

The acoustic correlates of "speechlike" : a use of the suffix effect

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The Acoustic Correlates of "Speechlike": A Use of the Suffix Effect

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SUMMARY

The stimulus suffix paradigm has been used to establish the importance of pre-categorical acoustic storage (PAS) as a theoretical construct in the investigation of attention and speech perception. Morton and Chambers concluded that sounds must have typical "speechlike" properties extracted at an early stage of processing in order to act as suffixes.

In this article we use the suffix effect to investigate the conditions under which a sound is treated by the acoustic system as speechlike. On the basis of our findings we then perform other studies that reaffirm the essentially precategorical nature of the memory source termed PAS by Crowder and Morton.

In Experiments 1-13 we demonstrate the complex basis on which sounds are classified. Our experiments show that a completely regular sound, in which a single pitch pulse from a naturally spoken vowel was repeatedly reproduced, still produced a substantial suffix effect. In addition a natural sound had to be quite severely filtered before the suffix effect began to vanish. However, a combination of regularity and filtering proved very effective, the two dimensions dramatically interacting in neutralizing the effect of the sound as a suffix. In two further experiments (14 and 15) we show that the classification parameters can be shifted by changing the acoustic properties of the stimulus list. However, forcing the subjects to make a linguistic classification of suffix sounds did not lead to any changes in their potency as suffixes. The classification of sounds, and thus the suffix effect, is an acoustic question, not a subjective one.

The distinction between subjective and acoustic influences was further demonstrated when subjects rated a variety of sounds for their naturalness and for their similarity to the original suffix (Experiments 17-22). These measures showed themselves sensitive to the filtering operations we performed but, unlike measures of suffix effectiveness, were insensitive to regularity. Another suffix that produced a full suffix effect was shown to be rated as very nonspeechlike. Contrary to recent claims, these results reinforce our view of a distinction between central, subjectively controllable factors and a strong precategorical effect that is automatic in action and is based on the decision of whether a sound is speechlike.

By using the stimulus suffix paradigm, Morton, Crowder, and Prussin (1971) established the importance of precategorical acoustic storage (PAS) as a theoretical construct in the investigation of phenomena of attention and speech perception. Their finding that a burst of white noise had no effect as a suffix was elaborated by Morton and Chambers (1976), who concluded that the auditory perceptual system could extract a feature of "speechlike" from a sound. Presence or absence of this feature would determine the mode of processing that the stimulus would undergo. This article presents a detailed investigation of the parameters of "speechlike."

The structure of this article is as follows. First we give some methodological and terminological preliminaries to establish the experimental and theoretical framework within which we are working. This section ends with a discussion of the two mechanisms that appear to operate in the stimulus suffix effect. In the second section we discuss the notion of "speechlike" in the context of the results of Morton and Chambers and more generally. We then describe a set of experiments that explore a pair of acoustic dimensions contributing to the speechlike qualities of a sound. In a second set of experiments we show how the effectiveness of a particular suffix, modified on one of these dimensions, is influenced by treatment of the stimulus list on this same dimension but is unaffected by the way in which the subject processes the suffix. We conclude that there are strong effects that are *precategorical* in origin and end with a pair of studies that strongly challenge a purely *central*, or *grouping*, account of the phenomena.

Preliminaries

The experimental paradigm used by Morton et al. and by Morton and Chambers was

We are especially grateful to David Routh but for whom the organization of the paper would have been appalling and without whom the opening sentence would never have been written. Experiments 1-3 formed part of an undergraduate project submitted in 1973 by Stephen Marcus in fulfillment of his BA degree at the University of Cambridge.

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serial recall. In this paradigm, lists of digits are presented that are just supraspan, and subjects are required to recall them strictly in the order in which the items are presented. If the stimuli are presented acoustically there is a very strong recency effect, with the final item recalled almost perfectly. With visual presentation this recency effect is absent. The suffix experiments involve acoustic presentation of the stimulus list, followed by an extraneous sound that does not have to be remembered. If the suffix is spoken in the same voice as that used for the digits, there is a large and selective interference, with recall of the later items in the list impaired. On the basis of such findings, Crowder and Morton (1969), following on Morton (1968), postulated the existence of PAS. This was conceived of as being a property of that part of the processing system responsible for the extraction of phonological features from a spoken input. The original idea was that information concerning the last items of an auditory list would remain in PAS until the time of recall. This resulted in an advantage on the final items for auditorily presented items over visually presented lists. According to this early view, a suffix had the effect of overwriting the information in PAS and so removing the advantage of auditory presentation.

Further experiments ruled this account out. It was found that if the suffix is delayed for a couple of seconds, there is no suffix effect (Crowder, 1969). For this and other reasons it seems necessary that the information be automatically transferred from PAS to some other store after the end of the list (Morton, 1970, 1976; Routh, 1971; Routh & Mayes, 1974). This transfer, in whatever form it takes, would be completed within about 2 sec. If a suffix arrives before this transfer is complete, subsequent recall of the list would be less efficient.

The ranges of some of the terms we use in this article are as follows.

PAS-based information is the information transferred from PAS to some other store after the end of the list, as referred to previously. The phrase "use of PAS-based information in recall" does not mean that we suppose PAS is used at the time of recall (cf. Morton, 1977).

The suffix effect is a shorthand way of

referring to the effect of a stimulus suffix on recall of the final item in serial recall of an acoustically presented list that is just supra-span and is presented at a rate that prevents constructive rehearsal—usually at 2 items/sec. The data are scored with regard to the serial position at which the subjects thought the items had occurred. The term *suffix effect* has been used for other paradigms and under other conditions. We discuss below and in the Discussion section how this has led to seemingly conflicting data.

We do not use the term *modality effect*, because it has been used in the literature to refer both to free recall and to serial recall. This leads to the assumption that one can argue freely from one paradigm to the other—a dangerous and unjustified practice.

Our theoretical position has its roots in a philosophy expressed in the Crowder and Morton article and used by both authors since then—that memory phenomena and particularly short-term memory phenomena are best comprehended in the light of mechanisms concerned with language, perception, attention, and general cognitive activity. Because of this we believe that the information available to subjects as they make their responses in short-term memory paradigms comes from a number of subsystems. We justify this from a metatheoretical viewpoint, since these subsystems already exist for reasons other than memoric (see, e.g., Morton, 1970). In different short-term memory paradigms, information from these subsystems has different relative availability and accessibility. It follows, then, that *short-memory* and *short-term store* are generic terms, not particular ones; they have only a conversational or prescientific use.

So far as the suffix experiments are concerned, we follow Morton (1976) in believing that there are two mechanisms involved and two effects. One effect is related to the overwriting of information in PAS. The other has to do with the effect of grouping the suffix with the stimulus items.

The PAS effect. We have already noted that since a delayed suffix has no effect, PAS cannot operate by being consulted at the time of recall. How then does it work? The suggestion in Morton (1970, 1976) was that some operation copies this information from PAS into another store. Note that this in-

formation is additional to that normally available immediately following presentation of the item, which would not otherwise be treated differently from any other item. Morton (1977) and Routh and Frosdick (1978) suggested that the PAS information provides a strong cue to the end of the list. This strong cue gives rise to almost perfect performance on the final item under the conditions of experimenting usually employed. The cue could be attached to whatever information is left in PAS and then transferred elsewhere. We can follow Morton (1977) and call the other location *store X* so as not to prejudge its function. It may, for example, correspond to what Hitch (1980) calls the *input register*. We know that the PAS cue, once transferred, is resistant to input interference, since a delayed suffix has almost no effect. We know it is relatively resistant to output interference, since there is only a small effect of a response prefix on recall of the final item in the list, although recall of the other items is greatly impaired (e.g. Crowder, 1967; Morton et al., 1971; Morton & Holloway, 1970). At the time of recall, then, the PAS cue can be used to identify the final item in the list.

Note that if there is some other way of identifying the final item, the effect of the suffix on PAS will not be visible. This was beautifully demonstrated by Salter (1975), who presented his subjects with lists of seven digits and one letter, with the letter always at the end. Under these conditions the suffix had virtually no effect. At time of recall, when subjects come across a letter, they output it at the end of the list. In this way there is an infallible cue as to which is the final item in the list, and the subjects have no need of the PAS cue. That all of this has nothing at all to do with PAS or the fact that the stimuli were presented acoustically has been shown by Routh and Frosdick (1978), who found a strong recency effect with the kind of lists used by Salter, but presented visually. The essence of the PAS effect is that it removes an advantage that acoustic presentation brings. If there is no auditory advantage in a particular paradigm, then arguments concerning the nature of PAS, which are based on that paradigm, collapse.

The grouping or "attachment" effect. The

second effect has to do with the categorized suffix being grouped together with or attached to the stimulus list in some way. This would take place in store X. This second effect is needed for at least two reasons, described in Morton (1976). First, the size of the suffix effect is not a simple function of the delay between the final item and the suffix. If the suffix effect were entirely the property of a sensory store, then such a relationship would be expected. Instead, there seems to be a peak effect at a suffix delay that equals the interstimulus interval (see also Crowder, 1971b).

Second, the suffix effect can be *reduced* by having three identical suffixes rather than just one. Clearly there is no way this could be accounted for with the mechanisms ascribed to PAS. Instead, Morton equated this result with the one that had inspired it, by Neisser, Hoenig and Goldstein (1969). These authors showed that a single stimulus prefix had a deleterious effect on recall of an acoustically presented list. This effect was abolished if the single prefix was replaced by a string of three prefixes. Neisser et al. surmised that the effect of the single prefix was due to its being grouped in store with the stimulus items, so that the list was then equivalent to one with an extra item in it. Presumably, when three prefixes were used, the three could form a group of their own and remain separate from the stimulus list, thus producing no interference at all. Although the effect of a triple suffix did not have such a dramatic result, the reduction in suffix effect being small, Morton assumed that the same explanation would be consistent as well as economical. A large residual effect after the triple suffix is consistent with there normally being a PAS effect plus a grouping effect with a suffix. Only the latter is removed by the triple suffix. Neisser et al. also showed that if a single prefix was in a different voice from the stimulus list, its effect was abolished. They attributed this, too, to a lack of grouping. We will discuss the equivalent suffix experiments shortly.

Thus in what follows we deal with a combination of two kinds of effects. The first is a function of whether the suffix has been categorized as a speech sound or as a nonspeech sound. With nonspeech sounds, one would expect to find no suffix effects at all.

Of course, such a strong claim depends on all subjects behaving in the same way with respect to the speech-nonspeech classification of the suffix. If the sound is classified by some subjects as speech and by others as nonspeech, then there would be an intermediate suffix effect.

The second kind of effect is one of grouping. There will be a number of factors influencing whether the suffix gets attached to the stimulus list. Speech sounds that are distinct in some way may have a full effect on the input but need not be grouped with the stimulus during recall. There have been certain manipulations of the suffix reported that gave rise to a reduction in the size of the suffix effect. Morton et al. (1971) showed that if the suffix comes on a different "channel" from the stimulus digits, then there is a reduction in the size of the suffix effect. Thus, when the digits were presented monaurally, the effect of the suffix was reduced by presenting it binaurally (and vice versa). Similarly, if the voice of the suffix differed from that of the digit lists there was a diminution in the interference. In both cases, however, there was still an effect of the suffix.

These channel effects may be accounted for in more than one way. In Morton et al. (1971) and Morton and Chambers (1976), a 1958 Broadbentian position was taken, wherein there was a strict channel separation precategorically. Part of the PAS effect was imagined to be channel-specific, and in this way a channel difference caused less interference. One reason for abandoning this aspect of the old account is that we need to postulate grouping effects, for the reasons already given from Morton (1976), and we need to account for related results in vision (Kahneman, 1973).

