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Is Attention Shared Between the Ears?1

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Abstract

This study tests the locus of attention during selective listening for speech-like stimuli. Can processing be differentially allocated to the two ears? Two conditions were used. The simultaneous condition involved one of four randomly chosen stop-consonants being presented to one of the ears chosen at random. The sequential condition involved two intervals; in the first S listened to the right ear; in the second S listened to the left ear. One of the four consonants was presented to an attended ear during one of these intervals. Experiment I used no distracting stimuli. Experiment II utilized a distracting consonant not confusable with any of the four target consonants. This distractor was always presented to any ear not containing a target. In both experiments, simultaneous and sequential performance were essentially identical, despite the need for attention sharing between the two ears during the simultaneous condition. We conclude that selective attention does not occur during perceptual processing of speech sounds presented to the two ears. We suggest that attentive effects arise in short-term memory following processing.

At what point in the information processing system does selective attention operate? A great deal of ambiguous research has been directed towards answering this question since Broadbent (1957, 1958) raised the issue to prominence. Current views of memory suppose that sensory systems analyze incoming information in a series of processing stages, dumping the results into short-term store (Shiffrin & Geisler, 1973; Norman, 1970; Melton & Martin, 1972). It is generally accepted that short-term store exhibits limited capacity and utilizes many selective mechanisms. These were termed “control processes” in Atkinson and Shiffrin (1968). The question remains: Does selective attention operate during perceptual processing, prior to short-term memory? Selective attention presupposes two things: 1) a limited capacity processing system and 2) control over the degree to which each input channel is transmitting or processing information at any given moment. In this context, channels are assumed to refer to physical sensory locations (such as the different body parts, the two eyes, the left or right visual field, the two ears, etc.), to specifiable characteristics of the stimuli (such as color in vision, pitch in audition, or size in the tactile modality), or to class membership of stimuli (such as letters vs digits or speech vs nonspeech).

Examples of three classes of perceptual processing models are shown in Fig. 1. The top panel illustrates a single-channel model in which information enters the recognition system from only a single source at any one moment. It is assumed in this model that attention is switched rapidly among various possible sources of sensory information. Broadbent (1958) proposed a filter-model that has been interpreted in this way, but may have in fact been

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closer to Model c. His model was developed in the context of split-span dichotic listening experiments. Franzen, Marko-witz and Swets (1970) proposed a model of this type for the processing of near-threshold vibrotactile information. Estes and Taylor (1964, 1966) proposed a model of this type for visual processing. Moray (1970a,b) proposed such a model for dichotic tone detection.

A less extreme attentional model is shown in the middle panel of the figure. In this attenuation model, total processing capacity is limited, but some input is simultaneously processed from many channels. The O's attentional control determines the relative amount of information processed in particular channels and sent on to the recognition devices in short-term store. Treisman (1969), Moray (1969), and Neisser (1967) have proposed models of this type with evidence primarily based on dichotic listening and speech shadowing experiments. Rumelhart (1970) and Norman and Rumelhart (1970) have proposed a model of this type based primarily on experimentation in visual processing. It should be noted that both types of limited capacity attentional models require a “preattentive” mechanism to direct attention to important channels (see Neisser, 1967, for a discussion of the need for pre-attention in these models).

The final class of models is seen in the lower panel of Fig. 1. These models assume minor limitations of capacity (such as masking) and no attention during perceptual processing. All attentional effects are due to characteristics of short-term store following perceptual processing. Deutsch and Deutsch (1963) and Deutsch, Deutsch and Lindsay (1967) have proposed such a model for auditory processing. Hochberg (1970) has proposed a more general model with similar properties. Shiffrin and Gardner (1972) and Shiffrin and Geisler (1973) have proposed this model for visual processing and general sensory processing; Shiffrin, Craig, and Cohen (1973) proposed such a model for tactile processing. LaBerge (1973) has argued for a model of this type based on reaction time data, as have Posner and Klein (1973).

These three models have received extensive examination in the last 15 years, but until quite recently the research has failed to clarify the issues. We will not attempt a critical review here because of space limitations, and because many previous workers have already carried out such reviews. Note in particular that these writers have not failed to note the ambiguity of the experiments. A few quotes should make this clear.

> A number of possible models turn out to be consistent with the existing data and it seems unlikely that current experimental techniques will allow us to distinguish unequivocally between them. (Lindsay. In Mostofsky, 1970, p. 170)
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> This dilemma has not been satisfactorily resolved … The theory that an ignored message may be attenuated rather than filtered out may be a partial explanation, but it is not clear that the attenuation theory accounts for all the data. (Keele, 1973, p. 151)
>
> Are incoming messages attenuated, or are responses selected? The evidence reviewed up to now is indecisive, a conclusion which is borne out by the fact that both sides in the controversy invoke the same experiments to support their rival views. (Moray, 1970a, p. 183)
>
> On the other hand, theory at present is lagging. It is not that we are short of theories; rather that they have been formulated for the most part at so imprecise a level that it has proved impossible to disprove any of them. (Moray, 1969, p. 93)
>
> Which model is preferable? At the moment the choice is somewhat arbitrary because critical experimental tests have not yet been performed. (Norman, 1969, p. 35)

> Some quantitative experiments on selective attention as sensory input gating are being done. The gap between these and the speech experiments yawns wide indeed. (Swets and Kristofferson, 1970, p. 355)

> Unfortunately, it is not obvious what distinguishes those situations in which subjects can filter readily from those in which they cannot. (Egeth, 1967, p. 56)

> This brief general review has shown how many problems remain and how scanty is the evidence so far available. (Treisman, 1969, p. 296)

Recently an experimental paradigm has been developed which appears to provide less ambiguous solutions to the selective attention problem. The basic method compares two conditions within a sensory processing task. In the simultaneous condition a single short time interval is defined. During this interval S must simultaneously monitor *n* channels for the presence of some specified information which randomly appears on one or more of these channels. In the sequential condition, S pays attention to the *n* channels one at a time, in a known order, during *n* successive well defined temporal intervals. In both cases, the *n* channels contain identical information. The simultaneous condition requires simultaneous sharing of attention among the *n* channels. The sequential condition allows all the attention to be given to each channel in turn. To insure that masking and other interactions between channels will be identical in the two conditions, the channels in the sequential condition that do not require attention at a given moment are filled with information similar to that presented in the simultaneous condition on those channels. Information on these irrelevant channels in the successive condition is extraneous and S is told to ignore it. Finally, care is taken so that short-term memory will not be overloaded. This insures that S will be able to scan the incoming information and complete his decisions before short-term forgetting occurs. Thus the simultaneous condition will not be inferior due to short-term memory limitations. Under these circumstances, a comparison of the simultaneous and sequential conditions should provide a direct test of the degree to which selective attention occurs during perceptual processing.

