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SOME EVIDENCE FOR 'SPEECH' AS AN ACOUSTIC FEATURE

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Under conditions of serial recall of auditorily presented lists of digits, recall of the last item has been shown to be adversely affected by the presence of a redundant item following the list. This is known as 'the suffix effect' (Crowder & Morton, 1969). In a series of experiments it is shown that the size of this effect is not influenced by the phonological complexity of the suffix. Non-speech sounds, on the other hand, produce no suffix effect even when the subjects are forced to process them. Certain speech sounds were also found to produce no effect. It is concluded that these sounds lacked properties which are characteristic of speech sounds and so were classified as 'non-speech' and that as a result, these sounds are processed by a separate system from the speech sounds.

It has long been known that when a supra-span list of unconnected items is presented for serial recall (i.e. recall in the order of presentation) there is an advantage for auditory over visual presentation. This advantage is restricted to the last few items in the list. Conrad & Hull (1968) and Routh (1970) have shown a similar advantage for visually presented lists when the subjects rehearse each item aloud at the time of presentation. Murray (1965) showed that the advantage given by vocal rehearsal is removed when the subject's voice is masked from himself by means of white noise. Thus it would appear that we are talking about a specifically acoustic effect and not something to do with such factors as ease or force of rehearsal. Crowder (1967) and Morton (1968) have also shown that the advantage of auditory over visual presentation can be removed by a *stimulus suffix*, an extra irrelevant or redundant item presented immediately after the last item in the stimulus list. We have, then, two characteristic shapes of error function which are shown in Fig. 1. With normal acoustic presentation or with visual presentation with vocal rehearsal we have the 'acoustic' curve in which the number of errors on the final item is approximately equal to the number of errors made on the initial item. With visual presentation, or with acoustic presentation with a stimulus suffix we have the 'visual' curve in which the number of errors on the final item is roughly equal to the errors made on items in the middle of the list.

On the basis of these results Crowder & Morton (1969) have postulated the existence of a precategorical acoustic store (PAS). This is conceived of as being a property of that part of the nervous system responsible for the extraction of phonological features from a speech input. There is a certain amount of evidence concerning the location of PAS (using the term 'location' functionally not anatomically). This evidence has been obtained from experiments involving the use of a stimulus suffix (hereafter simply 'suffix'). Thus Morton *et al.* (1971) have shown that if the stimulus is presented in one ear, then a suffix in the same ear (ipsilateral) has more effect on recall than a suffix in the opposite ear (contralateral). As a binaural suffix has the same effect as a contralateral suffix it is clear that the suffix is not ear-specific but is rather channel-specific in the sense of Broadbent (1958). Further

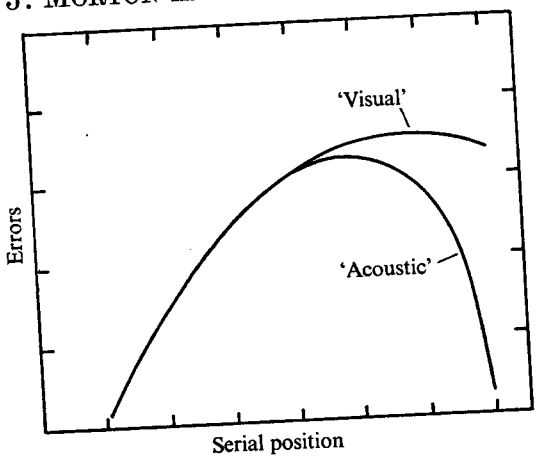

Fig. 1. Characteristic shapes of error functions with serial position for serial recall of lists of auditorily and visually presented items.

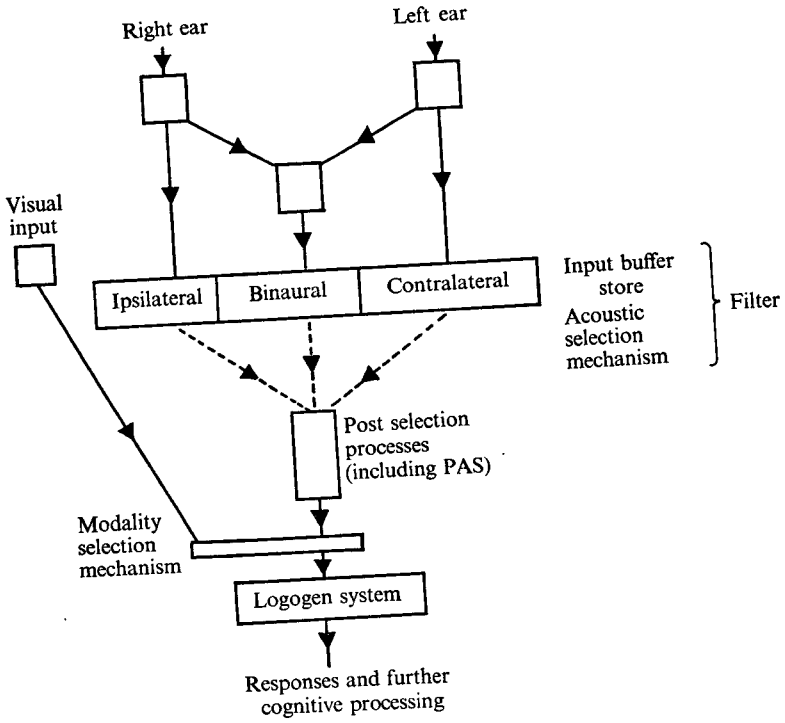

Fig. 2. Information-processing model of precategorical processes involved in the suffix effect.