In an alternative position we could say that if the suffix is in a different voice or in a different spatial location, its effect is reduced due to a reduction in the grouping. However, these channel effects differ from the nonspeech suffix, which had no effect at all on the final item. Since channel effects result at most in a reduction in the suffix effect, it would be most economical to restrict PAS to a general speech-based effect. We would in any case still need to add the notion of transfer from PAS elsewhere, and

thus PAS itself, to make the picture complete.

It is not our intention here to put forward and justify a complete theory of short-term memory. Rather we assume the essential features of a theory that has already been proposed (Morton, 1970, 1976). Certain aspects of this theory have been criticized recently. Some criticisms are based on experimental procedures that do not replicate an essential feature of the earlier work, the almost perfect performance on the final serial position following acoustic presentation. It is this almost perfect performance that is the essential contribution of PAS-based information. This is not to be equated with the modality effect, whereby there is an advantage of acoustic over visual presentation in a variety of other conditions, nor is it to be equated with "echoic memory."

Watkins and Watkins (1980) put forward the most recent and best argued case in favor of treating all three as equivalent. An adequate refutation is well beyond the scope of the present article, but let us mention one point. Watkins and Watkins presented data they claimed cast doubt on the earlier work concerning the nature of PAS-based information (which they termed "echoic memory"). Their experiments showed substantial suffix effects with delays of 4 sec. However, their lists were considerably supraspan, being eight letters long. At a .5-sec rate, the errors on the final item in their control condition were about 22% (estimated from their Figure 1). This contrasts with an error rate of about 5% with our stimulus lists. At slower rates of presentation their error rates fall to about 18% at a 2-sec rate and about 14% at a 4-sec rate (their Figure 3). These error rates indicate that the PAS-based information is not operating in the same way as it does when the lists are shorter. One piece of data supporting such a view is that whereas Crowder (1969) found virtually no effect of a suffix delayed by 2 sec following a .5-sec/item list, Watkins and Watkins showed a massive suffix effect under three conditions, errors in the final item rising from about 22% in the control condition to about 46% with a 2-sec suffix. Such a discrepancy is best accounted for by postulating both a PAS-based effect and a long-lasting (up to at least 20 sec according to Watkins

and Watkins' data) echoic effect that has different properties. Both these effects can give rise to a modality effect. Watkins and Watkins argued that the formal similarity between the experiments requires a unitary account. We acknowledge their position, disagree, and will take up the debate more fully elsewhere.

These preliminaries have been spelled out in some detail in order to set the stage for our experimental enquiry. We return to some of the issues in the final discussion. We hope to have established that a particular experimental procedure can throw light on the properties of the process responsible for the analysis of acoustic stimuli. We use a short-term memory paradigm, but our primary interest here is in the processes of acoustic analysis. The theory of memory is important, as it justifies the belief that our procedures do reflect the process we had intended to look at.

Speechlike as a Feature

One of the findings obtained by Morton et al. (1971) was that a burst of white noise had no effect whatsoever on recall. Morton and Chambers (1976) replicated this result. They found that a variety of nonspeech sounds failed to produce any suffix effect, irrespective of the instructions concerning their nature. Neither did it make any difference if the subjects were required to identify the nature of the nonspeech sound (as a tone or noise burst) before starting to recall the digit list.

One unexpected finding in the Morton and Chambers experiments was the existence of a particular spoken vowel sound that produced no suffix effect at all. This sound was a gated portion of an extended vowel that had been intoned for about 5 sec. Close inspection of this sound suggested that it was more regular in its constitution than other similar sounds that did produce a suffix effect. That is, there was less than usual moment-to-moment variation in the position of the formants. There were other features of the suffix that were unnatural—for example, the onset and cutoffs of the sound were abrupt—but these proved to be insufficient to remove a suffix effect with other examples of vowel sounds.

The conclusion of the Morton and Chambers article was that PAS was indeed a property of the speech analysis system. They supposed that non-speech sounds were processed by some other system and so could not produce a suffix effect even under conditions in which the subjects had to make a linguistic response to them. For this to be true requires that the perceptual mechanisms can readily discriminate between speech and nonspeech sounds on the basis of some fairly gross analysis that can be carried out before the stimulus penetrates that part of the system responsible for the PAS effects. A specific aim of the current series of experiments was to test the hypothesis that one such feature was the regularity of the sound, regular sounds being nonspeechlike.

It is instructive to consider how this functional definition of speech-like relates to various other speech/nonspeech and linguistic-non-linguistic constructs and hypotheses.

The long-standing dichotomy between consonants and vowels has motivated many experimental paradigms in speech research. Liberman and his co-workers (Liberman, 1970; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967) pointed out that speech is a complex code; there is no simple one-to-one correspondence between the sequence of consonants and vowels with which speech may be described and its acoustic representation; instead, in continuous speech, acoustic segments usually contain information on two or more adjacent phonemic segments. They claim that it is this "encodedness," the parallel coding and transmission of information, that allows speech to be such a fast means of interpersonal communication. They draw a fundamental distinction between transitional consonant and steady-state vowel information. Arguing from the results of experiments on discrimination of stimuli lying along an acoustic continuum between two phonemically adjacent consonants or vowels, they suggest that the perception of consonants is categorical; that is, an incoming stimulus is immediately identified as a member of a phonemic class, whereas vowel perception is continuous. This data led to a hypothesis of a "linguistic processor" specifically designed to process the "highly encoded" transient acoustic information present in consonants.

It has been known for some time that when speech is presented simultaneously to both ears, performance on stimuli presented to the right ear is significantly better than that on stimuli presented to the left (Kimura, 1961). Shankweiler and Studdert-Kennedy's (1967) demonstration that such a sizable and significant right ear advantage is only found for consonants led to the hypothesis that their hypothetical linguistic processor is located in the left cerebral hemisphere, which, under dichotic presentation, has the more "direct" neural connection with the right ear.

Subsequent research has shown the experimental results on which these hypotheses are based to lack the universality once supposed. Categorical perception can be demonstrated for very short vowels (Fujisaki & Kawashima, 1970; Pisoni, 1975) and for nonspeech sounds such as musical instruments (Cutting & Rosner, 1974). Similarly, with dichotic listening, right ear advantages have been demonstrated for vowels (Darwin, 1971; Haggard, 1971). Furthermore, Papçun, Krashen, Terbeek, Remington, and Harshman (1974) showed that using Morse code stimuli, right or left ear advantages may be demonstrated as a function of the complexity of the stimuli.

At one point it appeared that a consonant-vowel dichotomy applied also to the suffix effect, and that PAS functioned in a different manner with these classes of speech sounds. Crowder (1971a) demonstrated that when the set of stimuli presented for serial recall differed only in the initial stop consonant, there was no advantage for auditory over visual presentation, and no suffix effect was found. Conversely, when he presented stimuli differing only in the vowel, the normal pattern of responses was obtained. He concluded that PAS only stores steady-state vowel information and is not capable of holding short-duration transient consonant information. This conclusion implies that our term *speechlike* refers to something more fundamental than a hypothetical "linguistic processor," since we are dealing with performance differences with simple steady-state vowels. However, Darwin and Baddeley (1974) showed that Crowder's results, rather than demonstrating a consonant-vowel difference in PAS, demonstrate the

effects of the similarity of the pool of items in the to-be-remembered list. With a set of consonants widely separated, the normal pattern of suffix effects was obtained; with acoustically similar vowels, it vanished. In addition they showed that with intermediate stimuli such as fricative consonants, an intermediate-sized auditory-visual advantage is found. They argued that rather than demonstrating the operation of a "linguistic processor," the traditional Haskins results illustrate differences in persistence of the PAS representations of different classes of phonetic stimuli, vowels being the most long lasting due to their relatively simple acoustic structure.

Irrespective of whether we consider vowels and consonants as forming a perceptual dichotomy or forming a continuum, we are concerned in these experiments with a simple steady-state vowel polarity. The two tape loops with which our observations began were both steady-state vowels, yet one produced a suffix effect and the other did not. It therefore seems that we are dealing with those properties of speech sounds that are used to permit or deny very early access to a speech-processing mechanism, whatever its properties may be, and that once such access is allowed, a suffix effect is produced regardless of the encodedness of the suffix.

Experimental Method

The experiments reported here involve the serial recall of lists of eight digits that were presented at the rate of one per 500 msec. The stimuli were drawn from the digits 1-9. In each experiment there were six suffix conditions. In each condition there were nine lists; lists for the six conditions were presented in a random order with the restriction that no two lists in the same condition were consecutive, and the lists in given conditions were split 4:5 or 5:4 in the two halves of the experiment. The makeup of the lists was such that for each condition, each of the digits occurred once in each serial position. The successive lists were organized so that no digit ever occurred on two successive lists in the same serial position. Each experiment was preceded by a block of 24 practice lists in which all the experimental suffixes occurred. The experimental lists were split into two blocks of 27 lists, each of which was preceded by two practice lists. The lists were presented to groups of subjects over the loudspeaker of a Vortexion taperecorder.

The subjects wrote their responses in boxes on prepared response sheets. They were allowed 15 sec for this. They were instructed to wait until the end of the lists, including any suffixes, before starting to respond, and to write down the responses from left to right. They were told not to leave blanks but to guess if they were

unsure. They were also told that the responses would only be scored correct if they were in the correct position. In this way we intended to make sure that they put what they thought to be the last item in the last box on the response sheet. They were instructed to ignore the suffixes, which were always demonstrated to them, and were told that the suffixes were used as cues during the recording.

Subjects were watched closely during the practice to ensure that they followed instructions. This was necessary because an occasional subject found the strategy of reporting the last items first irresistible. During the test lists the subjects were monitored to ensure that the correct recall method was followed throughout.

Subjects were tested in groups of 6 to 20. Except where noted, the paid subjects came from the Applied Psychology Unit volunteer panel, were female, and were between the ages of 21 and 65.

Responses were only scored correct if they appeared in the correct serial position. As we wished to avoid floor and ceiling effects, we excluded subjects whose memories were either too good or too poor. The criteria we used were that if the subject had no errors at all in any of the six conditions or if the subject had five or more errors on the final serial position of the no suffix condition, he or she was excluded from further analysis. On these criteria 9% of subjects were excluded. The response sheets were copied into a computer, and all scoring and tests were then done by program.

Statistical Tests

We routinely applied multiple Wilcoxon tests to scores on the final serial position, following earlier practice (Morton et al., 1971). A few words in justification of this practice seem to be necessary. There is reason to suppose that scoring only the final item gives a pure measure of the effects we are looking at. Performance on the penultimate item is also affected by a suffix, but Morton and Holloway (1970) demonstrated a good measure of independence between performances on these two items. Similar independence was found in Morton (1976) and is seen, for example, in Experiment 3 of the current series. Basically we believe that performance on the penultimate item is susceptible to strategic influences whereas that on the final item is not.

Our use of multiple Wilcoxon tests rather than a parametric test rests on the differences in variance in the different conditions and on the fact that between some pairs of conditions we have a priori predictions as to the direction of the differences and in other cases we do not. A series of simple paired comparisons simplifies the problems of interpretation. There remains the problem of the appropriate significance level to take. We solve this by reporting the significance levels as computed. In general we only discuss differences with a significance level better than .01, but in any case there are scarcely any points of interpretation that hinge on whether a particular difference is reliable. In cases of doubt we leaned toward a conservative interpretation. Overall, then, the statistics are better seen as simply an index of variability.

