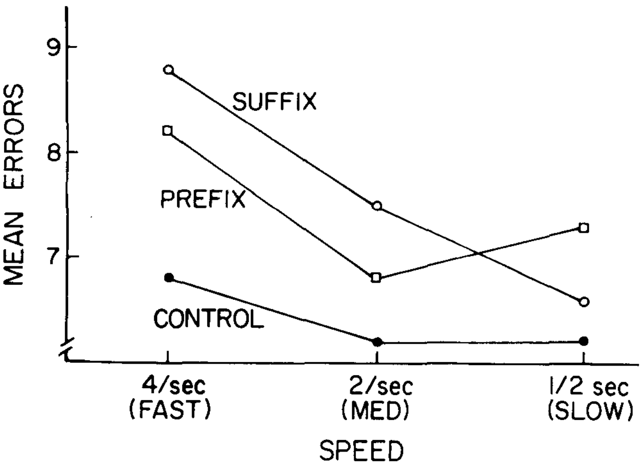

Fig. 6. Overall error frequencies in Running Memory Span, vocal presentation, as a function of experimental condition and presentation rate (Experiment 1).

rates, and the serial position data to be reported, suggest that a decay interpretation may be applicable to the information in PAS. The significant interaction of presentation rate and serial position [$F(14,231) = 2.86$, $p < .01$] will not be discussed. It shows that the inferiority of the fastest presentation rate is confined to the interior serial positions and almost surely reflects both ceiling and floor effects, since practically no errors were made on the last serial position and practically no correct responses were made on the first.

Certain critical aspects of the serial position data are further clarified in Fig. 7, which shows, separately for the three presentation rates, the absolute magnitude of differences between the suffix conditions and the control condition. These data show that not only does the stimulus suffix have a larger effect the faster the rate of presentation, but also that it has an *earlier* effect at the fast rate than at the moderate rate. (The Stimulus Suffix Effect at the slowest rate is within the bounds of experimental error.) If the suffix is thought to displace information in a decaying PAS system, then there should be both more complete and more extensive displacement the less decay from PAS there has been when the suffix is presented. The data of Fig. 7 confirm both points. [In short-term *visual* storage, a comparable finding is that an erasing stimulus (Averbach & Coriell, 1961; Sperling, 1963) is effective only within a certain time delay.]

Comment

In summary, Experiment 1 showed that the Stimulus Suffix Effect and Response Prefix Effect are found in running memory situations, provided the rate of presentation is comparable to those used in conventional immediate memory experiments. The effects of presentation rate further showed that the Stimulus Suffix Effect is greater the more recently S heard the stimuli at the time the suffix is presented. On the other hand, neither the selectivity with regard to serial position nor the dependence on presentation rate was true of the Response Prefix Effect. The obvious conclusion is that the Stimulus Suffix Effect and the Response Prefix Effect, similar though they may superficially be, depend on different theoretical mechanisms. We have suggested that the Stimulus Suffix Effect depends upon selective displacement of information in PAS. A critical test of this reasoning was made in Experiment 2. If the stimulus Suffix Effect depends on the displacement of information in PAS, and if PAS has the properties so far ascribed to it, then with visual stimulus presentation there should be no Stimulus Suffix Effect, because there should be no information in PAS. (Note that for the present discussion, the Stimulus Suffix Effect is being defined as a *selective* effect at the terminal list positions.)