experiments by the same authors indicate that PAS must largely be a property of processes which follow those mechanisms implicated in the selection of a particular acoustic channel. Furthermore, since Crowder & Morton (1969) and Morton & Holloway (1970) have shown that an acoustic suffix has no selective effect on recall of the final items of a visually presented list, and a visual suffix has no effect on recall

of an acoustically presented list, even when the full processing of the suffix was guaranteed, then we can conclude that PAS must be located before the convergence of auditory and visual information. These relationships are summarized in the flow diagram given in Fig. 2. This diagram has as a context a model for word recognition which was derived independently of considerations of memory (Morton, 1969). One implication of the model is that the semantic properties of the suffix should have no influence on the size of the suffix effect. This prediction has been confirmed by Morton *et al.* (1971).

Another acoustic variable which affects the action of the suffix is the relationship between the voices used for suffix and stimuli. If one is a male voice and the other a female voice the size of the suffix effect is reduced (Morton *et al.*, 1971, expts. XIV, XV). The suffix paradigm is clearly responsive to acoustic features of the suffix. Having the suffix in a different spatial channel or voice from the stimuli merely reduces the suffix effect. If a burst of white noise is used as a suffix, however, the suffix effect vanishes completely (Morton *et al.*, 1971, expt. XIII). There are a number of ways in which a burst of noise differs from the usual suffix – a spoken 'nought' or 'zero', and the purpose of the current series of experiments was to determine precisely the nature of the crucial variable. Two clear candidates were the phonetic complexity of the suffix and the extent to which the suffix resembled natural speech.

General method

Groups of subjects listened to lists of seven digits. The digits were recorded at a rate of 2 per sec. on a Vortexion tape-recorder and played through the recorder's loudspeaker. In all the experiments the basic method was to present lists of digits for serial recall under a number of conditions – the conditions corresponding to suffixes of different types. Unless otherwise mentioned, the conditions were randomized in a block of 54 stimulus lists, each condition being represented by nine stimulus lists within which all digits occurred equally often at all serial positions. In those conditions involving a suffix, the suffix followed the final digit at an interval of 0·5 sec. The test items were preceded by 16 practice lists which illustrated all the conditions which were to follow. Subjects were instructed to recall the digits by writing them down in their order of occurrence on prepared response sheets. They were requested not to leave any blanks and had 12 sec. to make their responses before a 'ready' signal for the next list. Each experiment took about 30 min. Only those responses in the correct serial position were scored correct. The subjects, all members of the APU subject panel, were females aged between 21 and 67. Subjects who made no errors at all under any one condition were excluded from the data analysis and do not appear in the subject numbers given below. This precaution was necessary as the pool of subjects had widely differing abilities, and for those subjects whose span exceeds eight items there could be no suffix effect under any conditions. It should be noted that the requirement for the subjects to recall the items in order of presentation (serial recall) is essential when the effects of suffixes are being investigated. In a short-term memory paradigm such as the one being used there appear to be a number of sources of information which the subject can use. While Crowder & Morton (1969) and Morton *et al.* (1971, expt. I) have demonstrated the effects of a suffix with

Table 1

Harmonic ...	1	2	3	4	5	6	7	8
Natural	17	16	23	24	31	26	0	10
Synthetic	20	22	28	31	34	31	26	7

other methods of recall, the effects are much smaller than those found with serial recall. Thus subjects were carefully watched to ensure the appropriate recall order was used.

EXPERIMENT I

There were six conditions involving variations in the suffix. It was expected that the different suffixes would give different effects as a function of their similarity to speech. In all cases the signal to be used was recorded on a tape loop. The stimulus items had been recorded on one channel of a two-channel Vortexion tape recorder in a female voice. This channel was played and a timing and gating circuit was arranged such that a 310 msec. segment of the appropriate suffix tape loop was recorded on the second channel 0·5 sec. after the onset of the last stimulus item. The rise and fall times of the gate were about 2 msec. The six suffixes used were:

1. *Natural 'AH' I*. A natural steady-state vowel /a/. of the same fundamental frequency as the stimulus items (210 Hz).
2. *Synthetic 'AH'*. A synthetic steady-state vowel sound made by passing a pulse source of 210 Hz through two formant filters adjusted to give approximately the same vowel quality as the natural vowel in condition 1. These two sounds were analysed by a Kay Sonograph and their harmonic components are given in Table 1.
3. *White noise I*. White noise was passed through the formant filters as set for condition 2. This produces a sound like a whispered /a/.
4. *Buzz*. The pulse train used in 2.
5. *White noise II*. Unfiltered white noise.
6. *Tone*. A pure tone of 210 Hz.