The Characterization of Speechlike

The objective of the first series of experiments was to find the acoustic correlate of

the nonspeech effect. Morton and Chambers suggested regularity as the crucial component. Another possibility we thought of was the spectral characteristics of the sound. The average spectrum of the human voice has a fall-off of 6 dB (SPL) per octave, and we had observed that strong deviations from this tend to make speech sound mechanical. These two factors formed the core of the first series of experiments.

Preparation of Stimulus Tapes

The stimulus tapes were prepared with the aid of a computer. Canonical forms of the nine digits were spoken by the third author (P.O.), recorded on a Vortexion tape recorder, and sampled and stored on the computer. The sampling rate was 20 kHz and the samples had an eight-bit accuracy. The digits were resident on disc, and complete stimulus tapes were prepared for each experiment with stimuli and suffixes recorded at the same time. The suffixes were prepared with a variety of techniques, often using the computer. These are explained in descriptions of the individual experiments. In most of the experiments there were two standard conditions, one with our reference sound, the naturally spoken vowel sound (PO-aah-1) and one without a suffix (no suffix). Because many of our manipulations changed the total energy in the suffix sounds, we adjusted the amplitudes in the computer so that the sounds were of the same subjective loudness as the stimulus items.

Experiment 1

The initial object of the experiment was to obtain a natural vowel that produced a good suffix effect for analysis, processing, and synthesis in later experiments. Since Morton and Chambers showed equal suffix effects for a variety of steady-state vowels, it was decided to use only the vowel /a/ ("aah"). Two such vowels were recorded in the same voice as the digits, and were designated *PO-aah-1* and *PO-aah-2*. Two natural /a/s were also recorded through a filter with varying stages of high frequency roll-off. This roll-off was at a rate of 10 dB/octave, and by so restricting the spectrum

it was expected to determine whether formants above F2 (which is around 1 kHz) are of importance in producing a stimulus suffix effect (SSE). The following suffix conditions were used: (1) a natural vowel /a/ (PO-aah-1); (2) a truncated version of (1) with the natural rise and fall removed (cf. Morton & Chambers, 1976, Figure, 5); (3) a natural /a/ rolled off from 1 kHz; (4) as (3) but rolled off from 500 Hz—negligible spectral components were present above 1.5 kHz; (5) a natural vowel /a/ (PO-aah-2); (6) no-suffix control condition.

Eighteen subjects listened to the recording in a single group.

Results

The serial position error curves are shown in Figure 1. The differences between the conditions were analyzed using the Wilcoxon test. Only those differences significant in the final serial position were considered relevant in the present series of experiments.

All conditions (1-5) were significantly different from Condition 6 (no suffix) in the final serial position at the 1% level. No other final differences were significant.

All suffixes were equally effective and therefore it appears that components above 1.5 kHz have no influence on the SSE.

The SSE was once again shown to be a clear, definite and easily demonstrable effect, remaining after a considerable degree of filtering and truncation. We arbitrarily decided to retain *PO-aah-1* for further processing in future experiments and as the upper control condition.

Experiment 2

Having selected a baseline suffix, we proceeded to process it in ways calculated to remove the suffix effect. The most obvious manipulation was designed to test the hypothesis put forward by Morton and Chambers (1976) that the key to the nonspeech classification was the regularity of the sound. Using the computer we produced a totally regular variant of the *PO-aah-1*. The program we had developed for speech processing enabled us to display the waveform as a series of points on a display tube. The

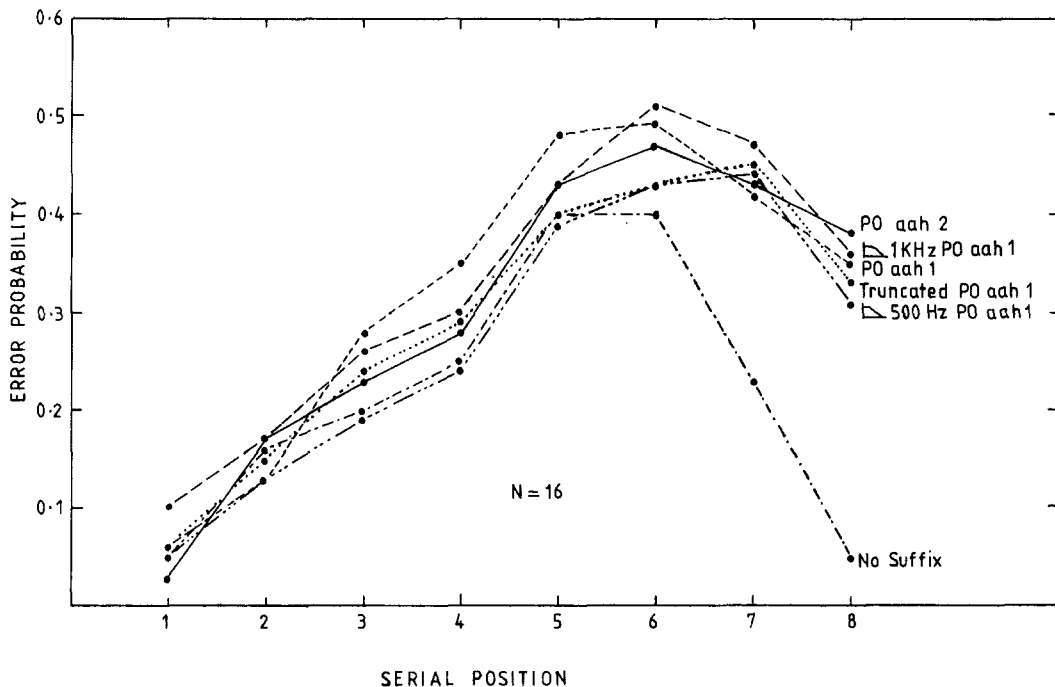


Figure 1. Error probabilities for natural and processed "aah" suffixes in Experiment 1.

waveform could then be edited in a variety of ways. To produce a perfectly regular sound we selected a pitch period from the middle of PO-aah-1 and instructed the computer to copy that sequence of numbers a sufficient number of times to produce a sound of 300-msec duration. This corresponded subjectively to the length of the original PO-aah-1. The result was mechanical sounding but still recognizably the same voice.

For a second suffix we introduced a little variability into the sound and accordingly selected a section of the original that included two pitch periods, a segment lasting about 20 msec. This was copied as before. The two other suffixes were made from the original by restricting the accuracy of the sampling. One of these was an operation called *infinite peak clipping*. This results in a waveform with only two levels (see Appendix A). Finally we made a two-bit version of the original using four amplitude levels to represent the waveform. These last two sounds have a periodic quality—that is, the pitch of the original voice is there. In addition it is possible to hear some of the orig-

inal vowel quality, but there is an extremely high level of noise superimposed on the sound that is perceptually very much part of the sound.

The six conditions in the experiment, then, were as follows: (1) PO-aah-1 (upper control condition); (2) a repeated single pitch pulse from (1); (3) two pitch pulses repeated from (1); (4) an infinite peak clipped copy of (1); (5) a two-bit coded copy of (1); (6) No suffix (lower control condition).

Nineteen subjects were tested in a single group.

Results

The serial position error curves are shown in Figure 2. Conditions 1-5 were significantly different from the no-suffix control condition on the last serial position by the Wilcoxon test. In addition, Conditions 4 and 5 differed from each other at the 1% level in Position 8.

These results were surprising, particularly with respect to the single pitch pulse suffix. Morton and Chambers found no suffix effect from a synthetic vowel and also found no

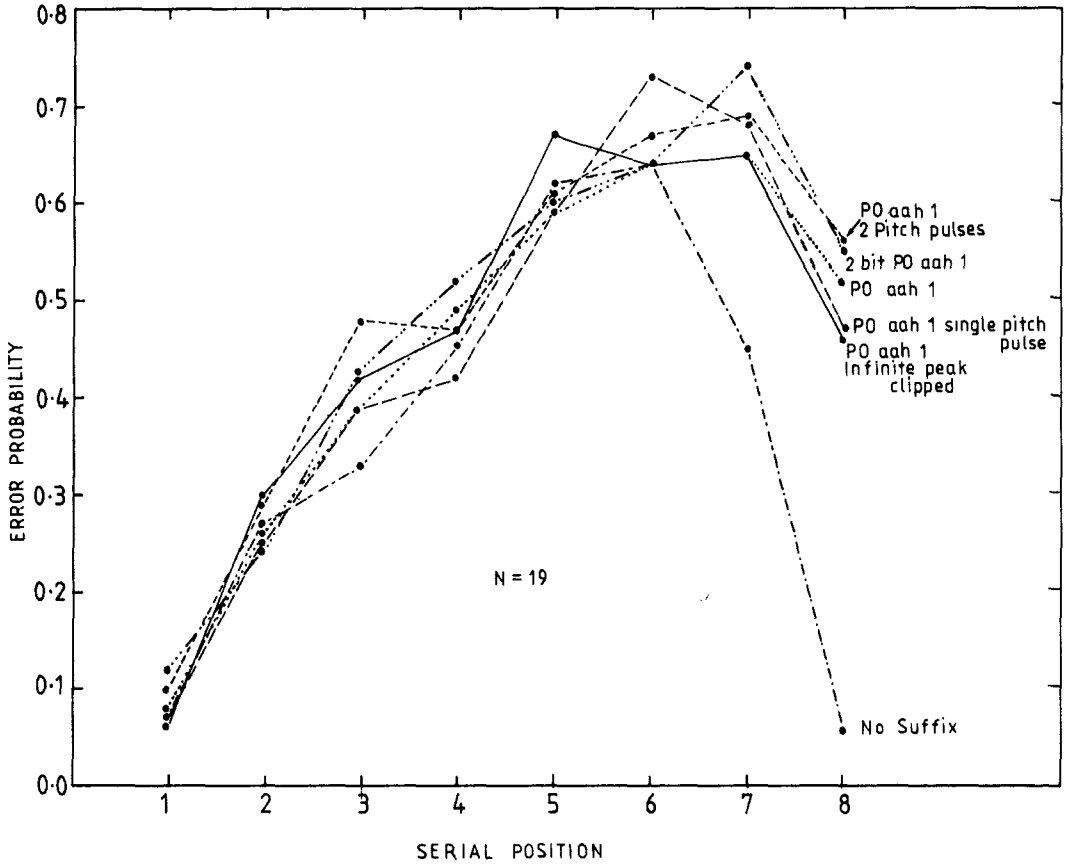


Figure 2. Error probabilities for PO-aah-1 suffix lists, suffixes processed for regularity, Experiment 2.

effect from the segment of a steady-state vowel that seemed to be abnormally regular. Regularity, therefore, seemed a good candidate as a potent variable. The single pitch pulse suffix in the present experiment was totally regular and yet produced a suffix effect that was indistinguishable from the full effect. Therefore the synthetic vowel and the steady-state vowel in the Morton and Chambers experiment must have deviated in some other way. The only other variable is that of the frequency spectrum of the steady-state vowel and of the synthetic vowel. However, Morton et al. (1971) found that a change of voice in the suffix, which almost inevitably means a change in spectrum, still led to a substantial suffix effect. There was a reduction, but no more than was found for a change in spatial location, in which there was no change in the frequency spectrum.

It seems difficult to believe, then, that spectral cues alone could have such a dramatic effect. However, the voices in the experiments of Morton et al., while different, were still undoubtedly human, and Morton and Chambers found that the steady-state vowel (called the "loop vowel" in that article) was not judged to be very "natural" (Morton & Chambers, 1976, Tables 2 and 3). This, then, seemed to be the direction to explore.