In Shiffrin and Gardner (1972) three experiments were carried out in which the “channels” consisted of visual spatial locations, and the task consisted of letter recognition. Shiffrin, Gardner, and Allmeyer (1973) presented two similar experiments except that the tasks consisted of dot detection. Shiffrin, Craig, and Cohen (1973) presented two experiments in which the channels consisted of spatial location on the skin and the tasks involved detection of a vibrotactile stimulus. Shiffrin and Grantham (1973) carried out tasks in which the channels consisted of the auditory, visual aud tactile modalities as a whole, and the tasks involved detection of weak signals in those modalities. In all of these experiments, performance in the simultaneous and sequential conditions was identical (if anything the results indicated a slight advantage for simultaneous presentation). We concluded from these results that Ss have no ability to attend selectively to desired channels during perceptual processing, that the sensory processing system acts automatically, without subject control, to encode stimulation and dump the results into short-term store.

These results from the sequential-simultaneous procedure are in fact supported by those from a number of important experiments in the literature. Grindley and Townsend (1968) showed independent visual processing from spatial locations and attention effects operating in memory. Eijkman and Vendrik (1965) showed that detection from ear and eye proceeds independently (but duration judgments do not). Sorkin, Pastore and Pohlmann (1972), Sorkin, Pohlmann, and Gilliom (1973), Pastore and Sorkin (1972), and Sorkin and Pohlmann (1973) have studied tonal detection where the two ears, frequency, or both are the attended channels. The general finding from these studies is that independent detection on these channels takes place. Posner and Boies (1971) have used reaction time measures in a stages-of-processing analysis to arrive at similar conclusions regarding the locus of attention. Gardner (1973) has come to independent processing conclusions from studies in visual spatial recognition.

Before continuing we should like to define what we mean by *perceptual processing*. We do so in the context of the model presented by Shiffrin and Geisler (1973). In this model, information is analyzed in a series of stages, through contact with features stored in long-term store. As each feature is contacted it is activated and placed in short-term store, where it can serve as a base for further processing. No distinction is made within active memory to separate iconic from short-term memories. Rather it is assumed that there is a series of levels of analysis, the higher levels tending to decay from short-term store at slower rates. It is assumed that sensory input is processed automatically through many levels of processing, depending on prior learning and the physical characteristics of the input, without the operation of selective processes. As information is placed in short-term store, the subject may selectively rehearse, encode, and make decisions about it. When we say perceptual processing, we refer to the automatic series of processing stages by which information is placed in short-term memory. Note that many effects may appear to be perceptual because delayed tests or multiple decisions will allow forgetting from short-term memory (forgetting that may take place in just a few milliseconds). In many cases, sophisticated tests are necessary to separate the locus of the observed effects, but the theoretical issue is nevertheless of paramount importance.

It should be noted that many, if not most, of the experiments purporting to demonstrate selective attention during perception have utilized the auditory modality (see below). Many of these tasks have utilized some version of a dichotic listening paradigm in which the channels in question have been the two ears. However, none of the experiments we have carried out have involved channels within the auditory modality. Other investigators who have carried out adequate tests of the locus of attention within the auditory modality have used very simple tonal stimuli. Thus Sorkin and his associates (see above), Moore and Massaro (1973) and even Moray (1973) have found that the two ears may process simple tonal information independently. However, the early work on selective attention used more complex stimuli, i.e., speech sounds. Therefore the present experiments were designed to extend our previous investigations and test whether S can selectively allocate attention to the two ears in processing speech sounds.

We will not attempt to review the voluminous literature in the auditory modality, although it is our belief that essentially all of these studies are ambiguous with respect to the locus of selective attention during perceptual processing. By way of example, we will discuss just a few of the better known paradigms and studies.

Most of the early research on selective attention was concerned with listening to one of several simultaneous auditory messages. Generally, the messages were speech stimuli and the experiments employed one of three basic procedures: (1) question and answer, (2) split memory span, and (3) shadowing. The results of many of these studies have previously been reviewed in detail by Broadbent (1958), Moray (1969, 1970a), and more recently Swets and Kristofferson (1970) and will only be summarized briefly below. A common conclusion from these studies is that listeners normally cannot perform several tasks together as well as they can perform the same tasks separately.

In the question and answer experiment, a listener is typically presented with one or more messages on multiple channels and then is required to repeat, identify, or respond in some appropriate way to the messages. Much of the early work described by Broadbent (1958) showed that a listener's task is easier when there is some physical difference between the two messages which keeps them separable, such as different voices. Egan, Carterette, and Thwing (1954) and Spieth, Curtis and Webster (1954) have found that listeners will treat two simultaneous inputs as distinct messages if they differ in pitch, loudness or relative position in auditory space. When the two messages resemble each other closely in terms of gross physical dimensions or similar content, listeners treat the inputs as a single message. Moreover, if only one of the messages is to be answered, Ss have great difficulty selecting the relevant from the irrelevant message (Broadbent, 1952a,b; Poulton, 1953). The difficulty may be overcome, however, when the relevant message is preceded by a cue such as a call sign. The listener's ability to select the relevant message improves substantially when additional information about the source or the content is provided.

Other findings relevant to selective attention have come from the early split-span experiments (Broadbent, 1954; Gray & Wedderburn, 1960; Moray, 1960). In this task, simultaneous pairs of items (i.e., digits, words, etc.) are presented to listeners dichotically through headphones. One member of a pair is presented to the right ear while the other member is presented to the left ear. Initially, Broadbent (1954) found that recall is organized in terms of ear of presentation rather than order of presentation under free recall instructions; listeners always report the items presented to one ear and then the items presented to the other ear. However, when recall was required in terms of order of presentation, performance dropped markedly. These findings were originally interpreted by Broadbent (1954, 1958) as evidence that the ears act as separate channels, each with distinct locations in short-term store. At relatively fast presentation rates (i.e., two pairs per second) recall of information in one location is accessed and grouped before the information in the other location. At slower presentation rates (i.e., one pair every two seconds), Ss can report the order of presentation of items if required. According to Broadbent's original single channel views, it is possible to switch attention back and forth between channels during presentation.