Once the two-channel recording had been prepared, five judges listened to the tape over a loudspeaker with the channels mixed and the playback levels of the different suffixes were adjusted until they appeared to be of equal loudness to the stimulus items. The stimuli and suffixes were then re-recorded on to a single channel maintaining the appropriate relative levels.

Eleven subjects listened to the recording in a single group. They were told 'You will hear lists of digits, each list followed by a noise. When you hear the noise you are to begin your recall.' The rest of the experimental method is described above under 'General Method'.

A further group of ten subjects listened to the same tape with slightly different instructions. They were told, 'After the digits you will hear one of a number of sounds – one of them me saying "ah".' We wished to ensure that the explicit reference to speech would make no difference to performance.

Results

There were no differences in performance attributable to the instructions. The differences between the conditions for the two groups were tested with the Wilcoxon test (Siegel, 1956, p. 75) at all serial positions. With 15 comparisons and seven posi-

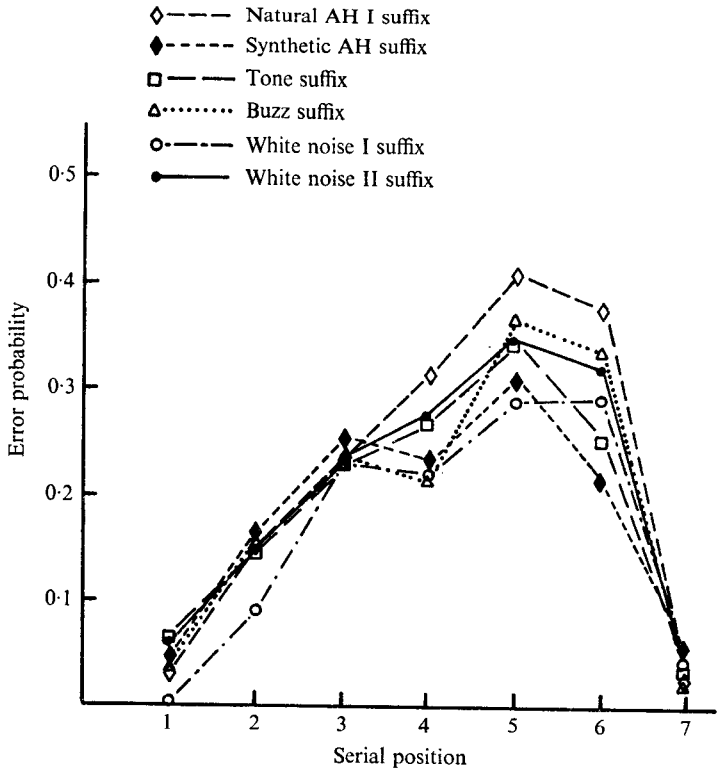

Fig. 3. Error probabilities by serial position for a variety of non-speech suffixes and a gated natural 'ah'. (Expt. I, $n = 21$.)

tions for each there were a total of 105 comparisons of which one was significant at the 1 per cent level, one at the 2 per cent level and five at the 5 per cent level. As the differences were completely unsystematic they were regarded as being the results of random variations. In addition there were no suffix effects in any of the conditions, the recall curves being typically 'acoustic' in shape. The mean error curves for the two groups are shown in Fig. 3.

Discussion

This result was rather surprising as we had every reason to suppose that a spoken vowel sound would produce a normal suffix effect. We supposed then that our expectations were incorrect and that a single vowel sound was too simple to produce a suffix effect. The next experiment was designed to include suffixes of increasing phonological complexity.

Experiment II

The stimulus lists were those used in the preceding experiment. The suffixes were spoken onto one channel of a tape recorder as the stimulus lists were being transcribed onto the other channel. The two channels were later mixed with the suffixes adjusted to the loudness level of the stimuli. The six conditions were:

1. 'Ah' – /a/.
2. 'Oh' – /ou/.