For the other results, since neither Condition 4 nor Condition 5 differed from the aah-1 condition, we decided that the differences found between them in this experiment were the result of chance variation. Finally, the result for the infinite peak clipped sound (IPC) was strange. Certainly it was extremely unnatural, as our subjects agreed. However, we concluded that it is the spectral properties of the sound that are important.

As can be seen in Appendix A, the lower part of the spectrum for the IPC suffix is identical to that of the original.

Experiment 3

The next stage was to manipulate combinations of treatments of the Po-aah to attempt to remove the suffix effect. We now looked at the combination of a single pitch pulse with filtering of various kinds. We used a series of filters with cutoff frequencies of 70 dB/octave, much sharper than the one used in Experiment 1. In this experiment we repeated the single pitch pulse suffix (SPP) and had three other suffixes in which the SPP suffix was filtered. The filtering was accomplished by recording the SPP suffix from the computer onto a tape recorder. It was then played through the filters and registered in the computer prior to the manufacture of the stimulus tapes. The six conditions in this experiment were as follows: (1) Po-aah (upper control); (2) SPP; (3) suffix (2) low-pass filtered at 1.5 kHz; (4) suffix (2) low-pass filtered at 750 Hz; (5) suffix (2) high-pass filtered at 1 kHz; (6) no-suffix control.

Twenty-four subjects were tested in two groups.

Results

The data are shown in Figure 3. The Wilcoxon tests confirm the eye. The SPP suffix is now significantly different from the PO-aah-1 suffix, but only at the 5% level. These two are different from the rest at the 1% level (except 2 vs. 3 at 5%), and there are no differences between the rest on the final serial position, even at the 5% level. Thus, a combination of regularity and filtering has had the effect of removing the suffix effect on the final item.

We can briefly note two pieces of data indicating that performances on Serial Positions 7 and 8 are not equivalent. The no-suffix condition is better than the SPP condition on both serial positions. The three conditions involving a filtered SPP suffix are equivalent to the unfiltered SPP condition on Position 7 and equivalent to the no-suffix condition on Position 8. A full account of

serial recall will have to explain such findings, but we need only note here that the magnitude of the suffix effect is not simply correlated with the effect of the suffix at earlier serial positions.

Note also that the emergence of a significant difference between SPP and aah-1 could be evidence of the operation of a context effect. In Experiment 2, all the other suffixes gave effects; here, three of them gave no effect. On the other hand, the context effect is small, whereas the SPP suffix still produces a large effect.

Experiments 4-13

Although we found that neither regularity alone nor filtering alone has much effect on the potency of the suffix, the combination of the two is dramatic. We then explored the space of cutoff frequencies, both with SPP and with the original PO-aah-1, in a series of experiments. The first three of these, Experiments 4, 5, and 6, were done in exactly the same way as the preceding ones. We then made some changes in the procedure, and continued with seven experiments that filled in the data points. The changes were as follows.

1. The original recorded versions of the digits were not as perfect as they could have been for a number of reasons having to do with the way in which they were registered on the computer. A new set of digits from the same speaker were therefore resampled and stored.

2. We found spurious frequency components at 90 Hz (half F_0 for PO-aah) and its harmonics. This was due to a problem with a clock interrupt to the executive routine in the computer. We remedied this with the insertion of a new clock process.

3. We noticed discrepancies between the suffixes in their pitch. These were only of the order of 1%, but might be noticeable. They were due to variation in the clock frequency when re-recording. In addition we now had a digital filter available and incorporated it into the program. This had a filter characteristic of 28 dB/octave. This was less steep than the other filters we had used, but guaranteed a better quality result, since we did not have the intermediate stages of magnetic

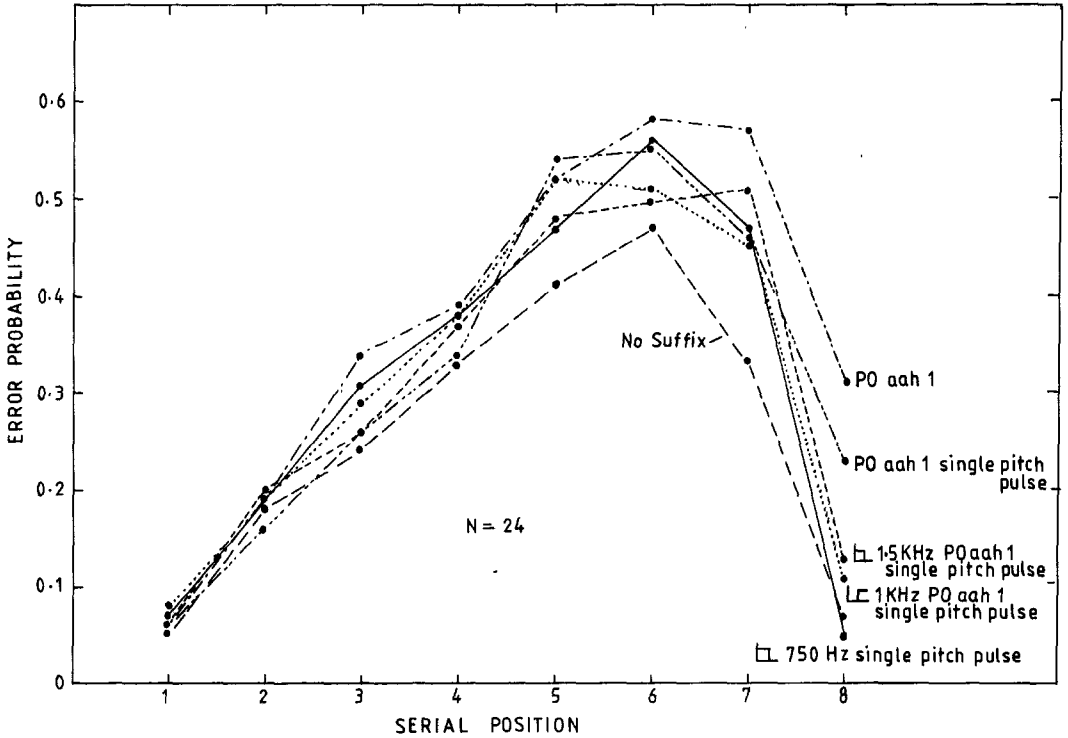


Figure 3. Error probabilities for PO-ahh-1 suffix lists where suffixes are processed for regularity (i.e., single pitch pulse [SPP]) and spectral properties (i.e., filtered with high [\square] and low [\square] pass cutoffs), Experiment 3.

tape recording that inevitably add noise, wow, and flutter.

4. By this time we had discovered perceptual centers (Morton, Marcus, & Frankish, 1976). The previous stimulus tapes had been prepared with the acoustic onsets of the digits at regular intervals. This, naturally, gave rise to perceptually irregular lists. In the second series of experiments this was corrected; the stimulus lists were P-center adjusted and so were perceptually regular.

These changes had neither major nor consistent effects on the data we collected, and we do not feel that presentation of 10 more serial position curves will be helpful. In Table 1, then, we list the conditions in the experiments in this series, together with the percentage errors on the final serial positions. We then have a problem of presenting all this information together and comparing it in a coherent way. It will be apparent from the serial position curves already shown that subject groups are not all equivalent to each

other. Within the range of our screening procedures, there is plenty of room for difference. This can be seen from the variation in both the no-suffix conditions and the PO-aah-1 condition in all the experiments. Thus it would be misleading to take the percentage errors as a useful indication of the performance with a particular suffix. Instead, we have taken into account the performance on the aah-1 and in the no-suffix condition, regarding performance on the latter as equivalent to zero effect and on the former as maximum effect (+1). The score for any one suffix, then, is given by the formula

$$SSE = \frac{s - n}{a - n},$$

where s is the score (percent errors) on the suffix condition, n is the no-suffix score, and a is the score in that experiment for the PO-aah suffix. The SSE has an ideal range of 0-1, but in practice, negative values and values greater than one are occasionally ob-

Table 1
Percentage Errors and Strength of Suffix on Last Serial Position in Each of the Six Suffix Conditions for Experiments 3-13
 (see Figures 5 and 6)

| Sound | % errors | Strength of suffix | Sound | % errors | Strength of suffix | Sound | % errors | Strength of suffix |
|---------------|----------|--------------------|------------------|----------|--------------------|------------|----------|--------------------|
| Experiment 3 | | | | | | | | |
| PO-aah | 31 | | PO-aah | 45 | | PO-aah | 47 | |
| PO-aah SPP | 23 | .67 | 750 LP | 44 | .97 | 3 SPP LP | 34 | .68 |
| 1.5 SPP LP | 13 | .25 | 1 HP | 42 | .92 | 4 SPP LP | 32 | .63 |
| 1 SPP HP | 11 | .17 | 1 LP | 41 | .89 | 250 SPP HP | 31 | .61 |
| 750 SPP LP | 5 | -.08 | 1.5 HP | 27 | .51 | 500 LP | 28 | .54 |
| No suffix | 7 | | No suffix | 8 | | No suffix | 6 | |
| Experiment 4 | | | | | | | | |
| Experiment 5 | | | | | | | | |
| Experiment 6 | | | | | | | | |
| PO-aah | 23 | | PO-aah | 47 | | PO-aah | 37 | |
| 5 SPP LP | 19 | .8 | 1 HP | 41 | .86 | Loop | 31 | .79 |
| 750 HP | 19 | .8 | 1 HP (digitized) | 37 | .76 | 1 LP | 22 | .46 |
| 250 LP | 7 | .2 | 750 LP | 35 | .71 | 1.5 SPP LP | 18 | .32 |
| 2 HP | 4 | .05 | 1 HP | 26 | .5 | 750 SPP LP | 13 | .14 |
| No suffix | 3 | | No suffix | 5 | | No suffix | 9 | |
| Experiment 7 | | | | | | | | |
| Experiment 8 | | | | | | | | |
| Experiment 9 | | | | | | | | |
| PO-aah | 33 | | PO-aah | 34 | | PO-aah | 39 | |
| Loop | 30 | .89 | Loop | 38 | 1.13 | 800 HP | 37 | .94 |
| 1.5 LP | 25 | .71 | 2 SPP LP | 16 | .4 | 3 SPP LP | 21 | .44 |
| 1 SPP LP | 24 | .68 | 1.5 HP | 11 | .23 | 4 SPP LP | 18 | .34 |
| 800 SPP HP | 17 | .43 | 1 SPP HP | 8 | .13 | 1.5 SPP HP | 9 | .06 |
| No suffix | 5 | | No suffix | 4 | | No suffix | 7 | |
| Experiment 10 | | | | | | | | |
| Experiment 11 | | | | | | | | |
| Experiment 12 | | | | | | | | |
| PO-aah | 30 | | PO-aah | 30 | | PO-aah | 30 | |
| 2 LP | 36 | 1.26 | 2 SPP LP | 13 | .23 | 2 SPP LP | 13 | .23 |
| 3 LP | 34 | 1.17 | 4 SPP LP | 18 | .45 | 4 SPP LP | 18 | .45 |
| 5 SPP LP | 19 | .52 | 3 SPP LP | 18 | .45 | 3 SPP LP | 18 | .45 |
| 1 SPP LP | 11 | .17 | 1 SPP LP | 16 | .36 | 1 SPP LP | 16 | .36 |
| No suffix | 7 | | No suffix | 8 | | No suffix | 8 | |
| Experiment 13 | | | | | | | | |

Note. SPP = single pitch pulse; LP = low pass; HP = high pass.

tained. We regard such aberrations as evidence of the power of the noise in the data. Values of SSE have been plotted against filter cutoff frequency in Figure 4. A good test of the validity of the calculation of SSE is that the four functions should all be monotonic. If there is any error it will be in the form of the slope; the bottom and top parts of the curves are correctly anchored, since if there is a vanishingly small amount of filtering, performance will be equivalent to the upper control (giving SSE = 1) in the case of the original vowel and equivalent to the SPP value in the other cases (which can be checked). If the filtering is severe, performance will be equivalent to that in the no-suffix condition, and SSE should equal zero.