Although the grouping strategies observed by Broadbent with simultaneous stimuli provided some evidence for distinguishing between sensory channels (i.e., ears), other studies have reported additional cues for organizing output. Gray and Wedderburn (1960), Yntema and Trask (1963), and Broadbent and Gregory (1964) showed that output may also be organized in terms of semantic categories rather than ear of presentation. For example, Gray and Wedderburn (1960) found that if “mice – five – cheese” was presented to one ear, and “three – eat – four” was presented simultaneously to the other ear, Ss often grouped the items into meaningful phrases such as “mice – eat – cheese.” Broadbent and Gregory (1961) replicated and extended Gray and Wedderburn's findings and found that at slow presentation rates performance improved for items alternating between two classes. Based on these findings, Broadbent and Gregory concluded that the two ears may or may not act as separate channels. Moreover, similar classes may be somewhat analogous to sensory channels.

Although the question-and-answer and split-span experiments have been used to argue for the operation of selective attention on input channels, most investigators now agree that these selective effects occur in short-term memory following perceptual processing (e.g., Egeth, 1967). Certainly, no one questions that short-term memory effects are important in these paradigms. Whether selective-attention effects in perceptual processing are present in these situations in addition to short-term memory effects is more difficult to decide.

Treisman (1971) has argued recently for the presence of processing effects rather than (or in addition to) memory effects in a complex variation of a split-memory-span experiment. We mention this study because it illustrates the difficulties involved in separating the source of the attentional effects in such studies. Treisman found that alternating digits in sequence from one ear to the other resulted in lower performance than presenting all digits to both ears in sequence (subjects were told to report the digits in the order of presentation).

Treisman attributed the difference to limitations on the ability to shift attention between ears during processing of the stimuli. In addition, it was found that the many errors in the alternating condition were divided almost equally between order errors and omission errors, while the few errors in the binaural condition were primarily order errors. These results were interpreted as supporting a perceptual processing problem in the alternation condition. However, the findings could equally well be due to memory problems. In dichotic presentation there is a well known tendency to report items by order of ears rather than sequence. Estes (1972) has reported data indicating that loss of order information can cause content information to be lost from short-term memory. Thus, in the alternating condition items may have entered short-term memory; the subjects' tendency to recall by ear may not only have resulted in order errors but also have caused loss from short-term memory and thereby produce omission errors. There were other relevant findings in this study but they also are subject to multiple interpretation. Studies of this type illustrate the need for paradigms which minimize the role of memory factors as far as possible.

A large body of research has studied the operation of selective attention during the shadowing of continuous speech. In these experiments, a sequence of words is presented to one ear and the listener is required to repeat them continuously word-by-word while listening. At the same time, a sequence of unrelated words is usually delivered to the listener's other ear and a variety of tasks have been examined. Much of the experimental evidence in favor of various attentional models in selective listening has been based on the results of these shadowing experiments.

In the early shadowing experiments, listeners were required to ignore the irrelevant information on the rejected, nonshadowed channel. After the experiment was completed, they were questioned about their knowledge of information presented on the rejected channel. Cherry (1953) first reported that the presence of irrelevant words presented to the nonshadowed ear could effectively be ignored or rejected by the listener. The content of passages presented to the rejected ear could not be recalled and shifts from one language to another could not be detected by Ss. However, when the rejected message shifted from a male to a female speaker or from continuous speech to a pure tone, differences could be reported. Cherry (1953) concluded that most of the information on one ear could be successfully rejected while shadowing a message with the other ear. Although the original findings by Cherry have been criticized on a number of procedural grounds by Moray (1969, 1970a) and Treisman (1969), these basic results are frequently cited by investigators as support for Broadbent's single channel model of selective attention. The filter blocks all but the simple physical characteristics of the rejected message from entering the processing system.

However, additional shadowing experiments have shown that not all of the information in the rejected message is ignored or filtered out. For example, Moray (1959) found that Ss could follow instructions presented on the rejected channel more often if they were preceded by the listener's name than if this cue were absent. If the accepted and rejected message were interchanged between ears during shadowing, intrusions from the rejected ear would occur (Treisman, 1960). Switches to the message on the rejected ear occurred more often when the original message was highly redundant than when it was low-order of approximation to English or merely lists of unrelated words. These findings led Treisman to propose an attenuation model (1969). Information on the rejected channel is not blocked completely by the filter as in the single channel case, but rather is attenuated after some initial processing of simple physical characteristics. Thus, the physical characteristics of a message are used by the filter to determine which channel is to be selected and which is to be ignored or attenuated. Filtering occurs during rather than before or after recognition.

Although the details of this attenuation process have not been specified very precisely, two studies attempted a direct test of this hypothesis. Broadbent and Gregory (1963) examined the detection of a tone in noise which was presented to one ear while a string of six digits was presented simultaneously to the other ear. In one condition, Ss were instructed to ignore the digits, while in the other condition they had to recall the digits and then provide a yes–no judgment about the tone. Broadbent and Gregory (1963) found a change in d' for tone detection with digit recall when compared with no recall. But no change in the criterion index B was observed. They concluded that this result argues against Broadbent's single channel model and provides support for Treisman's attenuation model.

An important study by Treisman and Geffen (1967) attempted to provide additional support for an attenuation model. Ss had to shadow one of two dichotic messages while simultaneously tapping whenever a specific target word was presented to either ear. If the target word was presented to the shadowed ear two responses were required, tapping and shadowing. However, if the target word was presented to the rejected ear, only a tapping response was necessary. Treisman and Geffen argue that since the secondary tapping response was identical for the two messages, any differences in tapping for the two messages would be due to a failure in perception of the secondary message. Moreover, if interference was found between shadowing and tapping to targets in the primary message, the result would be due to response competition since the target word would have been perceived. The results revealed two findings. First, most of the tapping responses were made to targets in the primary rather than secondary message, thus leading Treisman to argue that there is a perceptual limit on selective listening. Second, very little response competition was found between tapping and shadowing, implying that the two responses are organized at different stages in the perceptual sequence. Treisman and Riley (1969) reported similar findings.