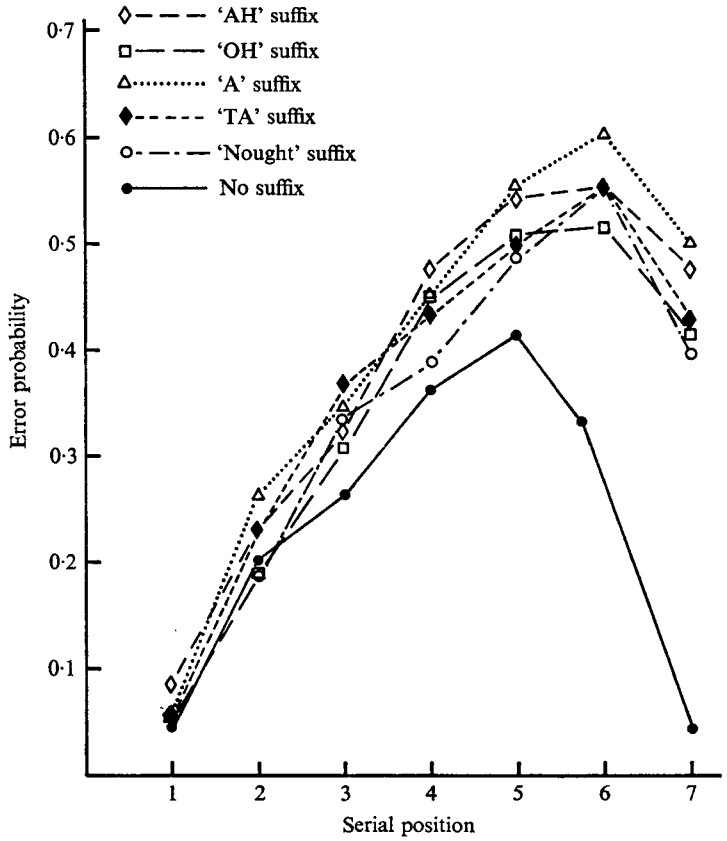

Fig. 4. Error probabilities for a variety of speech suffixes. (Expt. II, $n = 29$.)

3. 'A' – /eI/.
4. 'Ta' – /ta/.
5. 'Nought' – /nɒt/.
6. Control (no suffix).

Previous studies had shown that 'nought' gave a large suffix effect and we expected the other suffixes to give results between that and the control condition. Eleven subjects listened to the stimuli in a single group. They were told 'you will hear a spoken sound following each list of digits. Occasionally there will be nothing following. Begin recall as soon as the sound has occurred or as soon as the sound hasn't occurred.' Any confusion arising from these instructions was dispelled during the practice items.

A further 20 subjects listened to a similar tape on which the pairing of suffixes and lists was different.

Results

As there were no differences between the groups, data from all subjects was pooled. Wilcoxon tests showed that the only significant differences on the last serial position were between the control curve and all other conditions ($P < 0{\cdot}01$, two-

tailed). There were no significant differences among the suffix conditions on other serial positions. The pooled error curves are shown in Fig. 4.

The differences between the control curve and the suffix conditions at positions other than the final one are attributed to the suffix having an additional effect resembling that of a response prefix. This effect is considered to be unrelated to the suffix effect (see Morton *et al.*, 1971).

Our predictions in this experiment were that the more complex suffix would have a greater effect. Statistically there were no differences among the suffixes and, in fact, the simplest suffix 'ah' gave the largest effect and the most complex, 'nought' the smallest, though we are inclined to ascribe such differences as exist totally to chance. Since we are aware of no procedural artifact that could disguise a real effect we are willing to conclude that phonological complexity *per se* has no influence on the size of the suffix effect. (Note that in more recent unpublished experiments we have found that phonological similarity between the suffix and the final item in the list increases the size of the suffix effect. Such a phenomenon may interact with phonological complexity.)

Discussion

The results of Expt. II demonstrated that the phonological complexity of the suffix had no systematic influence on the size of the suffix effect. In Expt. I we found that the similarity of the suffix to a speech sound was immaterial; none of the sounds produced a suffix effect. The results of these two experiments appear to be in conflict. In Expt. I the suffix 'ah' had no effect; in Expt. II it had a great effect. The most obvious difference between the sounds is that the one used in Expt. I was initially recorded on a tape loop and then gated on to the stimulus tape with rise and fall times of only about 2 msec. With a naturally spoken vowel the rise times are more typically of the order of 40 msec. and the fall times are even more extended. Tracings of the envelopes of examples of the two sounds are shown in Figs. 5 (1) and 5 (2) respectively. A further experiment, in which naturally spoken 'ah' suffixes were truncated, revealed that truncation *per se* had no effect on the size of the suffix effect. In this experiment, naturally spoken vowel suffixes were gated at the beginning, at the end or both. The cut-off points chosen are illustrated in Fig. 5 by the marks *f* and *b*. The three kinds of suffix which resulted from the procedure were indistinguishable in their effects from an untreated vowel. A number of other experiments established that there were no artifacts in the earlier experiments as a result of instructions or the general 'context' of the suffix sounds (i.e. speech sounds *v.* non-speech sounds).

The source of the conflict was finally settled in the following experiment in which, for a number of now irrelevant reasons, we presented subjects with the same tape that was used in Expt. I but with a new gated 'ah' in place of one of the noise conditions.

Experiment III

We first made another loop 'ah' in the usual way. Then we inserted a gated portion of this loop in place of the White Noise I suffix in the tape we had used for Expt. I. The resulting tape was played to a group of 22 subjects, with the instructions 'The digits are followed by a noise, sometimes me saying "ah" ', and the usual procedure.