Figure 4 shows a reasonable degree of monotonicity in each of the four functions. The data from all the experiments have been averaged and presented in a single diagram in Figure 5. It can be seen that the effect of filtering the original PO-aah-1 only becomes noticeable at 1.5 kHz high-pass and 500 Hz low-pass. In both cases there is very little energy left. In the low-pass case there

are only two harmonics of the fundamental, and the resulting vowel, while maintaining its pitch, changes its quality to sound more like /U/. The high-pass 1.5 kHz has only the third and fourth formants remaining.

On the other hand, the slightest amount of filtering has a dramatic effect on the SPP suffix. As little as 750 Hz high-pass and 2 kHz low-pass was sufficient to give SSE values of below .4. A glance at the spectrograms in Appendix A, Figure A2 will show that very little of the spectral information has been lost.

To summarize, we have seen that neither the regularity of the suffix sound nor extreme filtering was sufficient to remove the suffix effect. When both were used, on the other hand, the effects were severe. We can only presume that some part of the system that analyzes speech inputs examines at least two factors, which correspond to regularity and overall spectral characteristics. If the sound fails on both of them, it is classified as a nonspeech sound and does not then pass through that mechanism responsible for the PAS effect.

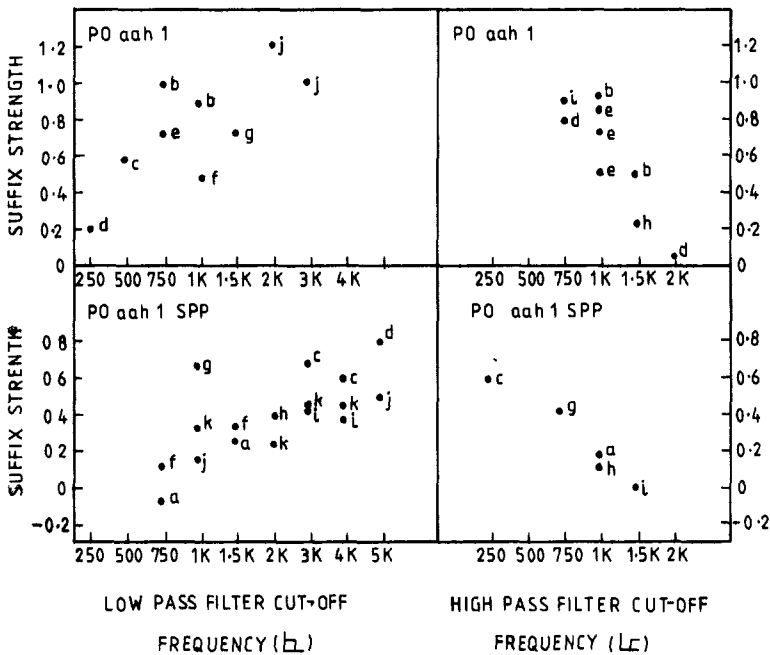


Figure 4. Data from Experiments 3-13 showing suffix strength of PO-aah-1 and PO-aah-1 single pitch pulse (SPP) suffixes with a range of high (L) and low (L) pass frequency cutoffs. (a = Experiment 3; b = 4; c = 5; d = 6; e = 7; f = 8; g = 9; h = 10; i = 11; j = 12; k = 13.)

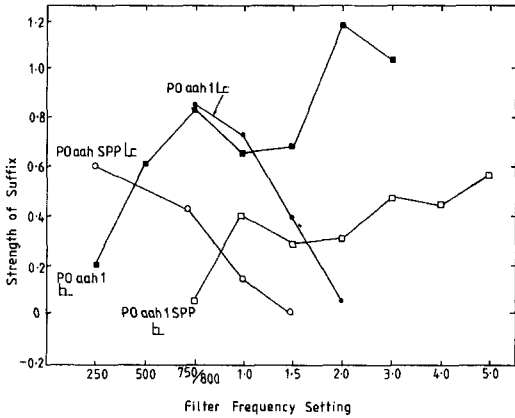


Figure 5. Summary of data given in Figure 4.

Speechlike—Relative or Absolute?

Having found interacting acoustic correlates of *speechlike*, we asked whether we were examining and manipulating some absolute speechlike properties or whether these are assessed relative to the context provided by the speech signal. Ottley, Marcus, and Morton (in press) showed that a particular steady-state vowel sound may or may not produce a suffix effect, depending on the set of suffixes with which it is presented. The following experiments examine whether filtering the digits themselves will alter the range of acceptable speechlike suffixes.

Experiment 14

The stimulus lists were recorded after they had been passed through a high-pass filter set at 1 kHz. This cutoff was as extreme as possible without severely affecting the intelligibility of the digits. As it was, the subjects needed a little practice with the digits before they were comfortable with them. The other point about 1 kHz high-pass was that the regular suffix PO-aah-1, filtered in this way, still had nearly a full effect. The SPP suffix, on the other hand, had virtually no effect when filtered at this point. We should, then, be able to examine the effects of an increase in similarity from two different starting points. The other suffixes were the regular PO-aah-1, the SPP suffix, and a truncated version of PO-aah that was included for reasons of historic interest only.

The READY signal that preceded each list was also high-pass filtered at 1 kHz.

There were 12 subjects, tested in a single group.

Results

The serial position curves are shown in Figure 6. It is clear that there is a strong effect of similarity between digits and suffixes. The high-pass filtered suffixes both gave effects that were greater than aah-1. All the suffixes gave effects compared with the no-suffix condition ($p < .01$) except aah-1 ($p < .02$). The SPP suffix was different from the high-pass filtered digits at the 5% level for the SPP and at the 2% level for the aah-1 filtered suffix.

We find, then, that the SSE is context sensitive. The potency of a suffix is affected by its relation to the properties of the stimulus list. The high-pass suffix is less effective than the unfiltered with normal digits; with filtered digits it is more effective, though the difference did not reach statistical significance. The 1 kHz filtered SPP suffix, which had virtually no effect with the normal digits, now has a full effect. Note that these effects are not completely symmetrical, since the unfiltered SPP suffix still has a full effect. We conclude that the context that was set up by the properties of the READY signal and the digits was sufficient to widen the range of what would be accepted as speechlike, and the similarity of digits and suffixes leads to the expected effect. However, in this case the properties of the digits did not cause a redefinition of the notion of speechlike, and sounds that would normally be considered speechlike were still treated as such.

This way of expressing the result helps us to relate it to an experiment by Routh and Lifschutz (1975). These authors used the same experimental method as we did. The stimulus variable they used was a pure tone superimposed on the stimulus digits on the suffix. There were four conditions, the digits with and without the tone paired with the suffix with and without the tone. They found that the suffix with a tone had an adverse effect on both kinds of stimulus list. The suffix played without the tone had only a half effect on the stimulus list that had a tone.

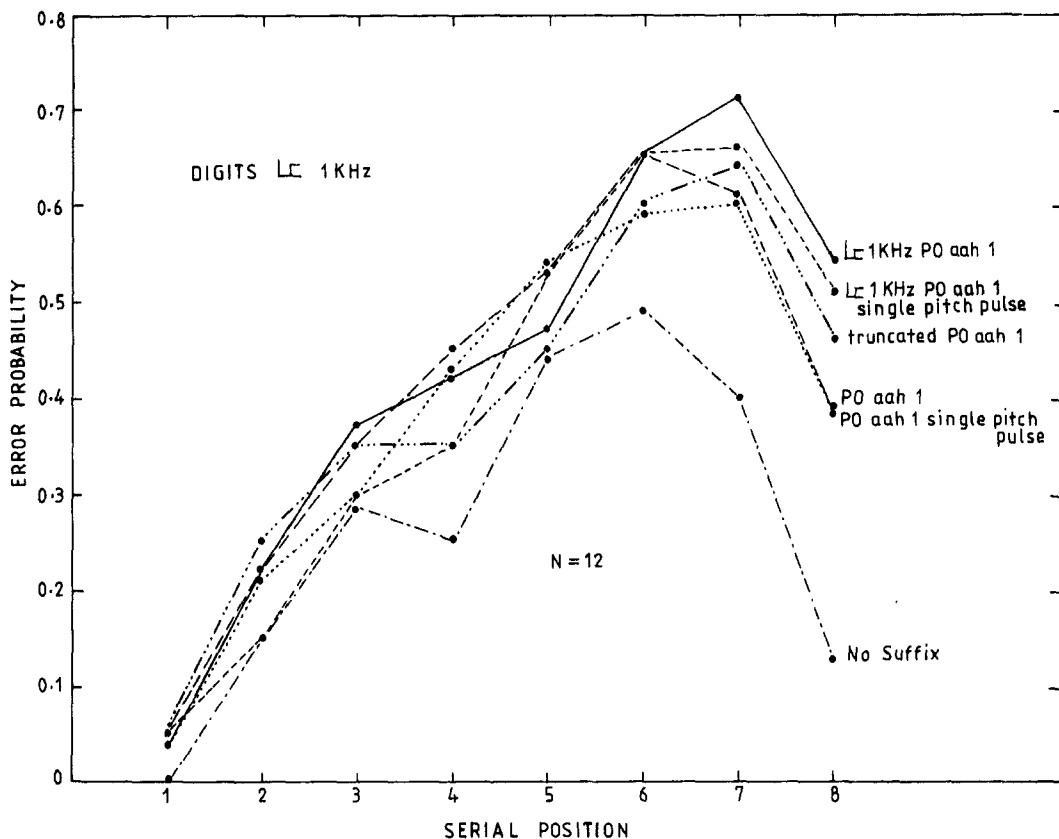


Figure 6. Error probabilities with lists and suffixes filtered at 1 kHz, Experiment 14.

In this case the addition of a feature to the suffix did not effect its potency; the addition of a feature to the stimulus list protected it against the normal suffix. The result of the Routh and Lifschutz experiment prevents us from suggesting that it is the normality of the SPP that preserves its potency in Experiment 14. The most general expression is that the properties of the stimulus list define the nature of a channel, and any stimulus suffix that fulfills the channel definition will have a full suffix effect irrespective of whether there is additional stimulation.

Experiment 15

In this experiment, again using high-pass filtered digits, we hoped to change the potency of particular suffixes in predicted ways. We included the aah-1 suffix and the 1 kHz high-pass filtered suffix as in the pre-

ceding experiment. We also included the 1 kHz low-pass filtered suffix, which produced an effect on normal digits ($SSE = .67$) about equivalent to that of the high-pass suffix. With the high-pass filtered digits we would expect a reduction in the size of the effect, as similarity should be reduced. With the 500 Hz low-pass, the reduction in potency should be more extreme than with 1 kHz. The 2 kHz high-pass suffix, on the other hand, gave no effect with normal digits ($SSE = .05$). With the high pass filtered digits the similarity of list and suffix will be higher, and we should expect this suffix now to produce some effect.

There was a single group of 15 subjects.

Results

The serial position curves are shown in Figure 7. The reversal of aah-1 and the high-

pass suffix found in the previous experiment is found again, though again the difference is not significant. The 500 Hz low-pass suffix is no longer significantly different from no-suffix, and the 2 kHz high-pass suffix now has a significant effect ($p < .05$). Unfortunately, the 1 kHz low-pass suffix, which we expected to have a reduced effect, still has a full effect. We can make a comparison between the two sets of digits by expressing the effects of the six different suffixes we used in terms of the performance on aah-1 and the control condition, as we did before. These values are shown in Table 2.

