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EXPERIMENTS WITH THE STIMULUS SUFFIX EFFECT [1]

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A number of experiments are described which use the stimulus suffix effect (SSE) to determine the properties of the precategorical acoustic store (PAS) described by R. G. Crowder and J. Morton in 1969. The SSE is a selective impairment of recall of the final items in a serial recall list engendered by a redundant acoustic event following acoustic presentation. First, it is established that such intrinsic properties of the suffix as its meaning, frequency of occurrence, and emotionality have no bearing on the size of the suffix effect. This confirms the precategorical nature of the store. Second, it is shown that variation in the acoustic properties of the suffix (such as its apparent spatial location, timbre, and pitch) with respect to the stimuli reduces the size of the SSE. Variations on this theme indicate that PAS is located after a mechanism of selection between acoustic channels and before the convergence of acoustic and visual analysis systems.

Two of us proposed in an earlier article (Crowder & Morton, 1969) that information concerning the last few items in acoustically presented immediate-memory lists is held in a Precategorical Acoustic Storage (PAS) system. This store is regarded as being a property of that part of the nervous system responsible for the analysis of acoustic inputs. The most obvious consequence of the PAS mechanism is the advantage observed in recall following auditory as opposed to visual presentation, an advantage specific to the last few serial positions. Conrad and Hull (1968) and Routh (1970) showed that if *S* vocalizes rehearsal of visually presented series, the typical "acoustic" result is obtained, while Murray (1965) has shown that such vocalization effects are removed if *S* received white noise sufficient to mask the sound of his own voice. Thus it seems apparent that genuinely acoustic information is implicated in the auditory–visual comparison.

In the earlier article, we demonstrated how the effects of a *stimulus suffix* (Crowder, 1967; Morton, 1968) could be interpreted by reference to PAS. The stimulus suffix (hereafter simply "suffix") is an extra locution pronounced after the terminal element of the to-be-remembered series; its effect is a sharp impairment of the last item or two. Essentially, the suffix effect removes the advantage of auditory over visual presentation. This is both a fair empirical generalization and in addition is the theoretical interpretation advanced by Crowder and Morton (1969). The proposed mechanism for the suffix effect is that the suffix overwrites information in PAS before such information can be used (or in some way "protected") by *S*. It should be noted that the effect of a suffix does not qualitatively resemble the effect of a response prefix (Conrad, 1958, 1960; Crow-

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der, 1967). The prefix impairs serial recall at all serial positions, whereas the suffix acts selectively on the very last portion of the function.

The set of questions we are addressing in the present article concerns how the suffix effect is a function of the various acoustic events one chooses to employ as a suffix. After an initial study concerned with the situational generality of the suffix effect, the remainder of the research will be composed of (*a*) studies revealing that the semantic nature of the stimulus suffix makes no difference to the suffix experiment, (*b*) studies showing the rather complex dependence of the suffix effect upon laterality arrangements used, and (*c*) studies exploring the dependence of the suffix effect upon "vocal" or acoustic properties of the suffix event.

The Generality of the Suffix Effect

Experiment I

The purpose of this study was to demonstrate that the suffix effect is not restricted to techniques where complete ordered recall is required. The reasoning was that such a demonstration would support the contention that the results to follow later in this study (virtually all based on the standard ordered-recall method) are of general relevance to human memory and not limited by a particular method of measuring retention. As in many of the studies to follow, the stimuli were lists of digits read at a rate of 2 digits/sec; however, instead of having to recall the whole list from beginning to end, *S*s in the present study were provided with cards showing the series they had just heard in its entirety except for a single digit. It was this single digit, represented by a dash on the test card, that *S* was responsible for recalling. This method constitutes a combination of position and associative probing. The *S* is free to use the item preceding the dash as his cue or he may identify the missing item by noting what position it occupies. In either case, *S* is released from the great burden of (*a*) recalling the entire series and (*b*) recalling order, as well as item, information.

Method.—Fifty-four Yale undergraduates, tested individually, listened to the same fixed list of 108 nine-digit series, each spoken at a 2 digit/sec rate with 1-sec. warning period and three trials a minute presented over a tape recorder. Each *S* served in all three conditions. In the *Control* condition as soon as the list had been presented, *S* was shown a 5 × 8 in. card on which eight of the nine stimulus digits had been typed in a row with a space left for the ninth (tested) digit and a dash drawn in its place. The *S* had before him a numbered list of 108 spaces, in which to write the probed digit for each trial. In the *Prefix* condition, everything was the same except *S* had to speak the word "zero" between hearing the last stimulus digit and receiving the test card from *E*. In the *Suffix* condition, the only change in procedure from the Control condition was that each test series as presented had a tenth element, the word "zero" spoken in the same voice as had originally recorded the series. Six subgroups of nine *S*s each received these three conditions in all possible orderings. However, since the same fixed list of 108 nine-digit stimuli was used for all *S*s, conditions and stimuli were completely balanced against practice and against individual stimuli.

Results.—The results are given in Fig. 1, which shows error probability as a function of condition and serial position. The overall effect of conditions was highly significant, $F\ (2, 106) = 20.03, p < .01$, coming chiefly from the superiority of the Control condition to the two other conditions. The critical outcome was, however, that while the Suffix and Prefix conditions were generally indistinguishable, in the last serial position

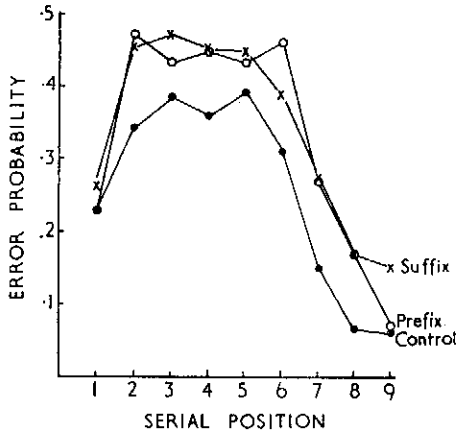

FIG. 1. The relation between error probability and serial position in Exp. I using a complete probe technique where, after presentation of the stimulus, *S* is presented with a response sheet complete save one item.

the Suffix condition revealed over twice as many errors as the Prefix condition. Analysis of the ninth serial position showed that the Prefix condition did not differ from the Control condition but that the Suffix condition did ($p = .002$ by sign test) and that furthermore the difference between the Suffix and Prefix conditions was highly significant ($p < .006$). Elsewhere, there were no significant differences between the two experimental conditions except for a marginal difference at Serial Position 6 ($p = .049$ by sign test) showing more errors in the Prefix condition. We shall assume this latter difference was a chance occurrence.

Discussion.—Exp. I shows simply that the suffix effect, i.e., the selective impairment of recall at terminal serial positions, is readily demonstrable in experimental arrangements other than those involving serial recall. Whether order information is or is not necessary for performance of this probe task is a question beyond the scope of this paper and beyond the grasp of modern theories in any case. However, it seems to us fair to observe that this task does greatly minimize whatever error tendencies lead, in serial recall, to inversions and other order errors. At the very least, the requirements of the present technique and of the standard immediate recall task are substantially different, notably with regard to what *S* must retain about serial order; occurrence of the suffix effect under both circumstances gives some measure of confidence that the phenomenon is not narrowly task specific.

In addition to the standard serial recall task, the suffix effect has been demonstrated with running memory span (Crowder & Morton, 1969) and with complete probing (see Exp. I, above). Still further documentation of the task nonspecificity of the suffix effect is, of course, much to be desired. However, our approach in the remainder of the present paper has been just the opposite. We have largely kept the task the same but have brought about very significant variations in the nature of the memory materials and in the way they have been delivered to our *S*s.

Experiments Confirming That PAS is Presemantic and Precategorical

In earlier experiments, a suffix effect has been found with the digit "zero" following a list of digits (Crowder, 1967; Dallett, 1965) and with an unpredictable digit following a list of letters (Morton, 1968). It is important to know whether there are any semantic effects associated with the suffix phenomenon. Since the underlying model (Crowder & Morton, 1969; Morton, 1969, 1970) specifies that PAS is located well before extraction of meaning, we must predict that there will be no variations in the size of the suffix effect owing to the meaning of the suffix location. The next several experiments confirm this null prediction in a variety of situations.

Experiment II

Method.—The *S*s were 48 volunteers from the Applied Psychology Unit *S* panel, all housewives aged from 25–45. They served in six groups of 8 *S*s each in accordance with a 6 × 6 Latin-square arrangement of the following six conditions: (*a*) *Control* (C): no suffix; (*b*) *Binaural Suffix* (B): the suffix (the word "nought") was at the same apparent loudness and location as the stimulus lists; (*c*) *Monaural Suffix* (M): for half of the *S*s the suffix ("nought") was presented to the left ear and for half to the right ear. The intensity of the suffix was the same as that presented to each ear in Cond. 2; (*d*) *"Recall" Suffix* (R): identical to Cond. 2 except the word "recall" was used rather than "nought"; (*e*) *Random Words* (W): suffixes were randomly selected AA words from the Thorndike-Lorge tables, a new word being used on each trial; (*f*) *Prefix* (P): identical to Cond. 1 except *S* was required to write the digit 0 between hearing the stimulus list and recalling it. A space was provided for this prefix on each line of the answer sheet.