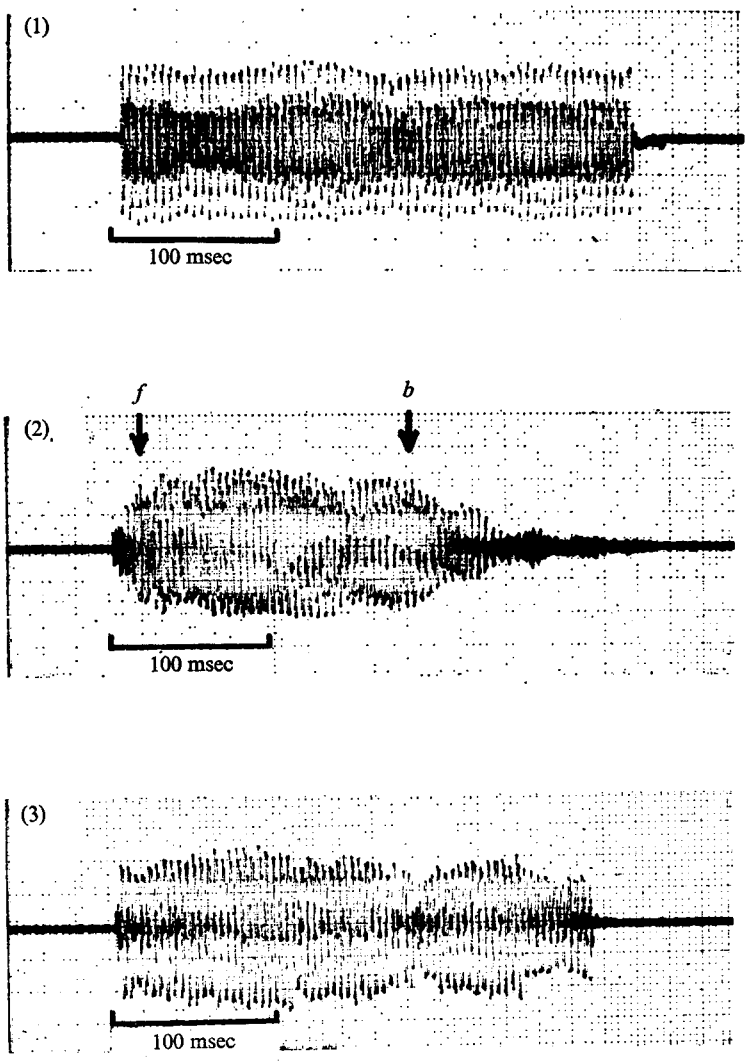

Fig. 5. Amplitude wave-forms for some of the suffixes used. (1) A gated portion of an extended spoken 'ah'. This sound failed to produce a suffix effect in Expts. I and III. (2) A natural spoken 'ah' showing the usual rise and fall characteristics. The arrows labelled *f* and *b* refer to truncation points typical of those used in the experiment described in the discussion of Expt. II. (3) A gated portion of an extended spoken 'ah'. This sound produced a suffix effect in Expts. III and IV.

Results

The mean error probabilities are plotted in Fig. 6. In this figure the new loop is termed 'Natural AH II'. Wilcoxon tests showed differences at the 1 per cent level between this condition and all other conditions on the last two serial positions. Performance in the condition using the original loop 'ah', termed 'Natural AH I' in the figure, is not significantly different from the remaining conditions even at the 5 per cent two-tailed level. Thus it appears that there are significant differences between the two natural loop suffixes.

MORTON, JOHN, ***Some evidence for 'speech' as an acoustic feature*** , British Journal of Psychology, 67:1 (1976:Feb.) p.31

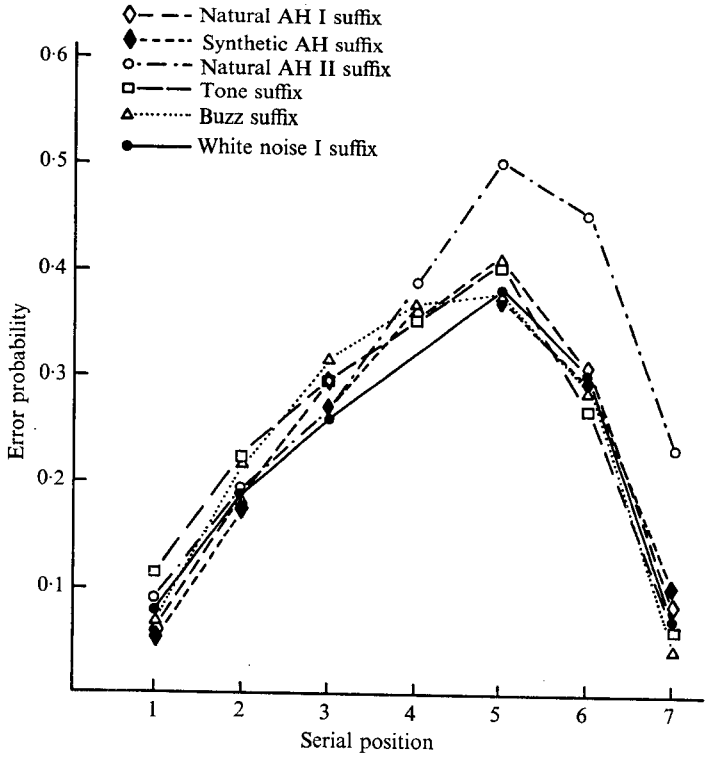

Fig. 6. Error probabilities for a variety of suffixes including one gated spoken 'ah' which produces a suffix effect and one which does not (Expt. III, $n = 22$).