In conclusion, filtered digits change the pattern of the suffix effects in a systematic way. Suffixes with the same filter characteristics have a greatly increased effect (1 kHz high-pass and 1 kHz high-pass SPP), a suffix more severely filtered than the digits has a greater effect than before (2 kHz high-pass) and a suffix filtered in the opposite way has a greatly reduced effect (500 Hz low-

pass). All of these are in comparison with the normal PO-aah suffix. Two other suffixes had the same effect with respect to this suffix as before, the SPP and the 1 kHz low-pass. We suppose that these two suffixes have sufficient characteristics of a speechlike suffix to be accepted by the PAS mechanisms under these circumstances.

Experiment 16: The Effect of a Suffix-Prefix Procedure

The previous experiments showed that sounds that had not produced a suffix effect with normal digits could be made to do so by changing the spectrum of the digits themselves. The next question was whether the same thing could be accomplished by forcing the subjects to make a linguistic response to the sounds. This was done by introducing a contrast between "aah" and "ee," and requiring the subjects to identify the suffix by writing down its name before starting their

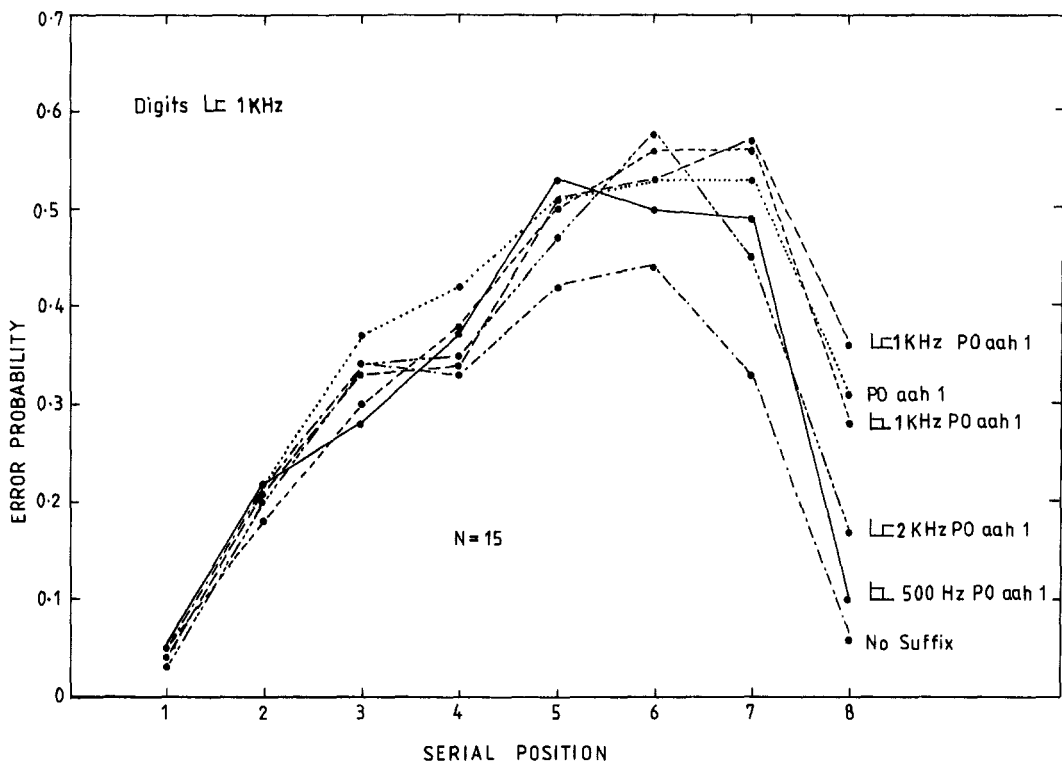


Figure 7. Error probabilities with lists filtered at 1 kHz and suffixes having varying filtered levels, high (L) and low (L) pass, Experiment 15.

Table 2
*Comparison of Suffix Effects on Normal Digits
 and on Digits High-Pass Filtered at 1 kHz*

| Suffix | Normal digits | Filtered digits |
|--------------|---------------|-----------------|
| 1 kHz | .62 | 1.58; 1.20 |
| 2 kHz HP | .05 | .44 |
| 1 kHz LP | .67 | .88 |
| 500 Hz LP | .54 | .16 |
| 1 kHz HP SPP | .15 | 1.46 |
| SPP | .77 | .96 |

Note. Figures represent the strength of the stimulus suffix effect ($SSE = [s - n]/[a - n]$) for errors on the final item, where s = the suffix in question, a = the PO-aah suffix; and n = the no-suffix control. HP = high pass; LP = low pass; SPP = single pitch pulse.)

response. This is the suffix-prefix paradigm used previously by Morton et al. (1971). They found that if the subjects were forced to identify the suffix (the words "tick" and "cross" were used) then a suffix presented in the opposite ear to the stimulus list (the *contralateral suffix*), which normally had only a half effect, now had an effect only slightly less than that of an ipsilateral suffix.

On the other hand, Morton and Chambers (1976) used the same technique with three nonspeech sounds—a tone, a buzz, and a noise—to which the subjects responded with T, B, and N before recalling the list. This procedure did not result in a suffix effect, which contributed to the belief in a speech analysis system associated with PAS that was separate from the nonspeech acoustic analysis system. However, the responses had not been linguistic ones. In the present experiment we used the full vowels "aah" and "ee" together with two filtered vowels that were very clear but had not given rise to suffix effects. They were 2 kHz low-pass SPP from an "aah" that had an SSE of .28, and a 2 kHz high-pass SPP from an "ee" that was very clearly an "ee" but had not given a suffix effect in a preliminary experiment. Our question, then, was whether these two sounds would produce a suffix effect if the subjects were forced to treat them as speech sounds.

There were six suffixes: two vowel sounds, "aah" and "ee"; two filtered SPP vowel sounds; and two conditions in which a square-

wave of the same pitch was used. The latter sounds like a buzz. Subjects were given no reason to distinguish between the filtered and the unfiltered versions of the vowels. There was one group of 16 subjects.

Results

The data are given in Figure 8. The two unfiltered vowel sounds did not differ from each other and both differed greatly from the other conditions. Note that errors on the first serial position were slightly higher than usual, a characteristic of prefix conditions.

Clearly, forcing the subject to make a linguistic response to a nonspeech sound did not alter the way the sound was treated either by the analysis system or in memory.

Discussion of Experiments 1-16

These experiments were aimed at examining some of the properties of that part of the acoustic analysis system responsible for deciding whether a sound is speechlike or not. We can summarize our conclusions as follows.

1. Speech sounds are characterized by an inherent irregularity, even in vowel sounds, and by particular spectral characteristics. Violation of either property has an effect on the acceptability of a sound as speechlike, and the two factors together interact strongly. A sound such as the infinite peak clipped suffix, which contains a great deal of distortion but preserves both the irregularity and the essential spectral characteristics, is perfectly acceptable by the analysis system.

2. The criteria for accepting spectrally limited sounds as speechlike can be changed by setting up a context of distortion, but not by forcing subjects to process the sounds as speech sounds. We conclude that the relevant process can learn to change its criteria, but is not affected by top-down constraints.

These interpretations of our data depend on accepting our account of the suffix effect. To restate it, if the suffix is accepted as speechlike, it enters PAS and disrupts the processes that would normally lead to near-perfect recall of the final item. If this account is not correct, then our interpretation of the data is inappropriate.

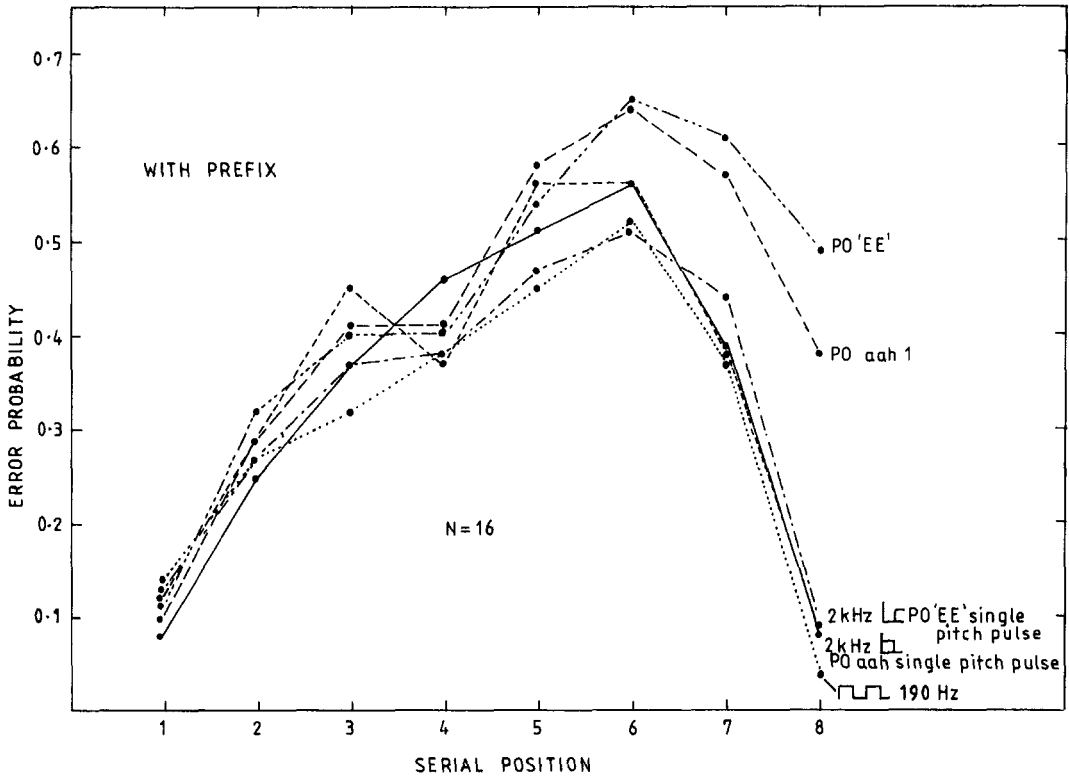


Figure 8. Error probabilities in lists for which subjects identified the suffix before recall, Experiment 16.

Subjective Correlations of Suffix Potency

An alternative interpretation of data such as these is that they simply reflect the similarity of the suffixes to the digits and that no precategorical account is necessary, central accounts being quite adequate. Such an account would be given by authors such as Kahneman (1973). If this challenge is to be more than tautological it should be possible to estimate the similarity outside the suffix paradigm and then check to see whether this derived measure does a satisfactory job. That is, we could regard all the suffix effects as examples of a general rule that interference is a function of similarity. Our claim is that the dimensions that contribute to the decision as to whether a sound is speechlike in PAS are different from general dimensions of similarity and should not be directly relatable to subjective estimates of similarity. We took two measures, one of similarity and one of naturalness, for a variety of sounds that we used as suffixes.

Experiments 17–20: Similarity Ratings

There were four experiments having to do with similarity ratings. In all of them the procedure was the same. Subjects heard pairs of sounds: The first pair was always the PO-aah-1 suffix. The other was the sound that, in effect, was being rated. Subjects were asked to make a judgment of the pair as to their similarity. They were told that on occasions the same sound would be presented twice, which should correspond to a similarity of 1. The largest difference should correspond to a rating of 7. Subjects were given response sheets on which were a series of 15 lines each with 7 marks numbered from 1 to 7. At the left was written "identical" and on the right "very different." Fifteen sounds were used in each of four experiments. Each sound was played (in pair with PO-aah-1) four times, once in each quarter of the experiment. A fifth playing of each pair constituted the practice sheet for the subjects and was not scored.