The stimuli were lists of eight digits, binaurally presented. There were 20 lists presented in each block, (i.e., for each of the six conditions) of which the first two were discarded as practice. In addition, *S*s started with a complete practice block in which all the suffix conditions were illustrated. The *S*s were informed before each block of trials which condition would follow. Stimuli were recorded on magnetic tape at a rate of 2 digits/sec and played via a Vortexion tape recorder through S. G. Brown 3C/1100/1 headphones. All suffixes occurred ½ sec. after the final item in a test series (i.e., 500 msec. following the start of the final item).

The stimulus lists were arranged so that no digit was repeated in any list and no digit occurred in successive lists in the same serial position. The digit lists in any condition were arranged so that each digit occurred an equal number of times at each serial position. These precautions ensured that no artifactual influences would contaminate the data.

Recall was written on response sheets with the proper number of spaces. Instructions warned

against starting recall before the list had been completely presented. There were also stipulations calling for ordered recall and for leaving no blanks (i.e., "Guess when uncertain").

In this and several subsequent studies, since the population of *Ss* was extremely heterogeneous with regard to memory ability, some method of screening was necessary. Where possible, this was done in advance. On other occasions, *Ss* were excluded who either scored the maximum possible number of errors at any one serial position in any condition or who made no errors at all in any one condition. Also, any *S* discovered not to be following instructions (writing down the digits at presentation, recalling in other than serial order, etc.) was eliminated from the study. Groups were then adjusted by random discarding of *Ss* from the study so as to balance the control over order of presentation.

Results.—The data from all groups were pooled and the errors at each serial position expressed as the proportion of the number of lists used. Conditions were compared by performing Wilcoxon tests on the pooled data for all serial positions. Only and all of those differences which are significant at better than 2% (two-tailed) are reported.

One might expect that the Binaural "Nought" condition would have a greater effect than either "Recall" or the Random Words conditions, since it belongs to the same set (digits) as the stimuli. In addition, it might be predicted that the Random Words condition would have a greater effect than the "Recall" condition since the latter was completely predictable. Neither of these suppositions are supported by the data, there being no significant differences between these three conditions at any serial position except W and B at Position 5. This isolated difference was attributed to chance. Accordingly, these three conditions are pooled in Fig. 2. All three of these conditions were worse than the Control condition except at Positions 1 (B, W, and R), 2 (R and W), and 5 (B and R). The impairment was greater at Position 8 than at other serial positions and greater at Position 7 than all others except the last. In this respect the Suffix differs from the Prefix, which was worse than the Control condition at Positions 3, 4, 6, and 7, but is indistinguishable from it at Position 8. These results confirm earlier results (Crowder, 1967).

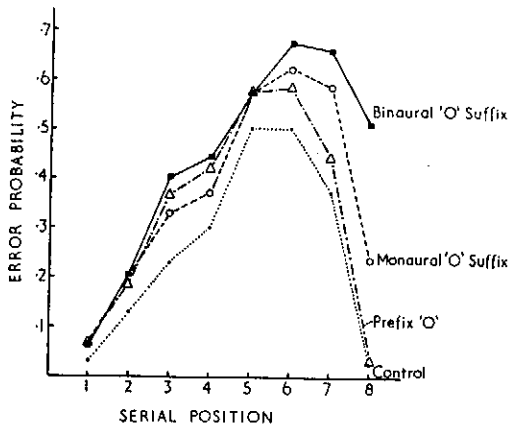

FIG. 2. Error probability in serial recall in Exp. II. (The *Binaural* "0" *Suffix* curve is the average of three conditions indistinguishable in the data. The stimuli were presented binaurally, hence the greater effect of the Binaural Suffix. The difference between suffix and prefix is clear. The prefix and recall were written.)

The Monaural Suffix differs from the Control condition at Positions 2, 3, 6, 7, and 8. It was not different from the other suffix conditions except at Position 8. The effects of the monaural suffix will be discussed in detail in later sections of this article.

The important result for the moment is that given both stimuli and suffix are binaurally presented, the effect of the suffix is determined neither by its meaning nor its predictability. The next several studies are directed toward the same point from slightly different angles. We consider it important to furnish considerable redundancy with respect to this result since a null-hypothesis outcome is predicted by the theory.

Experiment III

In this experiment, the prefix and suffix conditions were again contrasted; this time there was a pair of conditions in which the redundant element (prefix or suffix) was the word "zero" and another pair of conditions in which the redundant element was the location "uhh . . . .." This latter event was chosen because it is relatively "impoverished" in an articulatory sense

and contrasts sharply with the articulatory richness of "zero."

Our expectations for these conditions were that while there ought to be no difference between using "zero" or "uhh . . ." as a *suffix*, (for reasons cited above), it might make a difference when these two were employed as prefixes. Crowder (1969b) and Crowder and Morton (1969) have speculated that the prefix effect might result from articulatory interference. (These writers have insisted that the prefix effect is mediated by a different mechanism from that mediating the suffix effect; the nature of the former is not critical to arguments concerning PAS.) If this were the case, then the degree of similarity between the speech gestures involved in *S*s producing the prefix element and those involved in retaining or recalling the memory stimulus should be evident in performance. It seems fair, on this basis, to predict that since the sound "uhh . . ." involves practically no articulatory variety, it should lead to a smaller prefix effect than "zero."

Method.—Each of 20 *S*s (Yale students serving for pay) received the same 100 trials, arranged into five blocks of 20 lists, in the same order. The five conditions, *Control*, *"Zero" Prefix*, *"Uh" Prefix*, *"Zero" Suffix*, and *"Uh" Suffix*, were all presented to each *S*, although in different orders according to a pair of Latin squares. Since the digit lists used on any given trial were the same for all *S*s, the Latin-square arrangement produced complete balance with regard to individual stimuli, and, since the squares used were so chosen, with regard to first-order sequence effects among conditions.

The stimuli were random permutations of the nine digits (excluding zero). A new trial began every 20 sec. and consisted of a "ready" announcement, a 1-sec. pause, then the list of nine digits read at a 2/sec. rate, and finally a silent recall period.

In the two suffix conditions, the extra element ("zero" or "uh") was recorded in *E*'s voice exactly in time with the 2/sec rate. In the prefix and control conditions, only the nine-digit series were recorded. The *S*s were told, before each prefix condition, to emit the prefix as rapidly as possible following stimulus presentation. There seemed to be no problem in getting reasonably standard sounds for "uhh . . ." from the various *S*s; it seemed to many of them an extraordinarily natural thing to do as they prepared to initiate recall. Although recall for the memory series was written, on answer sheets providing the proper number of spaces, prefix emission was vocal. The *S*s were tested individually in a small room with playback through a single loudspeaker.

Results.—Each of the five conditions is plotted separately in Fig. 3. It can be seen in the figure that both types of redundant element had impressive overall effects on error rates whichever word was used. As predicted, more errors were made in the prefix condition when "zero" was used as the prefix element than when "uhh . . ." was used as the prefix element; however, for all positions combined, this result was not statistically significant. Wilcoxon tests showed, in fact, that only at Serial Position 6 were errors in the "Zero" Prefix condition significantly greater than in the "Uh" Prefix condition ($p = .022$).

There was not overall a statistically significant difference between the two suffix conditions, as predicted; however, unexpectedly there was a consistent tendency for the "Uh" Suffix condition to display more errors than the "Zero" Suffix condition in the last few serial positions ($p = .077$ at Position 7, $p = .041$, at Position 8, and $p = .036$ at Position 9). The experiment was, of course, conducted against the possibility that the "Uh" might be the less effective suffix of the two; to have shown a tendency toward the contrary is rather an embarrassment. The best hypothesis at the moment seems to us that acoustic energy reaches *S* earlier chronologically in the "Uh" condition

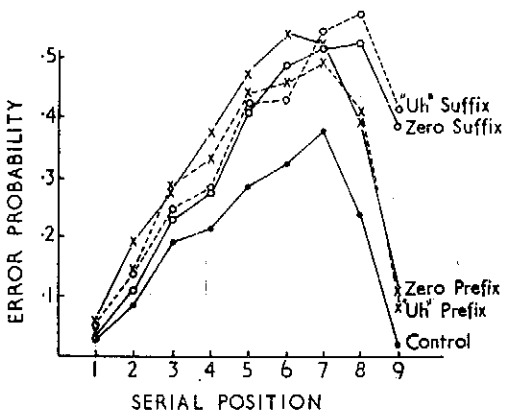

FIG. 3. The effect on error probabilities of two kinds of stimulus suffix and response prefix as a function of serial position. (The prefixes were spoken; recall was written. Data are from Exp. III.)

than in the "Zero" Suffix condition. This difference is inherent in the articulation of the two sounds, "Uh" reaching full intensity immediately and "Zero" not. Crowder (1969a) has recently shown that differences of 100 or 200 msec. in delay of suffix onset after the terminal item appreciably affect the magnitude of the suffix effect. In any case, Exp. III clearly supports the earlier study in failing to find an enhanced suffix effect when the suffix comes from the same semantic class as the memory materials as opposed to when it does not.