Experiment IV

Seeking to convince ourselves that there were no remaining procedural artifacts we made two more changes to the original recording, removing the white noise suffix to produce a control condition and replacing the original loop 'ah' by a normally spoken 'ah'. Our reason for running this experiment was that it was possible that the instructions used in Expt. III led the subjects to pick out one particular suffix (on the basis of some as yet unknown cues) and process this differently. This selection procedure could happen during the practice lists and could have been fully established by the beginning of the test lists. If this is the reason for the suffix effect found with Natural AH II in Expt. III, then in this experiment we would expect the normally spoken 'ah' to be selected and then would expect to get no suffix effect in the condition involving Natural AH II. We had used the same instructions with the second group in Experiment I and had found no effect with the original Natural 'ah' loop, but it was possible that other, unidentified procedural variations had crept in to the running of the experiments. The control condition was included to make sure that we had an unambiguous baseline against which to compare the effects of all the suffixes. A group of 20 subjects were used in the experiment which in instructions and procedure was identical to Expt. III.

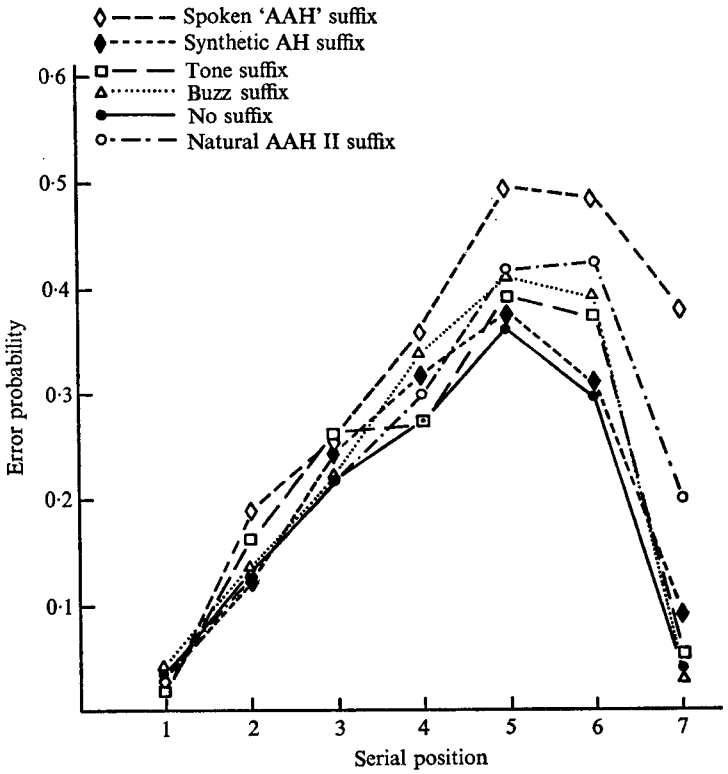

Fig. 7. Error probabilities for a variety of suffixes including a spoken vowel and a gated vowel (Expt. IV, $n = 20$).

Results

The mean error probabilities are plotted in Fig. 7. Wilcoxon tests showed significant differences on the final serial position between the spoken suffix and all other conditions and between the natural (loop) suffix and the remaining conditions. Both the spoken and the natural suffixes gave rise to more errors than the control condition on serial position 6. This experiment confirms that the difference between the gated natural vowels which was found in Expt. III was not a consequence of the particular instructions used. One consistent feature of the last two experiments is that the loop suffix used had about the same effect, giving rise to 24 per cent errors on the last position in Expt. III and 20 per cent in Expt. IV. In this it contrasts not only with the original loop suffix, which gave rise to only 2 per cent errors in Expt. I, but with the figure of 40–50 per cent errors found in Expt. II with normally spoken suffixes. These differences are unlikely to be due to differences in ability between the subjects in the various experiments since the errors made in the first four serial positions follow the same pattern in all the experiments. We are thus left only with the possibility that some vowel sounds which are sustained for about 10 sec. may have characteristics of synthetic sounds.

One way of describing the difference between the sounds is in terms of their 'naturalness'. The synthetic vowel sound we used in Expt. I was unambiguous in its

quality, being unmistakably an 'ah' sound, but was nonetheless clearly not a human sound. On listening to the natural loop 'ah' we had used in the first experiment it became apparent that it, too, in some way was not quite 'natural' in spite of its human origins. The next experiment was performed to verify our own intuitions.