The mean ratings for the sounds used over the four experiments can be seen in Table 3. The scores from the individual experiments are given in Appendix B. They have two properties that are essential. First, they are monotonic within each of the four classes of filtered vowel. Second, the effect of taking a single pitch pulse is to reduce the similarity ratings. Findings other than these would make us suspect the basis on which the ratings were made.

In Figure 9 we have plotted the SSE figures against the mean similarity ratings. Two points are immediately apparent. The single pitch pulse sounds have uniformly very much less suffix effect than the natural sounds with the same similarity ratings (note especially 1 kHz high-pass and 750 Hz low-pass). Thus there seem to be two effects of regularity, a small one on similarity and a relatively large one on SSE, the latter related to speechlike qualities. The second point is that the subjects rated the IPC sound as being very different from the PO-aah-1, whereas it had a very large effect as a suffix. These two factors confirm our belief that a major component of the suffix effect has to do with factors in the acoustics that are not

related to similarity and perhaps are not subject to awareness.

Experiments 21 and 22: Naturalness Ratings

A more direct approach to the relationship between the suffixes and "natural" speech was to ask the subjects to rate all the sounds for their naturalness. The design of the experiment was essentially the same as for the similarity ratings, except that sounds were played singly and not in pairs. A range of stimuli were chosen that exhibited a good span both of suffix strength and similarity rating in the previous experiment. Subjects were instructed to

decide on the 7-point scale just how natural you think (the various sounds) are. The human voice, which we consider natural, can make quite strange noises, but there are some noises it can't make. I want you to decide which of the following noises are natural or not by rating them on 7-point scale. One would mean a natural noise and 7 would mean it was completely unnatural.

The mean data are given in Table 4 and the full data from both groups are given in Appendix B. It will be apparent that subjects

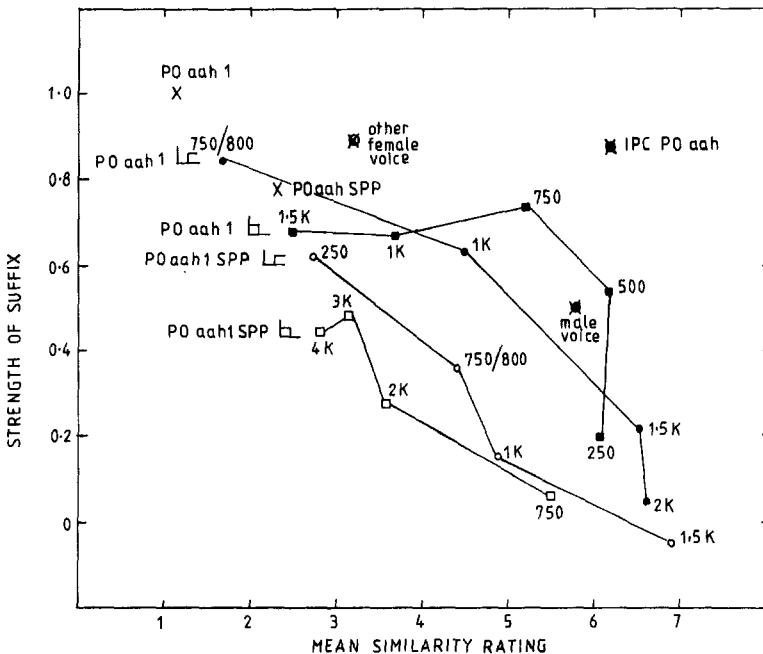


Figure 9. Similarity ratings for PO-aah-1 and PO-aah-1 single pitch pulse suffix lists with high (L) and low (H) pass frequency cutoffs.

Table 3
*Mean Similarity Ratings of Suffixes
 With the PO-aah*

| Filter setting | Filtered sounds | | | |
|----------------|-------------------|--------|-----|--------|
| | LP | LP SPP | HP | HP SPP |
| Specification | | | | |
| 250 | 6.13 | | | 2.7 |
| 500 | 6.15 | | | 4.4 |
| 750 | 5.2 | 5.4 | 1.7 | 4.4 |
| 1K | 3.58 | | 4.5 | 4.8 |
| 1.5K | 2.5 | | 6.6 | 6.8 |
| 2K | | 3.6 | 6.6 | |
| 3K | | 3.2 | | |
| 4K | | 2.8 | | |
| | Unfiltered sounds | | | |
| PO-aah | 1.03 | | | |
| SPP | 2.4 | | | |
| IPC | 6.3 | | | |

Note. LP = low pass; HP = high pass; SPP = single pitch pulse; IPC = infinite peak clipping.

do not discriminate between degrees of naturalness as well as they do similarity. Within the sounds we sampled for this rating, the departures from monotonicity as the severity of filtering is increased are not great, but the majority of the sounds are rated as between 4.5 and 5.5. A plot of the naturalness ratings against SSE is given in Figure 10.

Whereas similarity rating proved to be a poor indicator of suffix strength because sounds with the identical similarity rating could act very differently as suffixes, it can be seen that the relationship between naturalness ratings and suffix effect is knee-shaped. Large reductions in naturalness result in little change in suffix effect, until a point is reached where suffix strength rapidly decreases with little further change in naturalness. Naturalness, therefore, also seems to be a poor predictor of suffix strength. Note again that the IPC version of PO-aah-1 is rated as very unnatural although it produces a powerful suffix effect.

Discussion of Experiments 17-22

The rating experiments were designed to determine whether the relative effectiveness of the suffixes we used could be attributed to any general notion of similarity between test list and suffix. The ratings of subjective

similarity showed that the steady-state sounds (SPP) were uniformly rated as being more similar than natural sounds of the same suffix potency. We conclude that the acoustic mechanisms are more sensitive to this manipulation than the more central mechanisms we assume operate when subjects rate the sounds. Large changes in rated similarity are unrelated to the suffix potency of natural sounds. Ratings of naturalness do not separate out the feature of regularity, but there are changes in the rating of sounds that are not accompanied by changes in suffix effect. We conclude, then, that the mechanisms responsible for the suffix effect and those operating when subjects rate the sounds are sensitive to different acoustic properties. We assume that the former mechanisms are concerned with making a speech/nonspeech decision, though we have as yet no proof that this is the case.

General Discussion

Our aim at the start of the inquiry was to test certain hypotheses about the properties of a sound that are sufficient or necessary for it to be characterized as nonspeech by those mechanisms responsible for acoustic analysis, and, as a result, for the sound not to have a suffix effect. The specific hypothesis, produced by Morton and Chambers (1976), was that this property was that

Table 4
Mean Naturalness Rating

| Filter setting | Filtered sounds | | | |
|----------------|-------------------|--------|-----|--------|
| | LP | LP SPP | HP | HP SPP |
| Specification | | | | |
| 250 | 5.2 | | | 4.0 |
| 500 | 5.3 | | | 5.5 |
| 750 | | | | 5.5 |
| 1K | 3.1 | | 4.1 | 5.5 |
| 1.5K | | 4.8 | 5.6 | |
| 2K | | 4.5 | 5.3 | |
| 3K | | 3.6 | | |
| | Unfiltered sounds | | | |
| PO-aah | 1.43 | | | |
| SPP | 4.1 | | | |
| IPC | 5.6 | | | |

Note. LP = low pass; HP = high pass; SPP = single pitch pulse; IPC = infinite peak clipping.

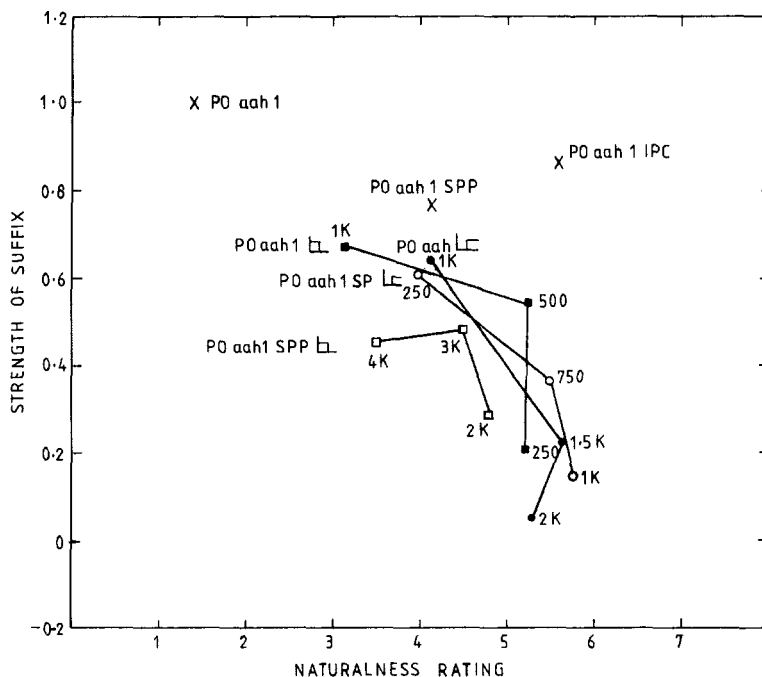


Figure 10. Naturalness ratings for PO-aah-1 and PO-aah-1 single pitch suffixes with high (\square) and low (\circ) pass frequency cutoffs. (IPC = infinite peak clipping.)

of regularity. The present state of knowledge is as follows.

1. Regularity of a sound is not sufficient for it to lose its effectiveness as a suffix.

2. Very severe filtering of an "aah" sound—up to 1.5 kHz high-pass filtering and down to 500 Hz low-pass filtering—is necessary to make any substantial difference to the suffix effect.

3. In combination with regularity, only very light filtering is necessary to cause a substantial reduction in the effect of the sound. Low-pass filtering at 2 kHz and high-pass filtering at 500 Hz are sufficient to make the regular sound be treated like a nonspeech sound as far as its effectiveness as a suffix is concerned. Thus a speechlike quality is not to be attributed to a particular part of the spectrum.

4. Subjects are consistent in rating the sounds for their similarity to the original vowel sound within any one type of sound, defined by filter characteristics and regularity. However, although regularity greatly influences the size of the suffix effects, the effects on similarity judgments are small. In addition, the IPC suffix, which had a full effect, was rated highly dissimilar to the PO-

aah-1 sound. We thus believe that the major factor giving a suffix effect is unrelated to perceived similarity.

5. Ratings of the naturalness of the sounds did not add much to our quantitative estimates of the magnitude of the suffix effect, and again the IPC suffix showed that a highly "unnatural" suffix could have a full effect.

6. The effectiveness of particular sounds as suffixes was affected by the nature of the digits. Earlier experiments showed that suffixes in different voices had smaller effects. We showed that filtering the digits with a 1 kHz high-pass filter had substantial consequences on the effects of particular sounds as suffixes. These effects were predictable on the basis of the spectral similarity of stimulus list and suffix. The one difference was that certain reasonably natural sounds, the single pitch pulse sound and the 1 kHz low-pass vowel, maintained their efficacy. We conclude that whereas the absence of energy in a particular frequency band can cause the sound not to have a suffix effect, the presence of energy cannot penalize a sound, under conditions that remain to be defined. This is true for the SPP suffix and the 1 kHz low-

pass suffix with the high-pass digits, and with the IPC suffix with normal digits, as well as with an experiment reported by Routh and Lifschutz (1975).