Disregarding the "zero–uh" comparison, it is of some interest to compare Fig. 2 and 3, in both of which there is a contrast among prefix, suffix, and control conditions. The obvious and important similarities are that in both studies the prefix and suffix each affect performance adversely, the former nonselectively across serial positions and the latter selectively with regard to items at the end of the list. The one notable difference in the two patterns of results concerns the comparison of suffix and prefix serial position functions. In Exp. II, these two experimental conditions are identical until Position 5, whereas in Exp. III the suffix effect is considerably smaller than the prefix effect until Position 7 where the situation reverses. In an overall analysis of variance in which the two prefix conditions were combined and also the two suffix conditions combined, this crossover showed up in a highly significant Position × Condition interaction, $F(8, 152) = 29.73$, $p < .01$. The most likely explanation for this discrepancy seems to us to be that in Exp. II a written prefix was used, whereas in Exp. III a spoken prefix was used. Crowder and Erdman (1968) have shown that a spoken prefix is more injurious to recall than a written prefix. If the prefix curve of Fig. 2 were simply elevated slightly, the pattern would be identical to that shown in Fig. 3. Other important differences exist between the studies, of course, different S populations, different list lengths, etc. The general lesson to be learned from comparing these two studies is not the specifics of procedures or outcomes. Rather, it is that the procedural circumstances of this type of study do make a large difference and that it is therefore not possible to generalize abstractly about what effect these operations have except that the suffix always has a position-specific effect and the prefix always has a nonselective effect. For example, in Fig. 3 if one shifts the suffix condition one position to the left it lines up almost perfectly with the first eight points on the prefix curve; this coincidence invites the conjecture that the prefix and suffix effects are really the same phenomenon but that in the prefix condition an extra event is added at the beginning of the list and in the suffix condition the extra event is added to the end of the list. This proposition is quite opposed to our own theoretical position and to those tempted to make this last interpretation we invite application of the same procedure to the data of Fig. 2 (i.e., shifting the suffix condition one position to the left). In this experiment, the shifted functions are a gross mismatch.

Further indications from Exp. III that the prefix and suffix operations differ fundamentally are provided by consideration of the overall error totals in the four experimental conditions. For every S, a number was computed representing the algebraic difference between the "Zero" and the "Uh" Prefix conditions and a second number representing the "Zero" minus the "Uh" Suffix conditions. Under the null hypothesis, that variation in the redundant element affects the prefix and suffix phenomena similarly, these two difference scores should be from the same distribution. However, a Wilcoxon test showed a significant interaction, $T = 56.5$, $p < .038$, indicating that contrasting outcomes in the prefix and suffix situations were observed when the redundant element's identity was varied.

Experiment IV

In this experiment, the critical condition was one in which S listened to a series of eight-digit lists with a suffix consisting of the first digit in the list presented again.

The instructions said that this was intended to help them achieve good recall by ensuring that they started right. A naïve associative theory might indeed be shown to predict a simple improvement on this basis. A slightly more sophisticated theory might suppose that the impairment would be worse than with the "nought" suffix since the digit could be regarded as a member of the set of stimulus items. Our prediction was that in agreement with the naïve associative theory, there might be some slight improvement quite early in the list for the repeated *Digit* condition as opposed to the "*Nought*" condition but that thereafter the two suffix conditions would be equally impaired.

Method.—The stimuli were eight digit lists which were presented binaurally. There were three conditions, Control (C), "Nought" Suffix (N), and Digit Suffix (D) (first digit repeated after the eighth), each receiving two blocks of 18 trials in a session consisting of six such blocks. Three groups of 9 *Ss* each were used, with the conditions distributed across the six blocks as follows: CNDNDC, NDCDCN, and DCNCND. In other respects, the procedure for Exp. II was identical to that used in Exp. IV.

Results.—The data from the three groups were pooled and the results are shown in Fig. 4. Wilcoxon tests confirm our predictions. The two suffix conditions differ only at the initial serial position ($p < .01$), the effect of the repeated digit being to give virtually perfect performance. There were smaller differences in favor of Cond. D at the sixth and eight positions, but these were only significant at the 5% level. There was no difference between the total errors made in the two conditions. Thus, the strategy of remaining within the class of digits for choosing suffix conditions but comparing digits which were or were not part of the vocabulary used on any given trial, again, yielded the null result, or, if a 5% significance level is thought worthy of further comment, there was marginal support for a smaller suffix effect from the within-class suffix.

Experiment V

In Exp. II, "nought" was compared with a variety of other words and no difference

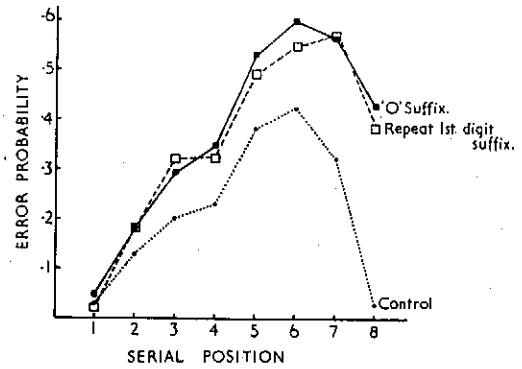

FIG. 4. The effects of a "0" suffix and a suffix which was a repeat of the first digit in the stimulus list (Exp. IV).

was found between the sizes of the suffix effects. It might be argued that "nought" was not properly a member of the digit set and that the effect of the block presentation with the "nought" always in the final position would be to further remove it from the digit set. In addition, it might be argued that in Exp. IV, repeating the first digit introduced complications which also invalidate any comparison on semantic grounds. In the following experiment, we anticipated such objections. The stimulus materials were lists of words from one of two clearly defined semantic classes (animals, utensils), and the suffix events were words either from the same class or from the other class as the to-be-remembered series.

Method.—The stimuli consisted of lists of six words drawn from one of two sets of nine: (*a*) animals: BULL, COW, DOG, HORSE, LAMB, MOUSE, PIG, RABBIT, SHEEP: (*b*) utensils: BOWL, CUP, DISH, FORK, GLASS, KNIFE, JUG, PLATE, SPOON. The materials were chosen to be monosyllabic words and so that no two words in any list began with the same initial letter. There were four blocks of 20 lists each, two of the blocks being made up from the animal list and the other two blocks from the utensil list. Within the blocks there were three suffix conditions which were randomized. For one-third of the lists there was no suffix, for another third of the lists the suffix was the animal name "cat," and for the remainder the suffix was the utensil name "mug." The stimulus population was written up for *Ss* and they were asked to respond by writing the initial letter of the appropriate word. This procedure was welcomed by *Ss*.

It will have been noted that for both stimulus sets, we have suffixes which are either semantically

similar or semantically dissimilar. There were two groups of 10 *Ss*; one heard the animal lists first and the other heard the utensil lists first. With the exception that male as well as female *Ss* were used in this experiment and also the use of a loudspeaker rather than headphones, the other procedural details were identical to those in Exp. II.

Results.—The data are shown in Fig. 5, pooled so as to reveal the outcome in terms of semantic similarity. There were no differences between the two experimental conditions, both showing the usual suffix effect.

Experiment VI

The preceding experiments seem to indicate fairly convincingly that the semantic relationship between the items in the list and the suffix has no influence on the suffix effect. It remains possible, however, that other properties of the word used as a suffix could influence the data. Thus, while we have established that a semantic code is not involved in the effects which we are interested in, it is still possible that the effects are postcategorical, (i.e., the signal has been uniquely identified), but prior to any semantic look-up procedure. Now there are believed to be certain stimulus properties which influence the categorization process (in the sense in which we use the term). These include the effects of

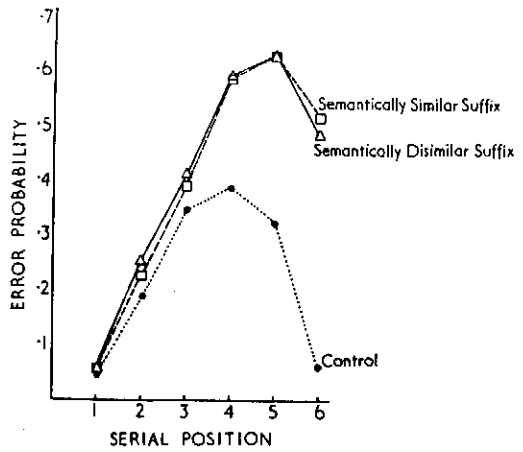

FIG. 5. Data from Exp. V showing the lack of effect upon errors of varying the semantic relation between stimulus items and suffix. (The conditions were randomly applied to lists.)

context and the frequency of occurrence of the stimuli (Broadbent, 1967; Morton, 1964, 1968, 1969) and its emotionality (Brown, 1961; Broadbent & Gregory, 1967; Natsoulas, 1965). These properties influence the recognition threshold of the stimuli at the stage which we term categorization. In addition, word frequency is a variable which affects the extent to which the presence of a word as an irrelevant apsect of a stimulus can interfere with color naming the relevant aspect of the stimulus (Klein, 1964). Therefore, if the suffix effect is operating postcategorically, we would expect both the frequency of occurrence and the emotionality of words occurring in the suffix position to exert an influence on the recall data.

Method.—The relevant words were taken from Broadbent and Gregory (1967), who provide lists of monosyllabic words of two frequency levels (AA and 10–49 per million) and three classes of emotionality, High, Neutral, and Low. Nine words from each set were selected and the 54 words arranged in a pseudo-random sequence in two blocks of 27. The usual constraints applied to the lists used for each condition both within and between lists and as they appeared in sequence. Each block was preceded by two practice items, and the experiment started with a practice block of 12 lists with two examples of each experimental condition. There were two groups of *Ss* who followed exactly the same procedure giving a total of 27 *Ss*. Otherwise, the procedure of Exp. V was followed.