The results of the experiments on shadowing have been used by various investigators to argue for the operation of selective attention during perception. Although most of these studies have shown attentional effects which may be due to capacity limitations, the results are quite vague and ambiguous with regard to where these effects are occurring during information processing.

In the Broadbent and Gregory (1963) study, the instructions to recall the digits could well have resulted in S's forgetting a tone even though it was originally perceived. This could have been accentuated by any covert rehearsal of the digits. Similarly, in the Treisman and Geffen (1967) experiment, Ss could be expected to rehearse and think about the shadowed message. It would not be surprising if the target word in the non-shadowed ear was perceived, entered into short-term memory, and then forgotten, all before an overt tapping response could be made. Similar points could be raised with respect to the Treisman and Riley study. Clearly, these memory explanations are attentional in nature, but the locus of the attentional effect may be post-perceptual. Thus these experiments do not demonstrate that filtering, attenuating, or gating occurs during input and perceptual processing.

In keeping with these previous studies, we decided to carry out an attention study using the ears as channels and speech sounds as stimuli to be detected. However, we made every attempt to reduce the memory demands of the situation. The two ears woud have to be given attention by S either simultaneously or successively in the two conditions we examined.

EXPERIMENT I

This experiment involved forced-choice recognition of one of four synthetic consonant-vowel syllables. On any trial only a single stimulus was presented. This stimulus was presented only to a single ear.

Method

Subjects—Twenty-four Indiana University undergraduates who were enrolled in introductory psychology served as Ss. They were fulfilling a course requirement for experimental participation. Ss took part in three separate experimental sessions, each about 50 min in length. They received 1 hr course credit for the first session, and at their option, either 1 hr course credit, or $2.00, for each of the two remaining sessions. There were five Ss who did not perform suitably during session 1 and were not asked to return for the experimental sessions. Six Ss were run simultaneously as a group in sessions 2 and 3. There were four such groups. All Ss in a given session heard the same stimuli in the same order at the same intensities.

Stimuli—Warning signals consisted of 50 msec, 1000 Hz tones, presented at intensities well above detection threshold. The speech stimuli were four synthetic consonant-vowel syllables: /ba/, /pa/, /da/, and /ga/, each 90 msec in duration. They were produced under computer control on a parallel resonance synthesizer at Haskins Laboratories. The formant transitions into the steady-state vowel were 45 msec in duration. The fundamental frequency of these stimuli was 120 Hz. All experimental trials took place in a background of uncorrelated white noise which was on continuously throughout a block of trials. The noise level was always set at 70 dB SPL.

Apparatus—The experiment was conducted in a small experimental classroom which is used for speech perception experiments. The magnetic tapes for each condition were reproduced on a high-quality tape deck (Ampex AG-500) and presented through matched and calibrated headphones (Telephonies TDH-39 300Z). The pairs of headphones were wired in parallel and in phase to the output of a mixer-amplifier which permitted independent control of each channel of the tape deck. All signal intensities were manipulated with pairs of separate decade attenuators (Daven; Models 2511, 2513) and were monitored during the course of each experimental session with a VTVM (Hewlett Packard Model 1051). A continuous background of noise was produced with separate noise generators (Grason-Stadler Model 455B) wired to each channel.

Procedure—The first session was a practice session, designed to screen out unsuitable Ss, classify the remaining Ss, and acquaint the Ss with the task. Ss first received 16 practice trials in which they listened bin-aurally to the four stimuli, four times each, in known order. They then were given three blocks of binaural identification trials, each block containing 20 trials/stimulus. In block 1 the signal intensity was 80 dB, and no noise was used. Block 2 utilized an 80 dB signal, and block 3 utilized a 76 dB signal, both against a background of noise. These data were analyzed and Ss with very poor performance were not asked to return. The best 24 Ss were divided into 4 groups of 6 Ss, according to their performance, and asked to return for the two experimental sessions.

The experimental sessions involved two basic conditions which are indicated in Fig. 2, Simultaneous trials consist of a diotic warning signal followed after 250 msec by a 90 msec consonant presented monaurally to one ear only. The stimulus and ear were both chosen without S knowledge, subject to the constraint that each consecutive series of 16 trials contained 2 examples of each one of the four consonants on each ear (unknown to S). The *Ss* gave two responses following each trial. First S indicated which consonant he felt had been presented. Second, S indicated which ear he felt had contained the signal. Sequential trials began with a diotic warning signal followed 250 msec later by a possible consonant in the right ear (but never one in the left ear). Then after 400 msec there was another diotic warning signal followed after 250 msec by a possible consonant in the left ear (but not in the right). There was always exactly one consonant presented on a trial, and the ear order, right, then left, was known to all Ss. The S did not know which interval would contain the consonant, nor which consonant would be presented. The permutation of presentations in groups of 16 trials was identical to that used in the simultaneous conditions. The S gave two responses following each trial, as in the simultaneous conditions. In both conditions there were 4 sec to respond before the next trial. To summarize, S had to pay attention simultaneously to both ears in the simultaneous trials, but could devote his entire attention to each ear in turn in the sequential condition.

Each of the two experimental sessions began with 16 practice trials, then utilized 4 blocks of 80 trials each. Each block consisted of 5 permuted groups of 16 trials. Two of these blocks consisted of simultaneous trials, and two consisted of sequential trials, in an ABBA order for session 1 and a BAAB order for session 2. Table 1 gives the order of simultaneous and sequential conditions and the signal levels used for each session for each group of Ss. Note that signal intensities were not altered until an equal number of simultaneous and sequential blocks were finished at the previous intensities.

Results and Discussion

In Appendix 1 we list the probability of giving a correct consonant judgment for all groups, stimuli, ears, and conditions. The location judgments (i.e., which ear) are not given since they were essentially perfect in all conditions. We do not analyze the data for absolute levels of performance, since these were adjusted via intensity control so that all Ss would be at roughly the same performance level. The analyses to be reported below were carried out by calculating appropriate contrasts on the data for each S, then performing *t* tests on the resultant numbers. The data of greatest interest is the comparison between sequential (SEQ) and simultaneous (SIM) conditions. Figure 3 shows the difference between SEQ and SIM performance for each of the 24 Ss. The difference between these over-all is .0227 in favor of SIM ($t(23) = 2.8$, $p = .01$).