EXPERIMENT 2

Method

Twenty-four paid undergraduate Ss saw 60 nine-digit stimuli presented serially by a filmstrip projector at a 2/sec rate. Counterbalanced blocks of 20 trials were run under control, response prefix, and stimulus suffix conditions. In the suffix condition a *vocally*-presented "zero" occurred .5 sec after the ninth (and last) element of the *visually*-presented memory series. In the prefix condition, S was told to say "zero" before recalling the series. Recall was vocal under all conditions. Stimuli were presented by a Graflex Compact Filmstrip projector associated with an Ektatape two-channel tape recorder. A continuous tape loop governed the events on each trial. There were pulses on one channel of the tape recorder which advanced the filmstrip projector so as to present the nine digits at the required rate; the second channel of the recorder was silent except for the recorded digit zero, which was located .5 sec after the last filmstrip-activating pulse on the first channel, for the suffix condition. For the prefix and

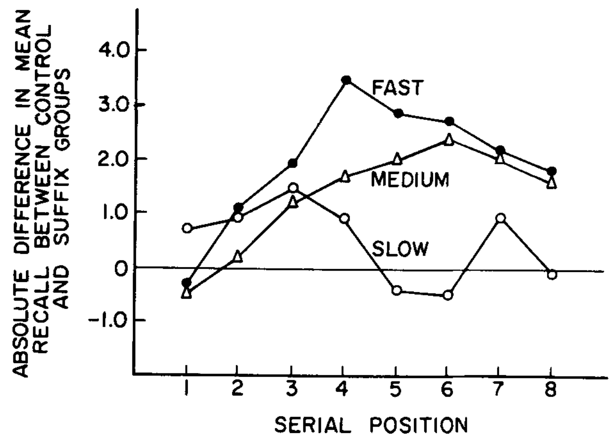

Fig. 7. Absolute differences in error frequency between the control and stimulus suffix conditions with Running Memory Span, vocal presentation (Experiment 1); the parameter is presentation rate.

control conditions, the volume was simply turned off on the second "speech" channel.

Results and Discussion

The main data are given in Fig. 8, which shows errors as a function of serial position with recall condition the parameter. Analysis of variance yielded significant main effects of serial position [$F(8,184) = 62.8$, $p < .01$] and of recall conditions [$F(2,46) = 7.3$, $p < .01$], but a nonsignificant interaction ($F = .65$). Inspection of Fig. 8 makes obvious why there was no interaction of conditions with serial position in this study: there was simply no evidence for a local effect of the stimulus suffix on the terminal serial positions as was found with auditory presentation. On the other hand, the Response Prefix Effect was strong and comparable to that obtained in auditory studies (see Fig. 1) in showing no obvious selectivity across serial position. All the curves are typical visual curves.

The differences in serial position curves between visual and auditory presentation are in accord with our general position and with the idealized functions of Fig. 2. These differences are clear from inspection of Figs. 8 and 3 together. With visual presentation, performance on the final element, while superior to that on the two preceding elements, is no better than performance on the middle positions. With auditory presentation, however, performance on the final element is often surpassed only by performance on the very first element. These differences may be regarded, as a first approximation, as being entirely due to the existence of useful information in PAS when presentation is auditory. With visual presentation only postcategorical information is available.

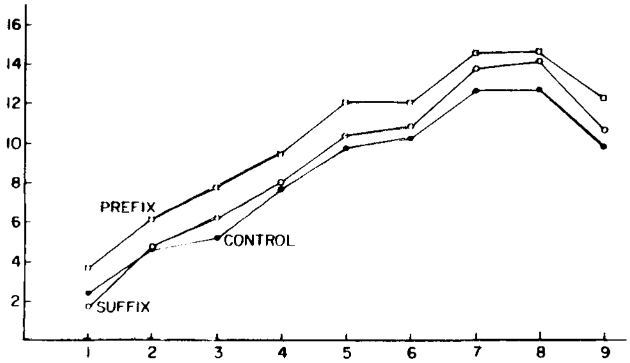

Fig. 8. The relation between serial position and error frequency with visual presentation to stimuli (Experiment 2). In the suffix condition an auditory "zero" followed the stimulus string.

The way is now open to distinguish between two separable effects on the final serial positions of immediate memory stimuli. The effect of PAS, since it is correlated with the passage of time, may properly be termed "recency." Recency is found only with auditory presentation according to our assumptions and the effect of a stimulus suffix is to reduce or eliminate it. The advantage of the final serial position over the previous two or three positions in visual presentation may be termed a "finality" effect. Our hypothesis is that the finality effect is due to the association of the item in question to conceptual "tag" denoting the termination of the list. In other words, recency comes from the precategorical domain of Fig. 1 whereas finality comes from the semantic domain of Fig. 1.