Results.—There were no differences to be found between any of the conditions taken singly or between the frequency classes or the emotionality classes. The data are given in Table 1.

Discussion of Experiment XIV

This study will be described in detail below. One of the independent variables it incorporated, however, was a contrast between the words "zero" and "rosy" when used as suffixes in otherwise comparable conditions. Since this comparison is relevent to the questions at hand and quite independent of the other information in Exp. XIV, we will report now that

TABLE 1

SERIAL POSITION ERRORS MADE IN EXPERIMENT VI GIVEN BY CONDITION AND POOLED BY CLASS OF SUFFIX

Cond. and class of suffix		2	3	4	5	6	7	8	Total
Good High	12	46	79	117	138	168	163	148	871
Neutral High	13	69	97	108	145	163	173	156	924
Bad High	11	54	99	128	143	174	183	149	941
Good Low	18	62	104	129	129	180	170	151	943
Neutral Low	12	45	78	118	134	173	166	150	876
Bad Low	10	53	91	118	142	174	165	145	898
Total High	36	169	275	353	426	505	519	453	2736
Total Low	40	160	273	365	405	527	501	446	2717
Total Good	30	108	183	246	267	348	333	299	1814
Total Neutral	25	114	175	226	279	336	339	306	1800
Total Bad	21	107	190	246	285	348	348	294	1839

the two conditions were indistinguishable both statistically and visually. We were, of course, aware that these two words are not phonemic reversals of one another (see Crowder & Raeburn, 1970). However, they do not present grossly dissimilar sounds.

Conclusions about Semantic Similarity

There are numerous further experiments one could do on how the suffix effect responds to variation in semantic similarity between the memory series and the suffix. We leave this further research to other investigators, however, being ourselves convinced that there are no such effects to be found. The experiments reported have failed to discover any systematic differences in the size of the suffix effect which might be attributable to intrinsic, as opposed to extrinsic, properties of the suffix. We regard this as strong evidence that PAS is "located" prior to any categorization process in spite of the evidence being all negative. The reason for this will become apparent in sections to follow where the phenomenon is revealed to be very sensitive to variations in the acoustic properties of the suffix.

EFFECTS OF PHYSICAL DIFFERENCES BETWEEN STIMULUS AND SUFFIX

While we did not expect there to be any differences in the suffix effect due to semantic variables, we would expect that changes in the physical nature of the suffix would lead to differences in recall of the final items in a list. We had, however, no prior expectations as to exactly which of the possible variables would have an effect and which would not, except a general belief that if a dimension proved to be important, then we would be able to describe the phenomena in terms of the similarity of the suffix to the stimuli. Thus far our notion of PAS is restricted to the belief that it is a property of some section of the acoustic analysis system, but it has not been necessary for us to specify where. As long as PAS is precategorical and is specifically acoustic, then, as far as its position in terms of current theories of memory is concerned, it is secure. The existence of the suffix effect enables us to be more precise, for it is undoubtedly of interest whether or not we are dealing with a phenomenon specific to the basilar membrane, one which exists centrally but separately for the two ears, or whether inputs to the two ears are treated alike in this respect.

Effects of the Laterality of the Suffix

What the following series of experiments demonstrates is that the information contributing to the effect with which we started (the difference between auditory and visual presentation on the final items) is located in a part of the system after the combination of information from the two ears, at a stage where intensity has been normalized but where a number of other variables are still separable.

specific part of the system would be unaffected). This would account comfortably for the data shown in Fig. 6.

With binaural presentation, all three parts of the system would be involved as shown in Fig. 7c. A binaural suffix would then affect all three parts leaving no information in PAS. A monaural suffix, however, would only affect that part of the system which was specific to the ear being stimulated together with the common part, leaving the other, ear-specific part unaffected. This is shown in Fig. 7d. Thus we would obtain the result described in Exp. II. Chronologically, Exp. VII was performed before Exp. II, the latter being, in part, a test of the model just described (see Morton, 1970).

One condition which had not, at the time, been presented, was the case of a monaural stimulus followed by a binaural suffix.[4] In the model described above, such a suffix would have the effect of eliminating all the PAS information since it would be equivalent to an ipsilateral suffix plus additional stimulation in the other ear. Thus we would expect a binaural suffix to have the same effect as an ipsilateral suffix, recall of the last item for both of these conditions being inferior to that with contralateral suffix.

On an alternative model of the process, a totally different prediction can be made. This is a model based on Broadbent's (1958) filter model and by analogy with the results on selective listening (Treisman, 1964a, 1964b). In such models, there is a point in the processing of stimulus information where particular channels (specified, for example, by spatial location) may be accepted or rejected. In terms of a filter model, PAS information may be located either before or after the filter. In either case, however, the model would predict that a binaural suffix would have less effect following a monaural stimulus than would an ipsilateral suffix since *binaural* specifies a different channel from *monaural*. PAS could be located before the filter, since the binaural suffix would, in some sense, be stored separately from the monaural stimulus and would not interfere with it. If PAS information is retrieved from after the selection mechanism, then we can assume that a suffix which is not ipsilateral can be selected out. The comparison of a binaural suffix with ipsilateral and contralateral suffixes following monaural presentation then becomes a crucia test between these two models of the processs.

[4] We are grateful to D. W. J. Corcoran for pointing out this rather obvious omission.

Experiment VIII

This study was designed to compare the effects of a binaural suffix and those of an ipsilateral suffix following monaural presentation of the stimulus list.

Method.—Three conditions were employed, in all of which the stimuli were played to the right ear. The stimuli, six blocks of 18 lists of eight digits each, were recorded on one channel of a two-channel Vortexion tape recorder, and the suffix "nought" was recorded on the second channel. External switching and mixing gear were used to provide the following three conditions: (*a*) *Ipsilateral Suffix* (I)—the intensity of the suffix was adjusted so that there was no perceptible change of loudness between the stimuli and the suffix. (*b*) *Contralateral Suffix* (C)—the suffix was presented to the left ear at exactly the same intensity as in Cond. I. (*c*) *Binaural Suffix* (B)—the suffix was presented to both ears, the intensity in each ear being exactly the same as in the above conditions. This meant that the loudness of the binaural suffix was greater than the loudness of the other suffixes.

There were three goups of four *S*s each. Each group listened to the blocks of stimuli in the same order but the suffixes were presented according to two 3 × 3 Latin squares. Otherwise, the procedure was the same as that used in Exp. II.

Results.—The data are presented in Fig. 8. In this graph, the data from all the groups have been pooled. The control curve, included for guidance only, is the mean of the control curves from other ex-

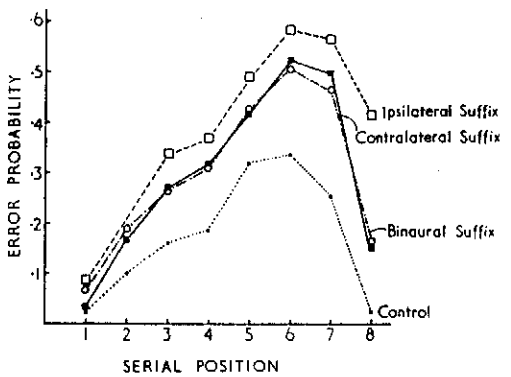

FIG. 8. The recall errors produced by binaural and monaural suffixes following a monaural stimulus presentation in Exp. VIII. (The effect of a binaural suffix being less than that of an ipsilateral suffix falsifies the model in Fig. 7. The control curve is an average from other experiments, being included for guidance only.)

periments, encompassing over 4,000 observations from 99 *Ss*. Wilcoxon tests revealed no significant differences between Cond. C and B even at the 5%, two-tailed level, at any serial position. Ipsilateral Cond. I was significantly worse than the other two conditions on the final serial position and overall ($p < .01$, two-tailed) and also significantly worse than the B condition at Position 7.

This result means that the first of the models proposed above (and in Morton, 1970) must be rejected, and we must conclude that PAS phenomena are due to processes which operate after the combination of information from the two ears, though, of course, the "channels" remain separate. It might be noted that the result of this experiment constitutes a very strong falsification of the rejected hypothesis. If the binaural suffix had produced a greater effect than the contralateral suffix, it could have been argued that this was because the binaural suffix was the louder, and as such more difficult to reject at the filter. This is the result one would have expected by analogy with the results in selective listening (Treisman, 1964a). As the binaural suffix—in spite of its greater loudness—did not have a greater effect than the contralateral suffix, we have three possible assumptions in this experimental situation with regard to the processes contributing to PAS: (*a*) that the loudness of a stimulus is ignored and so must be coded in digital fashion prior to the location of PAS, the stimulus iteslf being thus normalized; (*b*) that a binaural stimulus is "tagged" as having an intensity appropriate to one of the ears only. In this case, the information which gives rise to a subjective impression of increased loudness must be separated from the coded suffix; (*c*) that loudness is itself a cue upon which selection or rejection can be based. If this were not the case, then the binaural suffix might be having *less* effect than if it were equal in loudness to the stimuli.