The over-all p(c) for the individual stimuli are /ba/: .86, /pa/: .90, /da/: .71, and /ga/: .82. These differ from each other ($t(23) = 4.92$, $p < .001$), but there was no interaction with SEQ-SIM difference. The pattern of differences among the stimuli would be expected on the basis of a distinctive feature analysis (Miller & Nicely, 1955; Liberman, 1957). On the dimension of place of production, /da/ lies between /ba/ and /ga/ and hence is highly confusable with both of these targets. On the other hand, /ba/ and /ga/ are more distinct on this dimension and hence are less confusable. Finally, note that /pa/ is the only voiceless stop and, hence, might easily be identified on this basis. Over-all, right ear p(c) = .85 and left ear p(c) = .80. This difference was not quite significant ($t(23) = 1.72$, $p = .10$) and the difference did not interact with the SEQ-SIM variable. Right ear advantages are often seen with speech stimuli, but only in situations where there is competition in the other ear (Kimura, 1967; Shankweiler, 1971).

The SEQ-SIM comparison seems to indicate no ability to allocate attention between the two ears. In order to get a better quantitative idea of the strength of this result, let us examine a simple attention model of performance. Suppose that S has an ability to respond with probability of correct response, p, when S is attending to the channel (ear) containing the presented target. The value of p may be estimated from the sequential condition, in which full attention is devoted to the ear containing the target. Now suppose in the simultaneous condition that S always attends to one ear, and attends to the other ear with probability x. If $x = 1$, then we have a non-attention model. If $x = 0$, then we have a single-channel model. We wish to put bounds on x. To do so, assume that whenever a consonant is presented on a non-attended channel S guesses at random among the four choices. Then we can write:

$$\mathrm{P(C)_{SIM}}=1/2p+1/2xp+1/2\,(1-x)\,1/4 \qquad (1)$$

and

$$\mathrm{P(C)_{SEQ}}-\mathrm{P(C)_{SIM}}=p-1/2p-1/2xp-1/2\,(1-x)\,1/4 \qquad (2)$$

In order to find a minimum value for x, let us take a value for $\mathrm{P(C)_{SEQ}} - \mathrm{P(C)_{SIM}}$ which is three standard deviations greater than that actually observed (which was in fact negative), then substitute the value of p from the SEQ condition and solve for x. We get:

$$.0016=1/2\,(.81)-1/2\,(.81)\,x-1/2\,(1-x)\,1/4 \qquad (3)$$

and solving, x = .994. Thus the probability is greater than .997 that x is greater than .994. Even though the model upon which we based this result is a bit simple minded, the bounds on x should be representative of most attention models. For example, consider an attenuation model in which one ear is fully attended and the other is attenuated so that p(c) = xp. This model gives the same bounds on x as derived in Eq. (3). As a further demonstration of the power of our result, consider the prediction for the SIM condition for a single-channel model (x = 0). From Eq. (1), we find $\mathrm{P(C)_{SIM}}$ = .53, Note that $\mathrm{P(C)_{SIM}}$ actually was .83 with a standard deviation less than .01. To summarize, we have performed a quantitative demonstration of what was perhaps obvious to begin with—essentially no attention could have been operating in this situation.

Researchers who wish to salvage attention theories in the face of these results are not entirely without recourse. First of all, it could be argued that channel capacity is not exceeded when only a single stimulus is presented in a single channel. Perhaps attentional effects would appear if both ears received stimuli on each trial. Second, it could be argued that S is able to shift his attention very quickly to the ear containing the stimulus. This switch could occur so quickly that no loss of ability to identify the stimulus takes place. Of course, all of the cues enabling identification of these stimuli are carried in the formant transitions complete within 45 msec. Previous work (see Liberman, Cooper, Shankweiler & Studdert-Kennedy, 1967) would make it appear likely that the loss of even a few msec off the front of the consonant would significantly reduce identification. However, the possibility of very fast switching cannot be discounted. It is just these considerations that led us to carry out the second experiment of this paper. We simply added an irrelevant nonconfusable consonant-vowel syllable which was always presented to any ear not receiving a target stimulus. The presence of this extra stimulus insures that channel capacity will be strained (as much as possible) and insures that fast switching of attention to the target channel will no longer be possible.

EXPERIMENT II

Method

Subjects—Twelve Ss were utilized for sessions 2 and 3, in groups of 5, 4, and 3. Other details were similar to Expt I.

Apparatus—Same as Expt I.

Stimuli—Same as Expt I with the addition of a 90 msec stimulus sounding roughly like /wu/, with formant transitions somewhat slower than those of the target stimuli.

Procedure—The successive and simultaneous trials are illustrated in Fig. 2. The trials are identical to those in Expt I except that a /wu/ was always present on any ear not containing a target stimulus. All procedural details were the same except that the third block of 80 trials in the practice session consisted of the target stimulus and the /wu/ both presented to both ears simultaneously. Also, practice trials were not used in session 3. The order of presentation of conditions and the stimulus intensities are shown in Table 2.

Results and Discussion

Appendix 2 shows the breakdown of the results. In this experiment there were location errors (which ear); the probability of correct location judgment was .89 overall for the simultaneous condition. Of course there were only negligible errors of this type in the sequential condition.

As was the case for Expt I, we do not analyze the absolute levels of performance. The comparison between sequential and simultaneous performance is shown in Fig. 4 which graphs the difference for each S. Overall the difference is .014 in favor of simultaneous. This difference is not significant ($t(11) = 1.59$, $p > .15$). The over-all p(c) for the individual stimuli are /ba/: .72, /pa/: .83, /da/: .67, and /ga/; .78. These differ from each other ($t(11) = 2.1$, $p < .07$) but the effect did not interact with the SEQ-SIM difference. The pattern of differences is similar to that found in Expt I. Overall, right ear p(c) = .74; left ear p(c) = .75. This difference is not significant, and there was no interaction with the SEQ-SIM difference. The right ear advantage normally found occurs when the stimulation on the other ear is varied; in this experiment the distractor was always /wu/, and did not vary.