GENERAL DISCUSSION OF REDUNDANT ELEMENTS

Proper respect for the ambiguity of unrejected null hypotheses notwithstanding, the negative findings of Experiment 2, when taken in conjunction with the large Stimulus Suffix Effect with auditory presentation, seems to us strong supporting evidence for our contention that PAS must be precategorical. Furthermore the results of Experiment 2 argue against the position that a truly auditory code results from categorization, otherwise the auditory suffix should have had some selective effect. Altogether, the evidence of redundant elements leads us to the conclusion that the Stimulus Suffix Effect is interpretable in terms of precategorical information and that the response prefix effect is interpretable in terms of categorized information. Specifically, the suffix displaces (or otherwise degrades) a source of extra stimulus information (PAS) deriving from auditory presentation. The mechanism for the Response Prefix Effect is not directly suggested by the present data (nor is it critical to the arguments being made here); however, our proposal is that it results from *articulatory interference*. Since PAS is relevant only to the late serial positions the suffix has a selective effect; but since articulatory coding is a perceptual consequence for all elements in the list, the prefix has a nonselective, overall effect on errors.

If the Response Prefix Effect is caused by articulatory interference, then the similarity of the prefix element to the members of the memory series should be directly related to the size of the prefix effect. However, the particular dimension of similarity would be absolutely crucial, according to our formulation. Crowder (1967, Experiment 3) has previously shown that in terms of formal similarity (letters vs digits) the prefix effect does *not* vary according to the laws of retroactive interference. The present supposition is that the prefix effect will be larger the more similar the redundant element is to the nonredundant elements in terms of how they are *articulated*. A recent study (Crowder, in press) has confirmed this prediction by showing that when the dominant phoneme in a memory list was "ē," a larger decrement was obtained when the prefix was the letter "v" than when it was "k," all data having been collected with visual presentation and written recall.

A perfectly reasonable objection to the present analysis is that a voiced prefix, being an auditory event following closely upon stimulus presentation, should lead to loss of information in PAS just as does the stimulus suffix. Since the data presented here and elsewhere give no evidence of such PAS-disruption by the response prefix (i.e., no evidence that the response prefix selectively impairs performance at the end of the series) we are forced to assume that access to PAS can be selective according to channels of acoustic input. In practical terms this means that when the task-relevant information is reaching S by E's voice, auditory feedback from S's vocalization of the redundant element can be attenuated.[7] [Morton (1968a) has made a similar suggestion elsewhere for different reasons.] Since this selection is based on voice quality the attenuation must be relatively peripheral, unlike the "selective filter" concept of Broadbent (1958). The selectivity of access to PAS is being directly examined in our laboratory by studies concerning the range of auditory events which will lead to a selective Stimulus Suffix Effect. Preliminary results indicate that there is a high specificity not only to speech sounds, but also to the particular vocal quality used in recording the to-be-remembered elements. (Of course, it follows from the nature of the selective mechanism we have proposed that if S vocalizes a visually-presented list, vocal emission of a response prefix *should* affect PAS. This deduction has not yet been tested.)

One complication to the present interpretation of the Response Prefix Effect is the finding of Crowder and Erdman (1968) that a vocalized prefix leads to a larger effect than a written prefix following vocal presentation. On the surface this would seem to indicate that the acoustic intensity of the prefix affects performance through PAS; however, the increased effect of a vocalized prefix was not more pronounced in the terminal serial positions than elsewhere in the list. In other words, making a written prefix more like a suffix by having S pronounce it led to an empirical result more suggestive of an increased prefix effect than of a suffix effect. We must assume, therefore, that the feedback-attenuation is complete enough to completely protect PAS from a single spoken prefix. But why, then, was the spoken prefix more detrimental? One explanation is that prefix vocalization requires more complete articulation than the written prefix. This notion is especially reasonably when one considers that with practice, writing zero could be accomplished by S as a simple manual motor task without verbal mediation, viz, by drawing a small circle before each recall.