Experiment IX

The purpose of this study was to check against some of the possible artifacts mentioned above. In particular, the role of intensity was examined in a design otherwise identical to Exp. VIII.

Method.—The procedure, materials, and conditions were all identical to those used in Exp. VIII except that there were the following six suffix conditions: (*a*) *Ipsilateral* (I)—suffix same loudness as the stimuli; (*b*) *Ipsilateral*+ (I+)—suffix presented at 3.75 db. greater intensity than in I; (*c*) *Contralateral* (C)—suffix in opposite ear as stimuli at same intensity as I; (*d*) *Binaural* (B)—suffix presented to both ears at same intensity as in I and C; (*e*) *Binaural*− (B−)—suffix presented at intensity 3.25 db. lower than in Cond. B. At this level, the suffix was judged as being at about the same loudness level as the stimuli; (*f*) *Binaural*+ (B+)—suffix presented at 3.75 db. above the level in Cond. B.

The changes in intensity were achieved by means of a gain control on the tape recorder, the accuracy of settings being better than ± .25 db. Six groups of four *Ss* listened to the stimuli with the suffixes being presented according to a 6 × 6 Latin square design.

Results.—The data are shown in Fig. 9. There were no statistically significant differences at the 1% level in the number of errors made between the two I conditions, among the three B conditions, or between

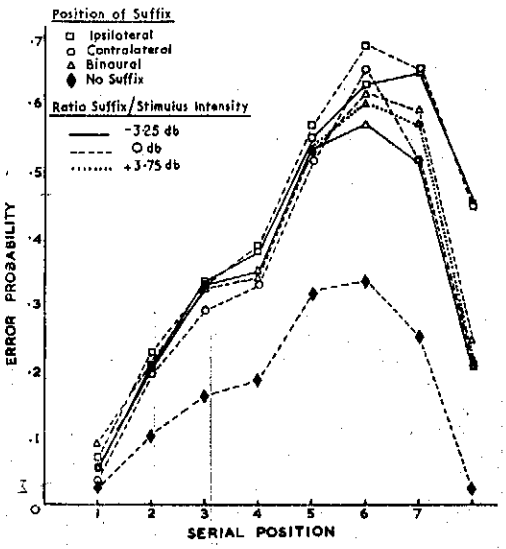

FIG. 9. An examination of the interaction of the apparent spatial location of the suffix and its intensity. (Two levels of intensity of the ipsilateral suffix were used (0 db. and 3.75 db. with respect to the stimuli. Three intensity levels were used for the binaural suffix (−3.25 db., 0 db., and 3.75 db.) and one (0 db.) for the contralateral suffix. There were no reliable effects of intensity (Exp. IX). The control curve is taken from other experiments.)

TABLE 2

RESULTS OF WILCOXON TESTS IN EXPERIMENT IX

Cond.	Cond.			
	B−	B	B+	C
I	7, 8, T.	8	8, T.	7, 8, T.
I+	6, 7, 8, T.	8	6, 8, T.	7, 8, T.

Note.—The numbers indicate the serial positions at which the I conditions showed more errors than the other conditions ($p < .01$, one-tailed). T refers to total errors.

the B conditions and C except for a slight increase in the number of errors on the initial position in Cond. B (B vs. C being the only difference which reached significance). The two I conditions differed from the other conditions as shown in Table 2. These data confirm the results of Exp. VIII and also indicate that the loudness of the suffix with respect to the stimulus is not a factor of importance in the suffix effect. (This latter conclusion will be discussed further below.) There is an interaction effect apparent in significance levels given in Table 2 such that the advantage of the B condition over the I and I + conditions is less than that of the B + and B − conditions for total errors and Serial Positions 6 and 7. This indicates that the binaural suffix has a *greater* effect when its intensity in each ear is the same as that of the stimulus list as was the case in Exp. VIII. This is a small effect, however (as there are no significant differences at all between B and B + or B and B −), and one which does not find any equivalent with the ipsilateral suffix. It might then be that intensity is a cue whose effect is too small to be seen in isolation but which interacts with another cue (laterality) to produce a visible effect. Further experiments will be required to decide this issue. It is quite clear, however, that loudness is not a significant factor on PAS either as a selection cue (in which case we would have expected B and B +, which were louder than the stimuli, to have less effect than B − or C), or as an attention-getting variable (in which case we would expect B + to have more effect than B or B −).

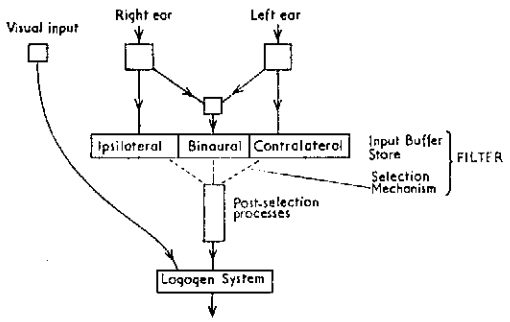

FIG. 10. A possible flow diagram of information in the case where the stimulus list is presented monaurally to the right ear. (The *logogen system* (described elsewhere Morton, 1969, 1970) is the point at which information from visual and acoustic stimulation converges. Since there was no visual-acoustic interactions with suffix experiments (Crowder & Morton, 1969; Morton & Holloway, 1970) PAS must precede the logogen system. The possible location of PAS is discussed in the text.)

Discussion.—Having concluded that PAS is a property of processes which follow the integration of information from the two ears, we now have to decide, in terms of the model shown in Fig. 10, whether PAS information is located before or after any selection mechanism. The two possibilities may be summarized as follows.

1. PAS information is located in the input buffer store. If the buffer store segregates information from different locations, then while an ipsilateral suffix overwrites PAS information, a suffix with a different spatial origin, i.e., from a different channel, will leave PAS undisturbed. This would account for the difference between the ipsilateral and the other suffixes. The fact that there is a suffix effect in the B and C conditions would be a result of incomplete separation of stimuli from different sources in the buffer store.

2. PAS information is located in the post-selection processes. The difference between the ipsilateral and the other suffixes would then be due to the selection system being set for the laterality of the stimulus list and subsequent items on another channel being "attenuated" (cf. Treisman, 1960). The extent of the suffix effect with suffixes on other channels would then be an index of the efficiency of the selection mechanism.

3. PAS information might be located both in the buffer store and in the post selection processes. In this case, the above restrictions would operate together.

Experiment X

In the experiments described above, *S*s always knew from whence the suffix would come and it can reasonably be assumed that they adopted a strategy to minimize its effect. It would thus be a further assumption of the above discussion that it is easier to exclude a suffix on a different channel from the stimulus (by maintaining the current filter setting) than to exclude a suffix on the same channel (by switching the selector to some other channel or trying to exclude *any* input).

If PAS is a property of the postselection processes, then it should be possible to increase the effects of a binaural or a contralateral suffix by keeping *S* uncertain as to the channel on which the suffix will be presented (assuming that the location of a rejected channel must be specified) or by forcing *S* to process the suffix before starting to recall the stimuli. In both these cases, the difference between the ipsilateral suffix and the others should be reduced. If, on the other hand, PAS is entirely a property of the buffer store, then such experimental manipulations should make no difference to the comparison between the different suffixes. In the present experiment, the suffix occurred at random on the right ear, the left ear, or binaurally.

Method.—The stimuli, lists of eight digits, were presented to the right ear and the intensities of the suffixes were determined as in Exp. VIII. There were four blocks of 29 trials of which the first two were not scored. The test stimuli were preceded by 16 practice trials for which the channel of the suffix was also randomized. There were 17 *S*s. In other respects, the procedure was the same as that used for Exp. II.

Results.—The averaged data are shown in Fig. 11 together with control data which were taken from several other experiments. Differences among conditions were tested with the Wilcoxon test. The Binaural and Contralateral conditions were indistinguishable statistically. The Contralateral Suffix condition differed significantly from the Ipsilateral condition at Positions 2, 5, and 8 and also for total errors ($p < .01$). The Binaural condition, however, was not significantly different from the Ipsilateral

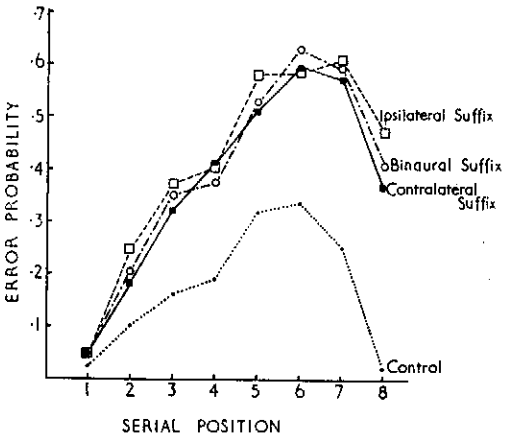

FIG. 11. The effect on errors of suffixes occurring in three spatial locations at random (Exp. X). (The differences between the Ipsi condition and the other two are reduced compared with Exp. VIII in which *S*s always knew the suffix location (cf Fig. 8). The control curve is taken from other experiments.)

condition at this level, the difference between these reaching only the 5% level at the last serial position (two-tailed). On more detailed examination, this turned out to be a consequence of two *S*s' performance, and a sign test showed the Binaural condition to be sharply better than the Ipsilateral condition for the last position ($p < .004$). Thus, we are not prepared to conclude that there is not a difference between binaural and ipsilateral suffixes under the conditions of this experiment.