As in Expt I, we can test the power of the results by putting bounds on the amount of attention that could have been present. Using the same model as proposed for Expt I we get an equation equivalent to Eq. (2). Three standard deviations added to $P(C)_{SEQ} - P(C)_{SIM}$ gives + .0124. We take p from the SEQ condition = .744, and get:

$$.0124 = 1/2\,(.744) - 1/2\,(.744)\,x - 1/2\,(1-x)\,1/4 \qquad (4)$$

Solving, x = .95. Hence the probability is at least .997 that x is greater than .95. As a further demonstration of the power of the results consider the single-channel (x = 0) prediction for the SIM condition. Using Eq. (1), $P(C)_{SIM} = .50$. Note that $P(C)_{SIM}$ was observed to be .76 with a standard deviation less than .01. These results again confirm what is perhaps obvious —there could have been essentially no attention operating in Expt II.

In the face of these results it is difficult to see how an attention view can be argued. The objections that could be raised to Expt I do not apply here, since there is a distracting consonant always present on the non-target channel(s). The S cannot switch his attention to the target channel until he has identified the signals arriving as /wu/ or “target.” This certainly cannot be done until at least the formant transitions have occurred (45 msec). But by this time the relevant information to discriminate the targets from each other will have already occurred, and the switch to the target channel will not be of value.

One alternative interpretation of these results would hold that processing proceeds in parallel up to some stage, and then stops; further processing proceeds when attention is directed to that item. Often it is proposed that processing proceeds automatically up to the level of a precategorical icon (e.g., Neiser, 1967; Morton, Crowder, & Prussin, 1969). Of course, it is difficult to know where to draw the line at which processing stops. Furthermore, even if one accepts this view, our results imply both that all of the information necessary for the decision is present at the lower level, and that this information remains intact in memory until attention is directed to it. However, if these conditions are accepted, one can explain how the simultaneous condition reaches the performance level of the successive condition. Shiffrin and Gardner (1972) were sensitive to this possibility and followed each visual stimulus with a post-mask. The mask degrades the visual representation and reduces the effectiveness of a possible later switch of attention. We considered the use of post-masks in the present experiments but decided against their use on the basis of previous work. In a backward recognition masking paradigm, Pisoni (1973) showed that consonant-vowel syllables as long in duration as those we utilized could not be masked, even by similar syllables at an ISI of zero. This result in itself tends to argue that processing for speech sounds is quickly completed through the categorical level. (We wish to argue in general that processing does not cease at some arbitrarily specified level, but continues to a level specified primarily by prior learning and the physical characteristics of sensory input. This paper is not the place for that argument, but see Keele, 1973; Jonides & Gleitman, 1972; Shiffrin & Geisler, 1973). Note that we do not claim that processing is always completed up to the "name" level in our experiments. We do argue that the partial information available to the subject in short-term memory will be identical (on the average) in the simultaneous and sequential conditions.

We propose that S does not selectively allocate attention to the two ears during processing. We suggest that findings of selective processes between the two ears are based on memorial and control processes in short-term store subsequent to perceptual processing. Our model is similar to that expressed in Shiffrin and Geisler (1973). Incoming sensory information is analyzed automatically by the processing system in a series of stages. The results of each stage are dumped into short-term memory as the processing occurs. Thus a flood of information is constantly arriving in short-term memory. Short-term memory has a limited capacity to retain all this information and, as a result, most of the arriving information will be lost from memory very quickly, within a few hundred milliseconds or less. Attentional effects will occur as S selects certain portions of the incoming material for rehearsal and coding, thereby prolonging the residence of that information in short-term memory. Furthermore, the information selected will be transferred to long-term memory and hence be recallable at a later time. Thus we view selective attention as occurring in short-term memory, following automatic processing.

Our results are of course limited to speech-like stimuli, but it should be noted that attention would be expected to have an increasing effect as the complexity of the target material increases. Thus, our results provide a stronger demonstration than a similar finding with simpler materials. Results supporting our conclusions have been reported recently by Kirstein (1971, 1974): the right ear advantage found for dichotically presented speech sounds was not affected by instructions to attend to one or the other ear.

We should note that a number of studies have utilized simple tones and have failed to find attention allocations to the two ears. Sorkin and his associates (Pastore & Sorkin, 1972; Sorkin, Pastore, & Pohlmann, 1972; Sorkin & Pohlmann, 1973; Sorkin, Pohlmann, & Gilliom, 1973) have carried out a series of studies using pure tones as stimuli. In these studies the two ears have been found to act as independent processors of tonal information. Furthermore, when different frequencies were treated as input: channels, these also appeared to be processed independently.[3] Egan and Benson (1966) carried out a study testing detection and lateralization of tones in noise. They found that advance knowledge of the ear

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[3] Sorkin, Pohlmann and Gilliom (1973) found one apparent exception to the general rule. Two tones presented simultaneously at different frequencies appeared to interact and reduce performance. Sorkin, *et at.* argued for an attentional explanation of this result, but high level masking between these tones could also have accounted for the finding. We believe masking is likely to be the correct explanation. However, the appropriate control to test this hypothesis, a two-tone presentation with a single frequency listening instruction, was not present in the original experiment. Hence additional research will be needed to settle this issue.

of input of the possible target tone did not appreciably affect detection accuracy. This finding with simple tones is essentially identical to our findings using speech stimuli.[4]

Moore and Massaro (1973) had *Ss* judge two dimensions of a single tone: pitch and loudness. They found that these judgments could be made independently and as well as judgments made on only one dimension at a time.[5] Moray (1973) has also reported a recent analysis of an experiment involving a rapid series of dichotic tone detections. He found that the two ears act essentially as independent processors of incoming information. In light of this new analysis Moray suggested reconsideration of his previous conclusions regarding single-channel or attenuation models for dichotic listening.

In summary, a central topic in information processing in the last twenty years has been the locus of attention. Does S have differential control over the amount of perceptual processing occurring in various input channels? The quality of information processed and utilized by the subject was not different whether one or two ears required simultaneous attention. Thus, the two experiments in this report support the contention that differential control, or selective attention, does not occur during perceptual processing from the two ears. This conclusion appears to be true when relatively complex speech-like stimuli are utilized, and to be true whether one stimulus is presented only to one ear, or two stimuli are presented to both ears simultaneously. The results parallel those from a series of similar studies in other modalities and between modalities. Taken together the results suggest quite generally that selective attention does not operate during perceptual processing.