MODALITY EFFECTS IN IMMEDIATE MEMORY

Our purpose is now to turn to the previous literature on immediate memory and apply the notions about PAS to some otherwise puzzling findings. The experiments to be taken up compare conditions which are logically, or informationally, identical. That is, Ss are presented with the same lists at the same rates, and asked for the same responses. What differs, within these comparisons, is the involvement of various peripheral mechanisms for perception and responding. That such peripheral features of the task are influential in determining performance is a measure of the inadequacy of any theory which treats the stimuli only as symbolic units.

Visual vs Auditory Presentation

Several available studies show differences between auditory and visual stimulus presentation. Comparing our Figs. 3 and 8, for example, makes the essential point that auditory presentation facilitates the last few serial positions. Corballis (1966) has shown the same thing within a single experiment comparing visual and auditory presentation for lists of nine digits; he found significant differences favoring the auditory mode only in the last three serial positions. Murdock (1967) has reported comparable relationships in a different sort of situation. In Murdock's experiment Ss saw or heard six pairs of common nouns and were tested for one by a probe technique. There was, in this experiment, roughly equivalent performance over the first four pairs, but an enormous advantage of auditory presentation in the fifth position (about 80% vs 40% correct recall). In still a different type of task, Cooley and McNulty (1967) obtained similar facilitation of the auditory mode. These authors presented CCC trigrams which were tested over intervals of up to 18 sec filled with an interpolated backward-counting task. Their finding was that the vocal mode was better than the visual mode at immediate and 3-sec tests, but no difference at 6 or 18 sec. These experiments all support the view that auditory presentation provides an extra source of

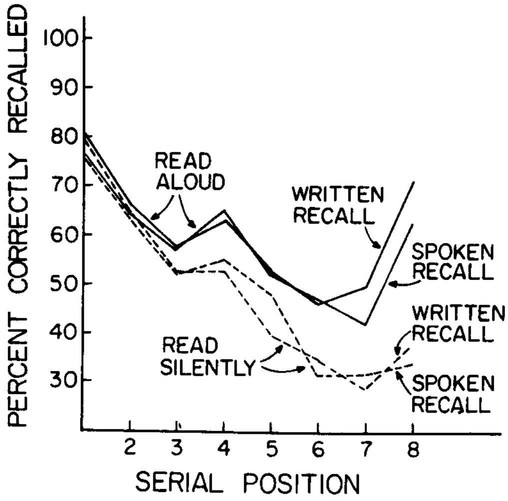

Fig. 9. The relation between serial position and correct responses in Murray's (1966) experiment. Visual presentation was either vocalized (solid lines) or silently read (dotted lines) and was followed by written or spoken recall.

information about recent stimuli which is not available through the visual mode.

Vocalization at Presentation

A set of related studies deal with the effect of Ss' reading the stimulus aloud during visual presentation. Murray (1966) presented eight-consonant lists visually, with instructions either to read the letters silently as they appeared or to read them aloud. Figure 9 gives the results. (Disregard for the moment the breakdown of written and spoken recall.) Clearly, vocalization facilitated recall, and increasingly so with the terminal serial position. It will be noted that the relative shapes of Murray's position functions for the vocalized and nonvocalized conditions correspond respectively to the auditory curve and the visual curve of Fig. 2. Conrad and Hull (1968) have recently confirmed the effect of vocalization at presentation upon visually-presented series. These data make it possible to conclude that the essential difference between the two presentation modes is not the original source of the stimulus information but rather whether or not auditory traces are set up. Evidence that this effect is in fact due to acoustic feedback via the S's ears is slightly circumstantial. It is possible that the effect could depend upon proprioceptive feedback from the muscles involved in speech, or through a monitoring of the efferent impulses sent to those muscles. Such signals could differ from those available in the course of silent rehearsal in their intensity. Such a proposal is seemingly contradicted by an experiment of Murray (1965a) who showed that the overall advantage of vocalized rehearsal is negated in noise unless the volume of the vocalization is sufficient to overcome the noise and make the rehearsed items audible.