The Effects of Random Suffix Positions

A comparison of the data in Exp. VIII and X (Fig. 8 and 11) will enable us to draw some conclusions as to the effect of the spatial location of the suffix being unpredictable. There are two effects visible: an overall increase in the number of errors and a reduction in the difference between the Ipsi and the other two conditions. As there are wide differences in ability between *S*s within each experiment, Mann-Whitney tests are rather weak, but confirm the visual impression, yielding significant differences between the experiments in the final serial position for both the number of errors in the B and C conditions ($p < .01$) and for the I–B and I–C differences ($p < .05$).

From this result, we conclude that in terms of the filter model, at least a large part of the PAS information is located after the selection mechanism. Otherwise, we would not expect the suffixes on different channels to the stimulus to have a greater effect as a result of unpredictability in suffix positions. In terms of the average error rate, there is also a suspicion that the number of errors made on the ipsilateral condition was greater in Exp. X. This difference could not be tested adequately owing to extent of the inter-*S* variance (from 24 to 186 total errors for individual *S*s in Exp. X and from 31 to 179 in Exp. VIII).

Effects of Suffix-Prefix

In the next two studies comparisions were again arranged among ipsilateral, binaural, and contralateral suffixes. The difference in procedures from Exp. VII–X was that in Exp. XII the suffix had to be *processed* by *S*. The increase in information-handling requirements by *S*s required moving to lists of seven digits rather than eight; otherwise, too many errors were made in recall. The suffix elements used were either the word "tick" or the word "cross," the choice for any given seven-digit series being determined randomly. In Exp. XI and XII, the suffix occurred at a random spatial location (ipsilateral, contralateral, or binaural) throughout. In Exp. XI, the suffix had to be ignored; in Exp. XII, *S* was asked to respond appropriately to the suffix before beginning recall (i.e., to write either a tick or a cross on his answer sheet before writing the digits). In spite of the loss of statistical power, we did not feel that we could use the same *S*s in both experiments owing to the danger of asymmetric transfer effects. In both experiments there were four blocks of 29 items preceded by 16 practice lists.

Experiment XI

Method.—The procedures and materials were similar to those used in Exp. X above. The three conditions were Binaural Suffix, Ipsilateral Suffix, and Contralateral Suffix; 20 *S*s were tested in four groups.

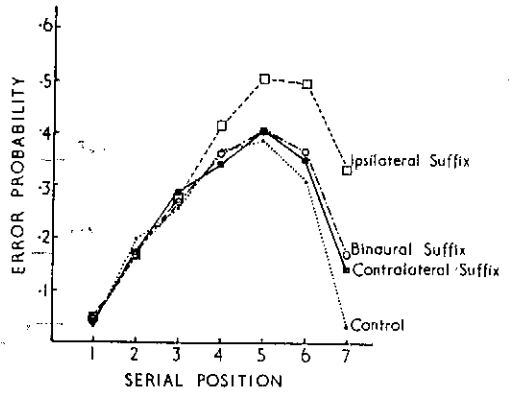

FIG. 12. The errors found in Exp. XI due to a suffix of the words "Tick" or "Cross." (These data confirm those of Exp. X (Fig. 11) and act as a control for Exp. XII (Fig. 13). The control data are for guidance only, being taken from other experiments.

Results.—The error probabilities in these three conditions are shown in Fig. 12. The control data were taken from other experiments and are there for guidance only. Wilcoxon tests permitted the inference that performance in the Ipsilateral condition was significantly worse than in the other two experimental conditions on Serial Positions 5, 6, and 7, as well as for total errors ($p < .01$, two-tailed). There were no significant differences between the Binaural and Contralateral conditions. When this outcome is compared with the data of Exp. VIII (Fig. 8), an interaction

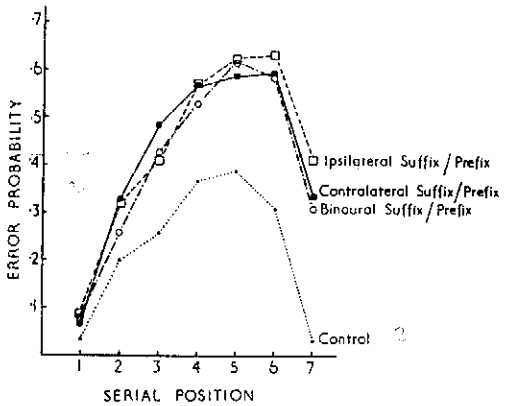

FIG. 13. Data from Exp. XII showing the errors caused by a suffix ("Tick" or "Cross") which had to be responded to as a prefix before recall of the stimuli. (The control curve was taken from other experiments).

is suggested between list length and the differential effects of the suffix such that with the shorter lists (and the same population of *S*s, though not the same individuals) the difference between the Ipsilateral condition and the other two is greater on the final serial positions than with the longer lists used in Exp. VIII. Comparison of the size of the effects of the ipsilateral suffix with different list lengths would be impracticable without a much more detailed model of all the processes involved in the recall task.

Experiment XII

Method.—All details were identical to those in the preceding experiment except that *S* was required to respond with the suffix (either "tick" or "cross") as a prefix before recalling the digits. Seventeen *S*s were tested.

Results.—The error probability scores are presented in Fig. 13.

The only significant difference among conditions was at Position 3, where performance was better following the ipsilateral suffix than following the contralateral suffix, and at Position 7, where performance after the ipsilateral suffix was worse than that following the binaural suffix. This result suggests the hypothesis that when *S* is required to process the suffix the difference between channels is reduced. This impression is confirmed by the results of a Mann-Whitney test shown in Table 3, which shows those serial positions at which the difference between conditions is reduced. This table shows that the differences between Ipsi and the other conditions are reduced more at the later serial positions. This result indicates a relative increase in the suffix effect of the Binaural and Contralateral Suffixes. It should be noted that the tests of differences between Exp. XI and XII are highly conservative. If *ratios* of error probability were used instead of differences, the serial position effect of the change in procedure would be emphasized more. Even without such a test, we feel confident that there is sufficient evidence to justify the claim that the comparison of Exp. XI and XII supports the conclusions from the comparison of Exp. VIII and X that PAS information is located after the channel selection. Only in this way can one account for a differential effect of forcing *S*s to process the suffix. The overall error rate is higher in Exp. XII than in Exp. XI as a consequence of the added Prefix operation.

Effects of Noise and Vocal Differences

Experiment XIII

We have shown in the first section that in a large number of situations the semantic properties of the stimulus suffix make no difference to the degree of performance failure occasioned by suffix persentation. In the section just concluded we have shown that spatially defined channel separation of the stimulus from the suffix can reduce the magnitude of the effect. It now remains to explore how physical properties of the suffix other than spatial location can influence the suffix effect.

Experiment XIII was designed to test our early conjecture (which now seems naïve) that nearly *any* sound would produce a suffix effect; this conjecture presupposes, of course, that PAS is more peripheral than several of the above studies have given cause to believe. Control series of nine

TABLE 3

VALUES OF MANN-WHITNEY *U* STATISTIC: COMPARING EXPERIMENTS XI AND XII

Difference compared	Serial position						
	1	2	3	4	5	6	7
Ipsilateral–Contralateral	135	137	108.5	88**	94.5*	65***	92**
Ipsilateral–Binaural	167.5	112	124.5	152.5	68***	96*	113

* $p < .05$
** $p < .02$
*** $p < .002$

digits were compared with four experimental conditions. The latter were arranged as a 2 × 2 factorial design; one factor was whether the suffix event was a spoken "zero" or a burst of random speech noise and the second factor was the intensity of the suffix.

Method.—Ten *S*s served for two sessions on different days, each session consisting of five blocks of 20 trials. Conditions (Control, Soft "Zero," Loud "Zero," Soft Noise, Loud Noise) were assigned to blocks according to two Latin squares (one for each day) such that first-order sequence effects between conditions were completely balanced. Two lists of 100 nine-digit stimuli were used, one list being used on Day 1 for half of the *S*s and the other list on Day 2 for the remaining *S*s.

All stimuli were read at a 2 digits/sec rate with the suffix arriving in time with the memory series. In the Control condition, no suffix was presented. In the two "Zero" Suffix conditions, *E* recorded the word "zero" following the last memory element such that in the Soft condition the intensity was the same as for the digit list and such that in the Loud condition the suffix intensity was subjectively twice as loud as the digit series. Subsequent measurement showed peak intensities of the Soft "Zero" to be the same as the memory series (around 66 db.) and the Loud "Zero" to be at around 85 db. In the noise conditions, a burst of white noise (actually a broad-band noise signal designed to cover approximately the same bandwidth as average human speech) was presented at the same time and for the same duration as the "Zero" Suffix. Subsequent measurement of these noise signals showed the Soft Noise to be 80 db. and the Loud Noise to be 90 db. Thus, it should be remarked that according to SPL readings the design of this study was not factorially pure—both noise signals were substantially more intense than the normal speech conditions. However, we felt it more important that the subjective loudnesses be matched with some care. In calibrating the noise suffixes, the subjective criterion applied was that the soft noise should sound equally loud as the intensity of the to-be-remembered digits (and hence equally loud as the Soft "Zero" condition) and that the Loud Noise be twice as loud.