Appendix

APPENDIX 1

Experiment I: R = Right Ear, L = Left Ear, M = Mean

	SEQ			**SIM**		
	R	**L**	**M**	**R**	**L**	**M**
Group 1 /ba/	.929	.646	.788	.888	.596	.742
/pa/	.988	.621	.765	.833	.692	.763
/da/	.946	.625	.785	.946	.617	.781
/ga/	.900	.688	.794	.883	.638	.760
M	.920	.645	.783	.888	.635	.761
Group 2 /ba/	.946	.954	.950	.938	.950	.944
/pa/	.992	.988	.989	.988	.992	.989
/da/	.679	.713	.696	.775	.758	.767
/ga/	.833	.854	.844	.879	.833	.856
M	.863	.877	.869	.895	.883	.889

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[4] It should be noted that the sequential condition did not cause S to confuse the target and nontarget intervals. It was always obvious to S which interval contained a target and which did not (though, of course, the particular target was difficult to recognize). This was true whether or not a distracting stimulus appeared on the nontarget ear. For this reason the sequential condition should logically be equivalent to a simultaneous conditon in which the subject is told before each trial which ear will contain the target. We carried out such a condition as a pilot experiment and found results equivalent to those reported above. That is, advance knowledge of the target ear in the simultaneous condition did not affect performance.

[5] Their results appear to be in slight conflict with a similar study briefly mentioned by Lindsay (1970). However, a procedural difficulty could have accounted for the single-channel like effects reported by Lindsay: When only one dimension was to be reported, the other(s) did not vary. Moore and Massaro varied all dimensions in all conditions so that only an instructional difference, and not a stimulus difference, varied between conditions. In addition, Lindsay utilized a post-cuing technique which could have allowed memory effects to take place.

		SEQ			SIM		
		R	L	M	R	L	M
Group 3	/ba/	.954	.925	.939	.954	.995	.950
	/pa/	.929	.933	.931	.938	.942	.939
	/da/	.717	.788	.752	.788	.817	.802
	/ga/	.829	.912	.871	.908	.925	.917
	M	.857	.889	.873	.897	.907	.902
Group 4	/ba/	.721	.758	.739	.833	.783	.808
	/pa/	.912	.904	.908	.946	.904	.925
	/da/	.475	.525	.500	.578	.650	.583
	/ga/	.671	.767	.719	.792	.817	.804
	M	.695	.739	.717	.772	.789	.780
Total	/ba/	.888	.821	.854	.903	.819	.869
	/pa/	.935	.861	.898	.926	.882	.904
	/da/	.704	.663	.683	.756	.710	.733
	/ga/	.808	.805	.807	.866	.803	.834
	M	.834	.788	.811	.863	.804	.833

APPENDIX 2

Experiment II: R = Right Ear, L = Left Ear, M = Mean

		SEQ			SIM		
		R	L	M	R	L	M
Group 1	/ba/	.690	.720	.705	.740	.740	.740
	/pa/	.870	.840	.855	.885	.865	.875
	/da/	.585	.685	.635	.620	.695	.658
	/ga/	.790	.895	.818	.845	.785	.815
	M	.734	.773	.753	.773	.771	.772
Group 2	/ba/	.725	.669	.697	.738	.719	.728
	/pa/	.888	.838	.863	.869	.838	.853
	/da/	.681	.656	.669	.669	.675	.672
	/ga/	.675	.813	.744	.775	.825	.800
	M	.742	.744	.743	.763	.764	.763
Group 3	/ba/	.742	.725	.733	.750	.750	.750
	/pa/	.725	.733	.729	.733	.783	.758
	/da/	.733	.758	.746	.633	.725	.679
	/ga/	.675	.750	.713	.717	.725	.721
	M	.719	.742	.730	.708	.746	.727
Total	/ba/	.715	.704	.709	.742	.735	.738
	/pa/	.839	.813	.826	.842	.835	.839
	/da/	.654	.693	.673	.639	.696	.668
	/ga/	.728	.810	.767	.789	.783	.786
	M	.733	.755	.744	.753	.763	.758

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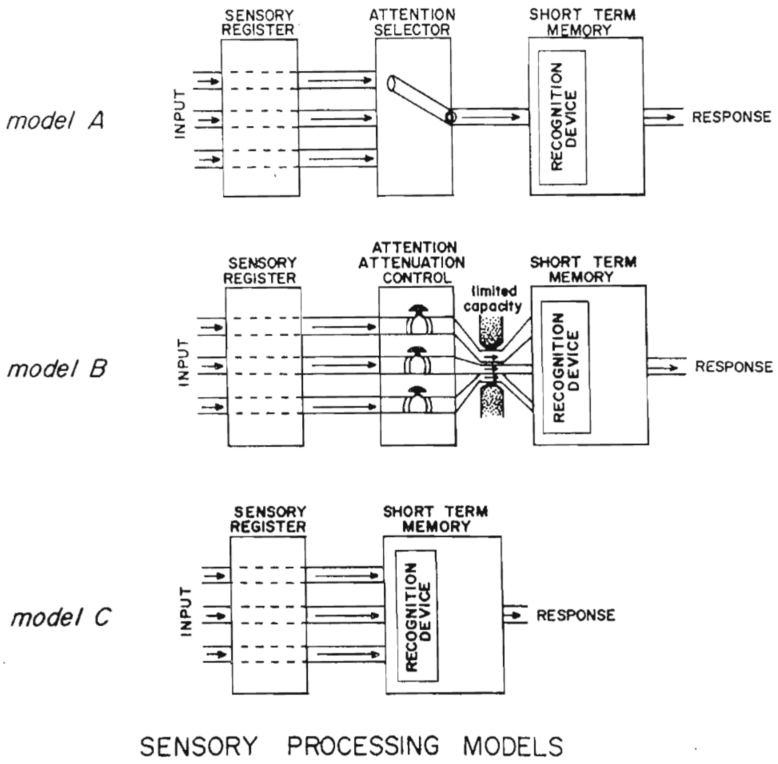

Fig. 1.

Models of sensory information processing. Top panel (a): single channel model. Middle panel (b): attenuation model. Lower panel (c): nonattention “independent” processing model.