7. Forcing the subjects to process filtered vowels linguistically did not induce a suffix effect.

8. Some sounds, at least those used in Morton and Chambers and tested in Ottley et al. (in press), could either produce a suffix effect or not depending on what other sounds were used as suffixes (see also Ayres et al., 1979). Such context effects may be caused by shifting criteria in the acoustic analysis system.

We therefore conclude that a large component of the suffix effect, that which we have called the PAS effect, is truly precategorical in nature and will be found unless the suffix is refused entry to further processing due to the absence of acoustic features that mark it as speechlike. These features include irregularity and the presence of a distribution of spectral energy appropriate in the context of the other stimuli in the list. The presence of one or more such features will cause the sound to be treated as speechlike and produce a full suffix effect. Neither the results nor the operation of this preselection are available to or can be influenced by conscious control, as shown by the similarity and naturalness ratings, and the suffix-prefix experiment, respectively.

There remain two kinds of suffix experiment that have been used to challenge the precategorical origin of the suffix effects.

Lip Reading

Our conclusions concerning the essentially precategorical nature of the effects discussed here are unaffected by recent studies involving lip reading. Spoehr and Corin (1978) showed that a lip-read suffix had as great an effect as a spoken suffix. Spoehr and Corin attributed their results to what they call "STM coding" and felt their results were "difficult to reconcile . . . with the notion that the recency effect is caused by the subject's ability to use information stored in PAS" (p. 585). We prefer to view the Spoehr and Corin data in the broader context of speech recognition. It is clear that lip reading can assist speech comprehension,

particularly in noisy environments. One can then pose the question as to the stage of speech processing at which the lip-read information operates. It is possible that the speech analysis mechanisms operate as best they can on the acoustic input, providing alternative lexical interpretations that are then discriminated among by some central mechanism. It seems more plausible, however, that the lip-read information has its effect at the level at which decisions are made as to which acoustic feature or phoneme is present. That is to say, lip-read information can be used by precategorical systems. If this is the case then the results of analyzing lip-read information, presumably in some phonological or related code, will enter PAS in the same way as would the results of analyzing a purely acoustic input. The PAS mechanisms, in the limit, would be incapable of distinguishing between the two, since they would now be in the same form. It would follow from this analysis that a list of items that a subject has to lip read will give a recency effect just like an auditory list rather than like a visual list. Such a result has been reported by Campbell and Dodd (1980). These findings have one enormous value in reminding us that the labels we give our processes are not to be taken literally. There is no paradox in accepting that a precategorical acoustic store can be affected by information that has its origin in the visual modality. It is the function of the construct that is vital, not its name.

Nonspeech Sounds

We have confirmed previous findings that nonspeech sounds do not produce suffix effects on lists of spoken digits. The complementary finding has been reported by Rowe and Rowe (1976). They played sequences of sounds (such as a whip and a telephone) followed by either a nonspeech suffix (a car horn) or a spoken suffix. The former had a greater effect. Rowe and Rowe are cautious about interpreting their results in terms of a precategorical store for meaningful nonspeech sounds. They seem to favor an account based on grouping, derived from Kahneman (1973). In this we concur, not least because the recency effects in this and an earlier study were small, with errors at

or above 35% on the final item without a suffix (Rowe, 1974, Figures 1 and 2) and between 30% and 55% for sounds with a speech suffix (Rowe & Rowe, 1976, Figures 1 and 2). Similar values are shown by Spoehr and Corin (1978, Figure 2). In such cases we endorse a grouping account of the effect of the suffix. However, it is not surprising that speech and nonspeech sounds differ in this respect, and we feel secure in our belief that a large portion of the stimulus suffix effect has its origin in a speech-specific pre-categorical store.

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Appendix A

Acoustic Properties of the Suffixes

The amplitude waveform of the sound PO-aah-1 is shown in Figure A1(a). The basic periodicity is apparent, corresponding to the pitch of the voice, as are the small variations between the two pitch periods. The single pitch period stimulus used in Experiments 2 and 4 was manufactured by taking just one such pitch period and repeating it. With a computer this is simple to do without any audible consequence of the joins. A portion of the two-bit suffix from Experiment 2 is shown in Figure A1(b). In this case, the waveform, instead of being continuous, is coded with only four voltage levels. The resemblance to the original is just discernable. The infinite peak clipped sound (IPC) used in Experiment 2 is illustrated in Figure A1(c). The arrows on the figure mark the periodicity. In this case all that remains of the original amplitude waveform is an indication of whether the voltage was positive or negative.

From the amplitude waveforms the resem-

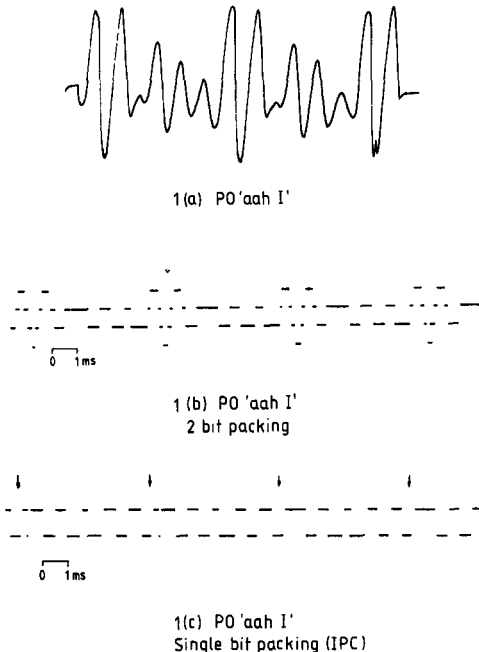


Figure A1. IPC = infinite peak clipping.

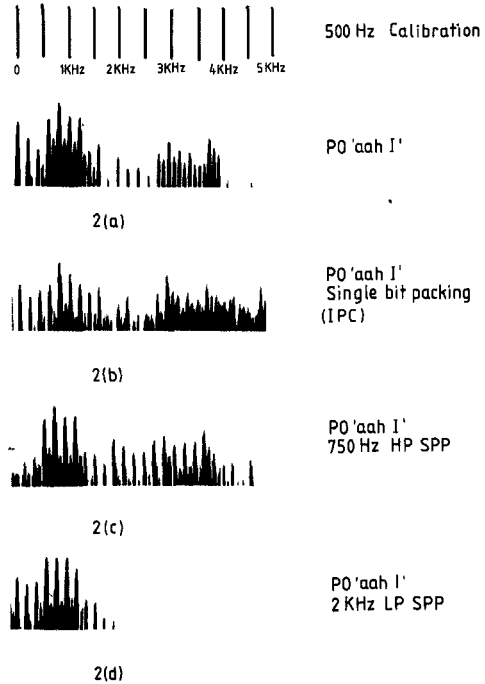


Figure A2. HP = high pass; LP = low pass; SPP = single pitch pulse; IPC = infinite peak clipping.

blance between the IPC suffix and the original vowel sound is not clear. If we look at the frequency spectrum, however, the relationship is clearer. In spite of the massive distortion, the essential aspects of the sound remain. In Figure A2(a) we have the spectrum of PO-aah-1. This shows the amplitude of the different components of the sound. These are mainly the harmonics of the fundamental frequency. The smaller components represent subharmonics of the fundamental that were introduced by a fault in the computer (see p. 578). There is a peak of energy, corresponding to the first two formants, at about 1 kHz. There is a smaller peak at between 3 and 4 kHz.

The IPC sound is shown in Figure A2(b). The amplitudes of the lower harmonics are the same as those in the original sound. The big differences

arise in the higher frequency range. The perceptual effect is that of hearing the sound heavily distorted. This sound produced almost a full suffix effect. By contrast the two sounds shown in Figure A2(c) and (d) produced scarcely any suffix effect.

They are the 750 Hz high-pass SPP suffix and the 2 kHz low-pass SPP suffix. The same filtering on the original PO-aah sound gives the same spectrum, but the resulting sound gives a firm suffix effect (see Figure 5).

Appendix B

Table B1
Scores for Experiments 17-22

| Sound | Similarity rating | | | | Similarity rating means | Naturalness rating | | Naturalness rating means | Strength of suffix |
|------------------------------|-------------------|------|-----|------------------------|-------------------------|--------------------|------|--------------------------|--------------------|
| | 1 | 2 | 3 | 4 | | 1 | 2 | | |
| PO-aah-1 | 1.1 | 1.02 | 1.0 | 1.0 | 1.03 | 1.7 | 1.17 | 1.43 | 1.00 |
| Low-pass | | | | | | | | | |
| 250 | | 6.59 | 6.4 | | 6.13 | 5.0 | 5.41 | 5.2 | .2 |
| 500 | 5.8 | 6.34 | 6.3 | | 6.15 | 5.0 | 5.52 | 5.26 | .54 |
| 750 | 5.3 | | | 5.1 | 5.2 | | | — | .74 |
| 1.0 | | 3.95 | 4.0 | 2.8 | 3.58 | 3.4 | 2.83 | 3.12 | .67 |
| 1.5 | | | | 2.5 | | | | — | .68 |
| High-pass | | | | | | | | | |
| 750 | 2.0 | | | 1.4 (800) ^b | 1.7 | | | — | .85 |
| 1.0 | 4.7 | 4.56 | 4.6 | 4.0 | 4.47 | 4.9 | 3.31 | 4.11 | .62 |
| 1.5 | | 6.54 | 6.6 | | 6.57 | 5.6 | 5.69 | 5.64 | .22 |
| 2.0 | 6.5 | 6.76 | | | 6.63 | 5.3 | | 5.3 | .05 |
| PO-aah-1 SPP | 2.2 | 2.22 | 2.0 | 3.2 | 2.41 | 4.9 | 3.32 | 4.11 | .77 |
| Low-pass | | | | | | | | | |
| 750 | | | | 5.4 | 5.4 | | | — | .03 |
| 2.0 | 3.5 | 3.29 | 3.4 | 4.2 | 3.6 | 4.9 | 4.69 | 4.8 | .28 |
| 3.0 | 3.6 | 3.17 | 2.5 | 3.6 | 3.22 | 5.3 | 3.69 | 4.5 | .48 |
| 4.0 | | | 2.2 | 3.4 | 2.8 | | 3.28 | 3.62 | .45 |
| High-pass | | | | | | | | | |
| 250 | 2.7 | 2.66 | 2.7 | | 2.69 | 4.6 | 3.31 | 3.96 | .61 |
| 500 | | 4.12 | 4.7 | | 4.4 | 5.8 | 5.17 | 5.49 | — ^a |
| 750 | | 4.44 | 5.0 | 3.7 (800) ^b | 4.37 | 5.9 | 5.17 | 5.54 | .36 |
| 1.0 | | | 5.4 | 4.3 | 4.85 | | 5.21 | 5.55 | .15 |
| 1.5 | | | | 6.8 | 6.8 | | | | -.05 |
| IPC PO-aah-1 | 6.3 | 6.17 | 6.2 | 6.4 | 6.27 | 5.8 | 5.34 | 5.57 | .87 |
| PO-aah-1 F∅↓ (low pitch) | 4.6 | | | | | | | | |
| PO-aah-1 F∅↑ (high pitch) | 5.3 | | | | | | | | |
| /a/ male voice | 5.8 | | | | | | | | .50 |
| /a/ female voice | 3.2 | | | | | | | | .89 |

Note. SPP = single pitch pulse; IPC = infinite peak clipping.

^a The data for the strength of suffix on 500 high-pass had to be discarded because of a technical fault.

^b The digital filter used for later experiments was not reliable at less than 800 Hz high-pass. Where 800 Hz high-pass was used instead of 750 Hz high-pass it is indicated by (800) in the table.

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