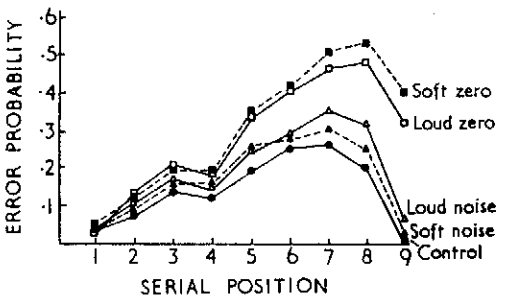

FIG. 14. Data from Exp. XIII showing that a non-speech noise gives no suffix effect. (The difference between "Soft Zero" (where the suffix was of equal loudness with the stimuli) and "Loud Zero" is properly to be attributed to differences in voicing not intensity.)

Results.—The results are shown in Fig. 14. The most striking finding is that while both conditions in which a speech response was used as the suffix caused a suffix effect, there was none whatever when the non-speech noise was used. Overall, the two noise conditions (which did not differ from one another either in total errors or in errors on Positions 7 and 8) occasioned more errors than the control condition, $T = 7$, $p < .019$; however, it is obvious from the figure that this was not a *selective* impairment. If the noises affected PAS, we would expect a large decrement on the final serial positions.

The data of Fig. 14 provide an empirical contradiction with Exp. IX in that they appear to show that the Soft "Zero" was a more effective suffix than the Loud "Zero." For Positions 7, 8, and 9 combined, the difference between the two speech suffix conditions was marginally nonsignificant ($p < .055$ by sign test); however, on the last serial position, the difference reached satisfactory levels of confidence, $T = 9.5$, $p < .042$ and $p < .011$, by sign test. We now believe this result is an artifact of the method used in the present experiment. In particular, *E* effected the variation in suffix intensity here by simply speaking louder (nearly shouting in fact) when he was recording the Loud "Zero" condition than when he was recording the Soft "Zero" condition. This shouting procedure probably entailed variation in much more than intensity alone—pitch differences, constriction of the vocal apparatus, stress differences, etc. As we shall describe below in some detail, our subsequent work has indicated these factors to be of large probable importance in the suffix experiment. Finally, since intensity alone in Exp. IX (where it was properly varied by adjustment of the gain control on playback equipment) was not an effective determinant of the suffix effect, we are confident in attributing the present difference to

factors confounded with the present manipulation of intensity.

Experiment XIV

In the preceding experiment, we have demonstrated that the set of sounds which will produce a suffix effect does not include bursts of noise. Knowing from the series of studies described above that laterality is a factor in the suffix effect and knowing also from the first group of experiments that semantic factors do not affect the suffix experiment, a correspondence with research on selective attention and shadowing is brought into sharp relief. It had been established in such experiments that when the rejected message is in a different voice from the shadowed message, the number of errors made in shadowing is greatly reduced. (Treisman, 1964a). Accordingly, we might expect that when the suffix is in a different voice from the memory series, it too will have less effect. The logic of this prediction is quite clear if one considers that *S*'s task in the suffix experiment is to *ignore* the suffix (an instruction we occasionally use).

Method.—The method in Exp. XIV was exactly the same as that used in Exp. XIII. The five conditions were formed by the Control condition (no suffix) and a 2 × 2 factorial combination of suffix word (either "zero" or "rosy"—see discussion following Exp. VI above) and suffix voice. The suffix voice was varied as follows. The to-be-recalled digit lists were always read in a male voice; in the Same Voice condition the suffix also was presented in the same male voice, but in the Different Voice condition the suffix was presented in a female voice. Ten *S*s were used.

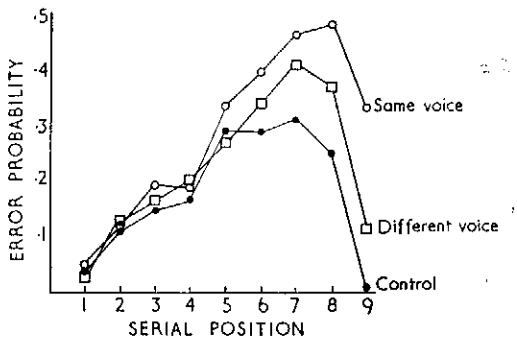

FIG. 15. The effect on errors of a suffix spoken in the same (male) voice and a different (female) voice as the stimuli. (In the control condition there was no suffix—Exp. XIV.)

Results.—Figure 15 displays the main data in terms of error frequencies for the conditions collapsed across suffix word (since, as was observed above, the latter variable had no effect whatever). The major findings were that (*a*) both suffix conditions produced significantly more errors than the control condition, $T = 0$, $p < .005$, for the same-voice suffix and, $T = 10$, $p = .042$, for the different-voice suffix, and (*b*) the same-voice suffix was significantly more detrimental to recall than the different-voice suffix, $T = 0$, $p < .005$. Although these inferences are based on total errors, it is obvious from the figure that the effects are occurring at the last few serial positions. This is confirmed by an analysis of the separate serial positions, the differences at Position 9 being greater than those at other positions for all comparisons. Thus, a shift in voice quality between the stimulus channel and the suffix channel produces a result quite comparable to the shifts in laterality channel studied in several of the experiments above. Both yield an attenuated suffix effect.

Experiment XV

This study was designed to complement Exp. XIV in showing that inherent differences between male and female voices were not responsible for the effect shown in Fig. 14. Thus, in the present experiment, the stimulus lists were read by a female voice and the suffix presented either in the same voice or in a male voice.

Method.—The stimuli were lists of seven digits presented in a female voice. The *S*s received two blocks of 29 digit lists in which the condition varied at random between a same (female) voice suffix and a different female-voice suffix and a male-voice suffix. The stimuli were played over a loudspeaker to 17 *S*s. All the other procedural details were the same as in Exp. VIII–XII.

Results.—The pooled data are shown in Fig. 16. Wilcoxon tests showed that the effect of the same-voice suffix was different only at Position 7 from the other female voice ($p < .05$) and from the male-voice

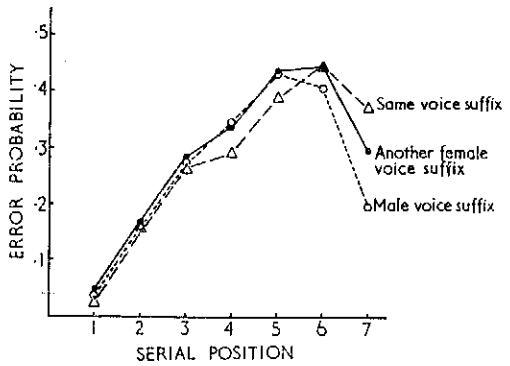

FIG. 16. Data from Exp. XV showing that with the stimuli spoken by a female voice, a suffix in the same voice causes more errors than a suffix in a different female voice. (A male-voice suffix has even less effect.)

suffix ($p < .01$). The (nonsignificant) advantage for the Same-Voice condition at Positions 4 and 5 is probably attributable to grouping effects and serves to emphasize the decrement at the final serial position. Thus, the previous result is confirmed and generalized to either relation between the male and female voices, and to differences between voices of the same timbre.

Experiment XVI

Given that the difference between male and female voices and differences among female voices lead to differences in the effect of the suffix, it is also of interest to see whether differential effects could be found when the pitch or accent of the suffix was varied.

Method.—In this experiment, there were six conditions each involving 18 seven-digit lists. The stimuli were recorded in a female voice. The six conditions are as follows: (*a*) Same-Voice suffix; (*b*) suffix in the same voice as the stimuli but at a different pitch, about a third higher; (*c*) and (*d*) the suffix was recorded in two other female voices, one American and one English; (*e*) and (*f*) two male voices were used for the suffix, American and English, respectively. There were three groups of four *Ss* who heard the conditions in the orders: 531462, 162534, and 425613, respectively. Otherwise, the method was the same as in the preceding study.

Results.—The only significant differences among any of the conditions occurred in the final serial position. The same-voice suffix produced the greatest effect, being significantly different from the other two female voices ($p < .02$ and $p < .05$, two-tailed), from the same voice with different pitch ($p < .02$) and from the two male voices ($p < .01$ in both cases). This result confirms the previous ones and adds the fact that the pitch of the voice appears to be a feature which can be used by the selection mechanism. The lack of distinction between the accents might be because a single word "nought" carries insufficient acoustic cues to signal the difference.

Experiment XVII

Having shown that a suffix of a different pitch from the memory series has a reduced effect, we ought now to be able to reduce that advantage by presenting suffixes at different pitches at random in the same way that laterality effects were weakened by random conditions of presentation in Exp. X.

Method.—All details of method were the same as in the preceding study. Three levels of pitch were used, one the same as the stimulus, one a musical third higher, and a third pitched a third lower. There was a single block of 51 scored trials (seven-digit lists) preceded by practice items. These were played to a single group of 14 *Ss*.

Results.—The only differences between the lists were between same and lower pitches on Position 5 ($p < .05$) and the lower pitch suffix caused fewer total errors than the upper pitch suffix ($p < .05$). These unpredictable differences can be attributed to chance. Thus, with a randomly varying pitch of the suffix, there were no differences germane to the suffix effect.