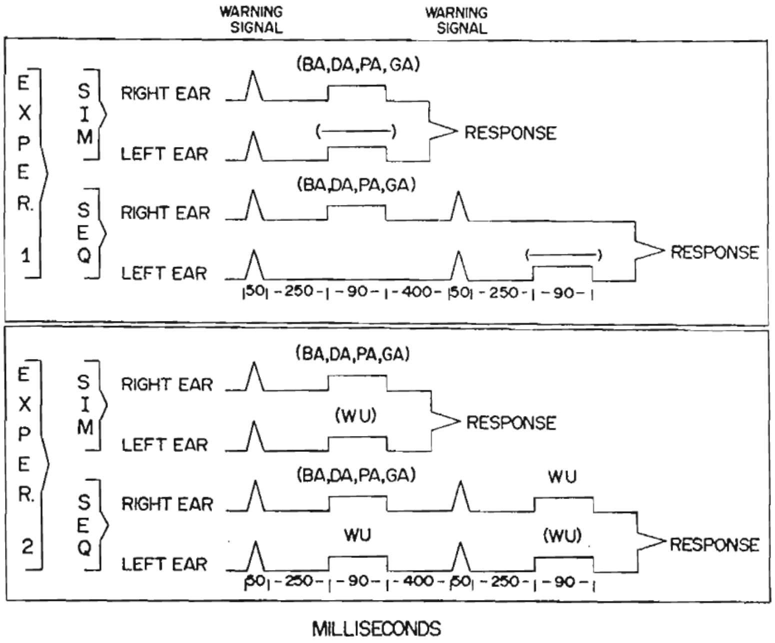

Fig. 2.

Trial sequences for Expts I and II. Timing is shown on the horizontal axis. When four stimuli are listed, only one is chosen for presentation (at random). If stimuli are given in parentheses, then the events depicted happen in that ear with probability ½ and in the other ear with probability ½.

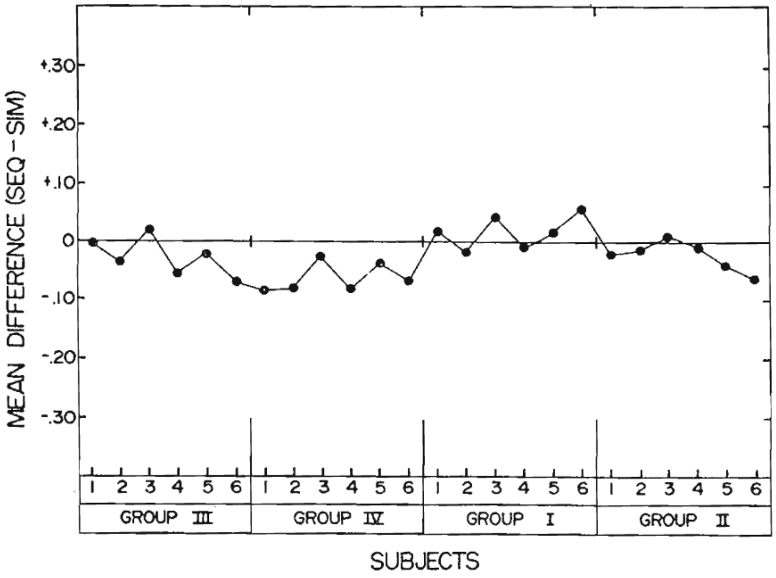

Fig. 3.

Data from Expt I. For each subject, the graph depicts the probability of correct consonant judgment during the sequential condition minus the probability of correct consonant judgment during the simultaneous condition. Points above the solid line represent a possible attentional effect.

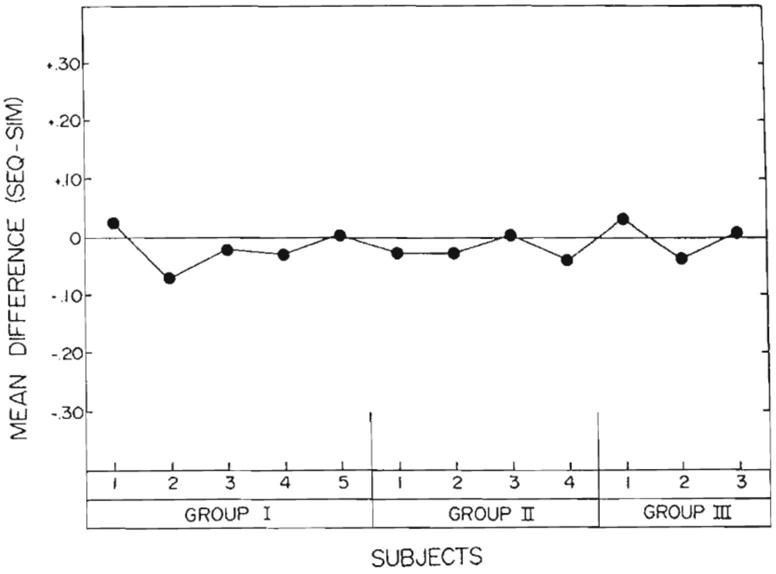

Fig. 4.

Data from Expt II. For each subject, the graph depicts the probability of correct consonant judgment during the sequential condition minus the probability of correct consonant judgment during the simultaneous condition. Points above the solid line represent a possible attentional effect.

TABLE 1

Order of Conditions and Signal Levels (in dB) Used for Each Group of Subjects in Experiment I. Each Number Refers to the Consonant Intensity for a Block of 80 Trials. Noise Level was Always 70 dB

	Session 2					**Session 3**				
Group	**Practice**	**SIM**	**SEQ**	**SEQ**	**SIM**	**Practice**	**SEQ**	**SIM**	**SIM**	**SEQ**
1	80	76	76	76	76	78	74	74	74	74
2	80	76	76	76	76	76	76	76	74	74
	Practice	SEQ	SIM	SIM	SEQ	Practice	SIM	SEQ	SEQ	SIM
3	80	80	80	80	80	78	76	76	76	76
4	78	78	78	78	78	78	78	78	78	78

TABLE 2

Order of Conditions and Signal Levels (in dB) Used for Each Group of Subjects in Experiment II. Each Number Refers to the Consonant Intensity for a Block of 80 Trials. Noise Level was Always 70 dB

	Session 2					**Session 3**			
Group	**Practice**	**SIM**	**SEQ**	**SEQ**	**SIM**	**SEQ**	**SIM**	**SIM**	**SEQ**
1	80	78	78	76	76	78	78	76	76
3	80	80	80	78	78	80	80	78	78
	Practice	SEQ	SIM	SIM	SEQ	SIM	SEQ	SEQ	SIM
2	80	80	80	78	78	80	80	78	78