Vocalization at Recall

We have stipulated elsewhere that the probable contribution of PAS to serial recall in immediate memory is the provision of extra read-out time for the last few elements at the time of presentation. Of course there would not be such facilitation of the early positions because their PAS traces would have been destroyed by hearing the subsequent positions. It is not incompatible with this possibility to suggest that in addition, at least under some circumstances, information about the terminal elements is stored in PAS long enough to be useful when S gets around to recalling them. If information is held in PAS long enough to be useful in recall, then any acoustic events coming over the same channel as the memory series which intervene between input and output of the terminal elements should reduce their recall. If presentation was visual and read aloud by S during presentation it follows that spoken recall should be worse than written recall, and specifically so on the last few serial positions, because then the acoustic properties of the input and the output channel would be identical. On the other hand, if visually presented series were read silently by S, no acoustic traces would have been set up in the first place and recall modality should not affect errors late in the series (or anywhere else for that matter). Exactly this pattern of results has been obtained by Murray (1966), whose data are shown in Fig. 9. In this study, Murray varied the output mode, either written or spoken, following, as we have seen, visual presentation which was either vocalized or read silently. As Fig. 9 shows, the only obtained difference between the two recall modes was in the last two positions of vocalized (in presentation) lists; the difference was statistically significant and favored silent recall. This study is a rough analogue of Experiment 2, above, in showing that acoustic events impair performance only when the relevant information came originally through Ss' ears.

Unfortunately, other experiments have not led to identical results under comparable conditions (Murray, 1965b) although serial position data were not reported. Also unfortunately, it has been shown (Crowder & Erdman, 1968) that recall vocalization increases recall failures following tape-recorded auditory presentation (i.e., where the relevant PAS information came from E's voice and not S's). Furthermore, like Murray (1966), Crowder and Erdman found recall vocalization had its greatest effect in the last portions of the series. This is puzzling because we have assumed above that S can attenuate entry of acoustic signals to PAS so long as the signals are from a different channel as the task-relevant information. (This assumption was, it will be recalled, necessary to account for why the response prefix has no discernible differential effect on the last few serial positions.) The question is then why the sound of his own voice recalling the early serial elements reduces S's recall for the terminal elements when the sound of his own voice emitting a prefix does not. The answer may lie in a limitation on the efficiency of the feedback-attenuation mechanism. In defense of the notion that attenuation of vocal feedback is almost complete, note that in Fig. 9, where around half a dozen potentially disruptive sounds have entered PAS through feedback, the effects on performance are small as compared with the effect of a *single* stimulus suffix letter given by E when recall is written (shown in Fig. 3). Looking at it another way, there is some adaptive value in *not* "blocking" the sound of one's own voice in vocal recall, for it may provide important contextual cues to S, in spite of its destroying the contents of PAS. This is obviously testable. Clearly, further research will be necessary before the full pertinence of output-vocalization to PAS can be evaluated.

IMPLICATIONS FOR MEMORY THEORY

There are two critical themes in the arguments we have made to this point. The first is the importance we have attached to the perception of language and speech with regard to the process of verbal learning (which term we mean to include the acquisition phase of a digit-span experiment). The second critical theme is the historical, or progressive, nature of this perception-learning process.

The intimate relation between linguistic perception and memory experiments serves to advance a whole class of variables, such as articulatory representation, which were not formerly considered necessary to S-R accounts of animal or human learning. Indeed, such variables are probably not useful in certain areas, such as perhaps learning of skills, recognition of faces, or acquisition of neuroses. However, what distinguishes the vast majority of human learning is its dependence on language and, in turn, the highly overlearned modes Ss have for dealing with language. Thus, both Hebb (1949) and McGeoch (1942) asserted that virtually *all* (adult) human learning is to be understood with reference to the process of transfer and that truly "new" learning is rare indeed among adults.