Experiment V

The object of the experiment was to compare the 'naturalness' of the spoken, loop and synthetic suffixes used in Expts. I and II. There were nine samples of the loop suffix and 18 of the other two. These 45 suffix sounds were re-recorded from the original tapes on to another tape in a semi-random order at 6 sec. intervals. Each sound was recorded twice, giving a total of 90 test stimuli. A group of 13 subjects were asked 'to give each sound a rating as to how natural it seems'. They were informed that the experiment had to do with the assessment of different recording and reproduction equipment. The responses were made on prepared sheets which had a seven-point scale to be marked for each stimulus. On this scale 'Natural' corresponded to a rating of 1 and 'Unnatural' to a rating of 7. Prior to the test items there was a block of 15 items, taken from the practice blocks of the same experiments. Unknown to the subjects, these items were treated as practice items.

Results

The ratings were treated in two ways. The distribution of the modal ratings for each stimulus item is shown in Table 2. It is clear from this table that the subjects considered the loop suffix to be closer to the synthetic than to the spoken 'ah'. The modal response of each subject to the three different sounds was also obtained. All 13 subjects had a lower rating of the spoken sound than the other two, and all except one subject rated the loop sound more natural than the synthetic. The other subject had the same *modal* rating to both sounds but a lower *mean* rating to the loop sound.

Experiment VI

The previous experiment showed that the loop 'ah' which did not produce a suffix effect was in some way 'unnatural'. We decided to investigate the 'naturalness' rating method further to see if it was more sensitive than the suffix effect. In the discussion to Expt. II we mentioned an experiment in which no differences had been found between the suffix effects of vowel sounds truncated in a number of ways. A tape was prepared with all the sounds used in that experiment. There were nine examples of each of five types of suffix. They were arranged in random order on the tape and played to a group of 11 subjects under conditions similar to those used in Expt. V.

Results

The mean ratings for the five sounds are given in Table 3. Differences between the sounds were tested by obtaining a mean rating for each group of sounds for each subject. Differences between these values were then tested by the Wilcoxon test. The significance levels are also given in Table 3. It is clear from this table that the rating method distinguishes between sounds which do not differ in their effectiveness

Table 2

	Distribution of modal ratings for individual subjects							Mean ratings	Distribution of modal ratings for individual items						
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
Spoken	3	10	—	—	—	—	—	1·76	14	21	1	—	—	—	—
Loop	—	—	2	2	7	2	—	4·60	—	—	1	5	8	4	—
Simulated	—	—	—	2	5	8	2	5·81	—	—	—	—	3	26	7

Table 3

Suffix	Mean rating	Significance of differences with other ratings			
		Back	Front	Front–Back	Loop
Natural	3·08	n.s.	0·05	0·02	0·01
Back truncated	3·10	—	0·01	0·01	0·01
Front truncated	3·41	—	—	n.s.	0·02
Front and back truncated	3·80	—	—	—	n.s.
Loop	4·32	—	—	—	—

as suffixes. This might be a result of a greater sensitivity in measuring the same variable. Alternatively it might be that the characteristics of sounds which cause them to have a suffix effect and those which lead listeners to rate a sound as more natural than another have only a partial overlap.

Discussion

The following facts appear to have been established.

1. Non-speech sounds do not produce a suffix effect irrespective of instructions concerning their nature or the set of other sounds which could also occur as suffixes (Expts. I, III and IV).

2. The size of the suffix effect with normally spoken sounds is not affected by the phonological complexity of the suffix, the simple vowel sound 'ah' producing as big an effect as the word 'nought' (Expt. II).

3. The naturally spoken vowel sound 'ah' produces a suffix effect irrespective of instructions concerning its nature or the set of other sounds which could also occur as suffixes (Expts. II and IV).

4. When a portion of an extended 'ah' vowel is used as a suffix it may or may not produce a suffix effect. One particular such sound failed to produce a suffix effect under a variety of instructions and contexts (Expts. I, III and IV). Other such sounds did produce a suffix effect (Expts. III and IV).

5. A good quality synthetic vowel produced no suffix effect.

6. When asked to rate for naturalness the loop 'ah' which did not give a suffix effect subjects placed it nearer a synthetic 'ah' than a spoken 'ah' (Expt. V).

7. The effect of a naturally spoken 'ah' is not diminished when the natural rise and fall characteristics are removed.

8. Subjects gave different 'naturalness' ratings to various truncated vowel sounds which had not given rise to differences in suffix effect (Expt. VI). It might be that the naturalness rating is more sensitive than the suffix effect or that the two do not depend on exactly the same parameters.