GENERAL DISCUSSION

Let us now summarize our conclusions with respect to PAS. In the Crowder and Morton (1969) article, we claimed to have demonstrated the existence of an information store which gave a special advantage to auditory over visual presentation for the final items in a list. This advantage was removed by the presentation of a stimulus suffix, a redundant item which did not have to be responded to. The postulated information store, PAS, could be placed in and related to other information-processing func-

tions in the context of a more general model for information processing, the logogen model (Morton, 1969, 1970). It was predicted from this model that the intrinsic characteristics of the suffix should be irrelevant in determining the size of the suffix effect. Experiments II–V in the present paper confirmed this prediction with respect to meaning, frequency of occurrence, and emotionality. Crowder and Raeburn (1970) also showed that reversed speech yielded a suffix effect.

The later experiments reported above have investigated variables which do bear on the size of the suffix effect. Experiments VI and VII, together with one comparison from Exp. II, established that of the apparent spatial location of the suffix differs from that of the stimulus list, then its effect is reduced. The finding that a suffix presented to both ears is equivalent to a suffix presented to the opposite ear from the stimulus list established that the effect operates after the combination of information to the two ears. Experiment VIII showed that there were no artifacts in this result which could be ascribed to the loudness of the suffix with respect to the stimuli.

The importance of the voice characteristics of the suffix were shown in Exp. XII–XIV, in which it became apparent that the less the suffix resembled the stimuli, in timbre or pitch, the smaller the decrement in recall.

We have also claimed that a large part of the suffix effect can be attributed to events occurring after some attention mechanism. Our evidence for this is that the differences between suffixes can be reduced either by making their characteristics unpredictable (Exp. IX vs. VII for location and Exp. XIV vs. XV for pitch) or by forcing *S*s to process the suffix before recalling the digit string (Exp. XI vs. X). It might be noted here that the latter procedure did not succeed in producing an effect of a visual suffix on an acoustic stimulus or vice versa (Morton & Holloway, 1970). This result was also in accordance with the underlying model which asserts that prior to categorization, there is no overlap between the mechanisms involved in processing the two modalities.

We regard PAS as just one of a number of information stores which can be used in the course of an investigation into memory. It reveals itself maximally when *S*s are constrained to recall the stimuli in their order of presentation, where the contribution of PAS as shown both by the visual–auditory comparison and in the effects of the suffix are large and consistent. We have, however, also shown that it plays a role in the running memory span (Crowder & Morton, 1969, Exp. II) and in a design where *S* had to recall but one item, being given all the other items as a cue to recall. In these experiments, the effect of the suffix was numerically smaller than in the serial recall design (but no less significant) owing to the presence of other sources of information. These sources of information have been discussed at length by Crowder (1970) and Morton (1970).

It has recently become apparent that one change might be required in the model. We have claimed that PAS can only account for the advantage of auditory over visual presentation for the last few serial positions. However, Murdock and Walker (1969) have shown an advantage for auditory over visual presentation over the last five or six items of a free recall list. Since this difference existed for a rate of presentation of one English disyllable per 2 sec., Murdock and Walker argued that it is unreasonable to suppose it due to greater difficulties in processing the visual material. Murdock and Walker argued in favor of the existence of separate prelinguistic auditory and visual short-term stores with a persistence of up to 5 or 10 sec. If their arguments are accepted, then it is clear that such an acoustic store does not correspond to PAS since in the first place the auditory-visual difference is too small and second the difference covers too many serial positions and third there is evidence that PAS lasts no longer than 2 sec. (Crowder, 1969a, 1971). If it were shown in the free recall paradigm that a simulus suffix removed the advantage for acoustic presentation, then our opinion would have to be revised.

It might also be noted that PAS cannot account for the preperceptual auditory images described by Massaro (1970). Massaro showed that the identification of a pure tone was affected by a subsequent masking tone as a function of its closeness in time. However, unlike the suffix effect, this masking was unaffected by whether the masking tone was in the same or the opposite ear to the test tone.

In the course of the paper, we have noted that the suffix curves differ from control curves over the whole or most of the list. We have, however, referred to "the suffix effect" as restricted to the last few serial positions. Our justification for this procedure rests in the acknowledgment that the effect of a suffix is not restricted to "the suffix effect." When the suffix is presented, *S*s, perforce, process it and, at a subvocal level, respond to it. This implicit response should, according to the under-

lying model, act as a prefix. The effect of a prefix is to reduce performance in serial recall over the whole of the list (except the final item with auditory stimuli) as shown in Fig. 2. Crowder (1970) has shown that a comparison of suffix and prefix curves indicates that the suffix comparatively affects only the last two items.

We believe that PAS is now firmly established as a distinct theoretical construct. The effects associated with it can now be used as a tool to investigate phenomena such as attention and speech perception.

REFERENCES

BROADBENT, D. E. *Perception and communication.* New York: Pergamon, 1958.

BROADBENT, D. E. Word frequency effect and response bias. *Psychological Review*, 1967, **74**, 1–15.

BROADBENT, D. E., & GREGORY, M. Perception of emotionally toned words. *Nature*, 1967, **215**, 581–584.

BROWN, W. P. Conceptions of perceptual defense. *British Journal of Psychology*, No. 35, 1961.

CONRAD, R. Accuracy of recall using keyset and telephone dial, and the effects of a prefix digit. *Journal of Applied Psychology*, 1958, **42**, 285–288.

CONRAD, R. Very brief delay of immediate memory. *Quarterly Journal of Experimental Psychology*, 1960, **12**, 45–47.

CONRAD, R., & HULL, A. J. Input modality and the serial position curve in short-term memory. *Psychonomic Science*, 1968, **10**, 135–136.

CROWDER, R. G. Prefix effects in immediate memory. *Canadian Journal of Psychology*, 1967, **21**, 450–461.

CROWDER, R. G. Improved recall for digits with delayed recall cues. Paper presented at the meeting of the Psychonomics Society, St. Louis, November 1969. (a)

CROWDER. R. G. Phonic interference and the prefix effect. *Journal of Verbal Learning and Verbal Behavior*, 1969, **8**, 302–321. (b)

CROWDER, R. G. The role of one's own voice in immediate memory. *Journal of Cognitive Psychology*, 1970, **1**, 157–178.

CROWDER, R. G. Waiting for the stimulus suffix: Delay, decay rhythms and readout in immediate memory. *Quarterly Journal of Experimental Psychology*, 1971, in press.

CROWDER, R. G., & ERDMAN, H. P. Output interference in recalling digits. Paper presented at the meetings of the Eastern Psychological Association, Washington, D. C., April 1968.

CROWDER, R. G., & MORTON, J. Precategorical acoustic storage (PAS). *Perception & Psychophysics*, 1969, **5**, 365–373.

CROWDER, R. G., & RAEBURN, V. P. The suffix effect with reversed speech. *Journal of Verbal Learning and Verbal Behavior*, 1970, **9**, 342–345.

DALLETT, K. "Primary memory": The effects of redundancy upon digit repetition. *Psychonomic Science*, 1965, **3**, 237–238.

KIMURA, D. Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology*, 1961, **15**, 166–171.

KLEIN, G. S. Semantic power measured through the interference of words with color naming. *American Journal of Psychology*, 1964, **77**, 576–588.

MASSARO, D. W. Preperceptual auditory images. *Journal of Experimental Psychology*, 1970, **85**, 411–417.

MORTON, J. A preliminary function model for language behaviour. *International Audiology*, 1964, **3**, 216–225.

MORTON, J. Selective interference in immediate recall. *Psychonomic Science*, 1968, **12**, 75–76.

MORTON, J. The interaction of information in word recognition. *Psychological Review*, 1969, **76**, 165–178.

MORTON, J. A functional model for memory. In D. A. Norman (Ed.), *Models for human memory*. New York: Academic Press, 1970.

MORTON, J., & HOLLOWAY, C. M. Absence of cross-modal "suffix effects" in short-term memory. *Quarterly Journal of Experimental Psychology*, 1970, **22**, 167–176.

MURDOCK, B. B., JR., & WALKER, K. D. Modality effects in free recall. *Journal of Verbal Learning and Verbal Behavior*, 1969, **8**, 665–676.

MURRAY, D. J. The effect of white noise on the recall of vocalized lists. *Canadian Journal of Psychology*, 1965, **19**, 333–345.

NATSOULAS, T. Converging operations for perceptual defense. *Psychological Bulletin*, 1965, **64**, 393–401.

ROUTH, D. A. "Trace strength," modality, and the serial position curve in immediate memory. *Psychonomic Science*, 1970, **18**, 355–357.

SHANKWEILER, D., & STUDDERT-KENNEDY, M. Identification of consonants and vowels presented to left and right ears. *Quarterly Journal of Experimental Psychology*, 1967, **19**, 59–63.

SHANKWEILER, D., & STUDDERT-KENNEDY, M. Hemispheric specialization for speech perception. *Journal of the Acoustical Society of America*, 1970, **48**, 579–594.

TREISMAN, A. M. Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology*, 1960, **12**, 242–248.

TRIESMAN, A. M. The effect of irrelevant material on the efficiency of selective listening. *American Journal of Psychology*, 1964, **77**, 533–546. (a)

TREISMAN, A. M. Verbal cues, language and meaning in selective attention. *American Journal of Psychology*, 1964, **77**, 206–219. (b)

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