What seems to us the critical advantage of identifying verbal learning with language perception, rather than, say, classical conditioning, is that linguistic materials go through a somewhat stereotyped progression of perceptual stages (Posner, 1967). "What is learned" by the S in an experiment may then be said to depend on how far into such perceptual processing the materials have passed at the termination of stimulus presentation. To this point, we have concentrated on what is probably the most "primitive" level of perception or learning in memory experiments (along with the visual preperceptual system). It seems necessary to distinguish at least two or three further levels of analysis which become involved when human Ss are given alphanumeric materials. A commitment has already been made to articulatory representation as the process into which precategorical information is fed through a passive recognition system. The articulatory representation of elements must, for other reasons (Morton, 1968a) be directly correlated with semantic features developed through S's lifetime. Our position is that the involvement of such semantic features will depend on how much time S is given to spend with the stimulus, as will the complexity of those semantic features. It is our belief that the term "semantic" will prove ultimately subject to analysis into several distinct dimensions, or levels, of complexity.

The consequences of such a progressive and stratified account of linguistic perception, and hence of verbal learning, is that there is great variety in what Ss learn about nominal stimuli, depending on what happens at the time of presentation. Such diversity in the product of learning is bound to have important behavioral consequences. It is important to recognize, however, that postulating a multiplicity of storage dimensions does not in any way prejudge the theoretical mechanisms responsible for performance decrements. That is, there could be diversity in *product* but unity in process. Interference based on similarity, for example, could be the fundamental mechanism at all levels (Melton, 1963). What these considerations do imply, however, is that similarity and interference must refer to the appropriate level of coding. Thus, if lists of eight consonants are learned primarily as articulatory representations, we would not expect interference effects along semantic dimensions; nor, if free-recall lists are learned according to semantic cues, would we expect articulatory interference to show up. There is some experimental evidence to show that interference operates according to a kind of compatibility mechanism, where the functionally relevant levels of analysis must match between the to-be-remembered material and the interfering materials (Baddeley, 1964, 1966; Baddeley & Dale, 1966).

By the same token, it is inadequate to appeal to interference explanations only in terms of their defining operations, retroactive and proactive inhibition, without specifying what dimensions of similarity underlie such inhibition. Thus, to "explain" both the suffix and the prefix effects as being due to Retroactive Inhibition (true by definition) is to miss the whole point of the present paper. Such statements take us little farther than the data. The kind of progress which seems to us valuable is to specify precisely the dimension of the interference.

A final point is that in the light of what has been said about the essential multiplicity of coding processes in memory, the distinction between long- and short-term memory appears counterproductive. There will be dramatic differences in the permanence of memory traces and in their susceptibility to various sorts of interference; but according to our position, such differences reflect differences in what, precisely, has been perceived (and therefore stored) by Ss, and not the number of seconds, minutes, or hours, over which retention is tested.

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4. For similar reasons, the present conception of PAS places it logically prior to the S-system of Broadbent (1958) since apparently both auditory and visual information can pass through the latter.

5. This is not to say that S cannot tell whether he saw or heard a stimulus once it is categorized. Rather, it means that the informational nature of the categorized element is the same in both cases.

6. The null hypothesis that the prefix and suffix effects were essentially similar for the data of Fig. 3 was rejected on the basis of Wilcoxon signed-ranks tests showing (a) a significant difference in the proportion of total errors which occurred in the last half of the series for Conditions 80:8 and 8:08 ($T = 32$, $p < .05$), and (b) a significant difference in the frequency of errors at the eighth position for these two conditions ($T = 6$, $p < .01$).

7. We are using the term "attenuated" advisedly, and in preference to the term "blocked."

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