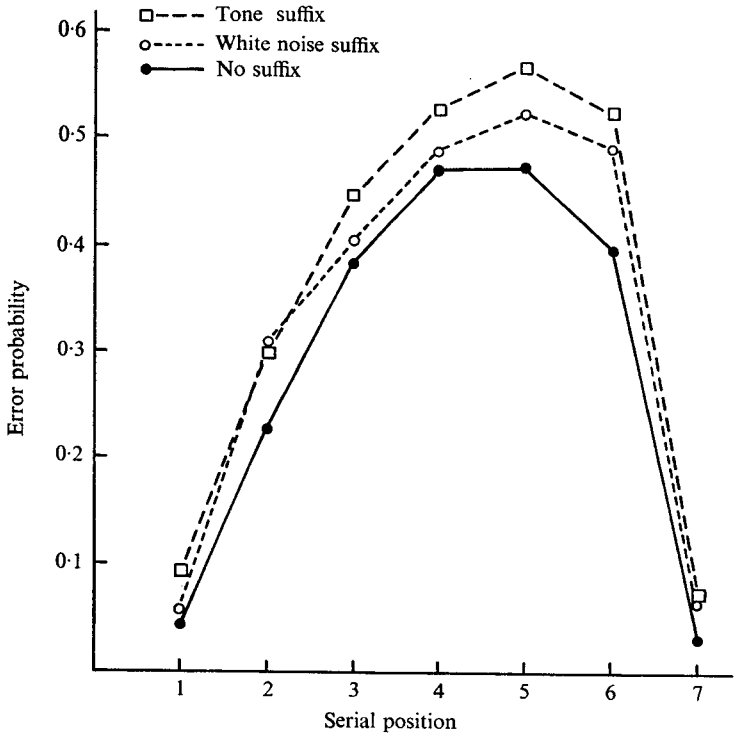

Fig. 8. Error probabilities in a suffix–prefix experiment where subjects had to identify the suffix by writing I for tone, *N* for noise or a cross for no suffix. This procedure failed to induce a suffix effect (Expt. VII, $n = 22$).

The precise nature of the acoustic feature which distinguishes a sound as 'natural' or 'speechlike' and thus gives rise to a suffix effect is unknown. The two main possibilities are the amount of variability in the fundamental frequency of the sound and in the formant frequencies. The natural loop suffix which failed to produce an effect showed very little variability in the waveform with time. This can be seen in Fig. 5 which shows the amplitude waveforms of this suffix, a normal 'ah' and the natural Loop II which did produce a suffix effect. The irregularities in the latter two are clear.

We suppose, then, that incoming sounds are automatically analysed in various ways to establish whether or not they are speech, one of the characteristics of speech sounds being some kind of irregularity. Speech sounds would then be automatically selected and passed through PAS to produce a suffix effect. Non-speech sounds would be routed through another system or completely blocked.

We must note here that it is not possible to suggest that non-speech sounds are processed in PAS but do not interfere with the trace of the final item. Such a statement would be a mixed metaphor. In a functional model non-interference of the kind demonstrated is a sufficient condition for requiring different systems.

When we claim that non-speech sounds do not produce a suffix effect we are, of course, only generalizing from the rather narrow range of sounds we employed. It remains possible that sounds like a cough, a dog barking or the chime of Big Ben

could produce an identical effect. We must leave such discoveries to others. Equally, the possibility of a store for non-speech sounds with properties similar to those of PAS remains to be investigated. Clearly non-speech sounds can be stored. Massaro (1970) provides some evidence for storage of pure tones but he obtained contralateral interference effects as great as ipsilateral. PAS cannot be implicated since Morton *et al.* (1971) showed that contralateral effects are greatly reduced. We presume that the brief auditory store described by Treisman & Rostron (1972) on the basis of experiments using pure tones is to be equated with that required by Massaro.

There remains to test the possibility that non-speech sounds are blocked from PAS. It is legitimate to ask whether the non-speech sounds would produce a suffix effect if they have to be processed. The following experiment tests this.

EXPERIMENT VII

Using the same procedure as outlined in the General Method section a group of 22 subjects listened to the digit lists. There were three suffix conditions. In one of them the list was followed by a 300 msec. burst of white noise. In the second condition was a 300 msec. pure tone of 210 Hz. For the third condition there was no suffix.

The main variation from the General Method was that prior to recall the subjects had to indicate the nature of the suffix. This they did by writing *N*, if the suffix was noise, I if it was a pure tone and putting a cross if there was no suffix. Otherwise the conditions of presentation, instructions and scoring was as before.

Results

The mean error curves are shown in Fig. 8. Differences between the conditions were tested by means of the Wilcoxon test. The noise condition differed from the control condition at position 6, and the tone differed from the control at positions 1, 5 and 6 ($P < 0{\cdot}01$, two-tailed). There were no differences between conditions on the final position even at the 5 per cent level.

DISCUSSION

Under conditions similar to those used in this experiment, Morton *et al.* (1971, expt. XII) found that the effect of a suffix presented in the opposite ear to the stimulus was greatly increased compared with the results when the subjects did not have to respond to the suffix. They took this result as evidence that PAS is located after the selection mechanism which operates to reduce the effect of the unattended contralateral suffix. Where the suffix has to be processed the selection mechanism cannot operate and the suffix then affects the information in PAS.

The present experiment shows that non-speech sounds do not produce a suffix effect even when they have to be recognized and responded to. We therefore conclude that PAS is a property only of the speech analysis system and that non-speech sounds, even when fully processed are not processed by the part of the system implicated in the suffix effect.

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