DOCUMENT RESUME

ED 113 639 95 CG 010 143

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TITLE Division of Attention Relative to Response Between Attended and Unattended Stimuli.
SPONS AGENCY National Center for Educational Research and Development (DHEW/OE), Washington, D.C. Regional Research Program.
BUREAU NO BR-2-E-003
PUB DATE Jun 73
GRANT OEG-5-72-0025(509)
NOTE 31p.; Because of copyright, Appendix II has been removed from this document, and is not included in the pagination
AVAILABLE FROM Appendix II is available as pp. 231-234 of Behavioral Research Methodology and Instruments, Vol. 5(2), 1973

EDRS PRICE MF-$0.76 HC-$1.95 Plus Postage
DESCRIPTORS *Attention; *Auditory Discrimination; Auditory Perception; Behavioral Science Research; Recall (Psychological); *Response Mode; Selection; Semantics; *Stimulus Behavior; *Task Performance

ABSTRACT

Research was conducted to investigate two general classes of human attention models, early-selection models which claim that attentional selecting precedes memory and meaning extraction mechanisms, and late-selection models which posit the reverse. This research involved two components: (1) the development of simple, efficient, computer-oriented methods for generating rigorously precise stimulus material (these required human attention experiments); and (2) the execution of two experiments which employed computer-generated stimuli. The first experiment examined the filtering characteristics of attention mechamisms when subjects were required to select from either acoustically or semantically similar competing messages. Results show that semantic similarity is disruptive only at a slow presentation rate, while the effects of acoustic similarity do not depend on presentation rate. In the second experiment, subjects performed a tone detection task in one ear, while simultaneously monitoring a digit sequence presented in the opposite ear. Digits were recalled following presentation. Tone detection performance decreased as the number of digits to be recalled increased. Both findings are interpreted as supporting early-selection attention models. (Author)

Final Report

Project No. 2-E-003
Grant No. OEG-5-72-0025 (509)

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DIVISION OF ATTENTION RELATIVE TO RESPONSE BETWEEN ATTENDED AND UNATTENDED INFORMATION STIMULI

June 1973

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Office of Education

National Center for Educational Research and Development
(Regional Research Program)

Project No. 2-E-003
Grant No. OEG-5-7?-0025(509)

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Barry H. Kantowitz, Principal Investigator

Abstract

Research was conducted to investigate two general classes of human attention models: Early-selection models claim that attentional selectivity precedes memory and meaning extraction mechanisms while Late-selection models posit the reverse. This research involved two components: (A) The development of simple, efficient, computer-oriented methods for generating rigorously precise stimulus material required human attention experiments, and (B) the execution of two experiments which employed computer-generated stimuli.

The first experiment examined the filtering characteristics of attention mechanisms when required to select from either acoustically or semantically similar, competing messages. Two competing messages were presented dichotically at either a fast (2 words/sec) or slow (1 word/sec) rate. A probe technique was used to assess recall of attended and unattended messages. Results showed that semantic similarity was disruptive only at slow presentation rate, while effects of acoustic similarity did not depend on presentation rate. These findings were interpreted as supporting an Early-selection attention model with hierarchical filtering.

In the second experiment subjects performed a tone detection task in one ear, while simultaneously monitoring a digit sequence presented in the opposite ear. Digits were recalled following presentation. Tone detection performance decreased as number of digits to be recalled increased. This effect was considered to be localized in perceptual, rather than memory, stages and was interpreted as further support for Early-selection attention models.

3/4/2.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Page

Project No. 2-E-003
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DIVISION OF ATTENTION RELATIVE TO RESPONSE BETWEEN ATTENDED AND UNATTENDED INFORMATION STIMULI

Barry H. Kantowitz, Principal Investigator

INTRODUCTION

The research described in this final report was aimed at distinguishing between two general classes of attention models. The early-selection models such as those of Broadbent (1958) and Treisman (1969) claim that attention focuses on the stimulus representation and limits the amount of information available for later processing; thus attention serves to gate out or attenuate irrelevant information thereby protecting the organism from information overload. The late-selection models such as those of Norman (1969) and Deutsch and Deutsch (1963) claim that all stimulus information is processed so that a memory system is an integral part of the attention process. Meaning is extracted from incoming signals before selection is accomplished.

Much of the data base form which these models have been derived have utilized a dichotic listening task. Separate messages are presented via earphones to left and right ears. Sometimes subjects are required to repeat the message in one ear (shadowing) or sometimes only to attend (monitor) a specified ear without vocal coding. A serious issue in dichotic stimulation concerns the methods used to generate dichotic stimulus tapes. It is important that messages in both ears by equated for intensity, duration and onset time. Since humans are quite adept at auditory localization, small temporal differences in onset asynchrony may provide important cues in the dichotic stimulation task. It is essential that such onset asynchrony be carefully controlled and limited to less than one msec. Most prior research has not maintained this standard and a major accomplishment of this project has been the development and testing of a minicomputer system to generate dichotic stimuli to these specifications. This system is described in a following method section of the report.

The first major model of attention was proposed by Broadbent (1958) in an influential text entitled Perception and Communication. A later text, Decision and Stress (Broadbent, 1971) discussed modifications of the model based upon accumulated evidence especially that of Treisman and her colleagues. Broadbent originally posited a filter mechanism which prohibited the flow of unattended information while passing attended information. However, Broadbent's model did not remain long unchallenged. Gray and Wedderburn (1960) used the dichotic listening paradigm to present words which were divided between both channels. Thus, the left ear might be presented with the syllables one tir three, while the right ear received ex two pate. If a filter existed which completely rejected the unattended channel, subjects should be unable to report complete words. Findings were unequivocal with subjects being able to attend to both ears to report complete words, even at fast presentation rates. Unless we allow the filter to switch back and forth between channels at very high rates, the filter model seems questionable. Treisman (1964, 1969) has suggested an attenuation model to replace the rejection model of Broadbent. Thus, an unattended message is still received but its intensity is greatly reduced. Therefore, the information in the unattended channel can be retrieved if it is high priority (e.g., subject's name or contextually relevant).

Broadbent and Gregory (1963) conducted an experiment aimed at distinguishing between rejection versus attenuation of the unattended channel. Using the dichotic listening method, digits were fed into the listener's left ear and burst of noise into his right ear. Digits were presented at a rate of 2 per sec in series of six-item lists. Half of the noise bursts contained a pure tone of 1000 cps. The observer was required to judge if the tone had been present within a noise burst. In condition DA (divided attention) subjects were required to first write down the six digits before rating the presence or absence of the tone. In the C (control or concentrated attention) condition the digits were to be ignored. In terms of the theory of signal detection (TSD) a filter or blocking model predicts that listener sensitivity (d') should be unchanged for both conditions while a large increase in receiver criterion (beta) should occur in the unattended channel. Attenuation theory predicts a change in detectability (d'). Broadbent and Gregory found condition C to result in greater receiver sensitivity and concluded that Broadbent's earlier formulation was incorrect. However, there were two flaws in the Broadbent and Gregory experiment. First, in condition DA, the report on the tone was delayed until the digits had been recalled. Part of the observed decrement may therefore be due to memory loss rather than change in receiver sensitivity. This illustrates the danger of trying to study attention as an isolated portion of human behavior. Second, utilization of channel capacity to memorize the digits may interfere with tone processing on a higher (e.g., non-sensory) level, yielding a decrement despite the total availability of the tone as a sensory event. A tone detection experiment conducted in the present research was designed to remove these difficulties.

Both filter and attenuation models are similar in that selection occurs at an early stage of information processing. Both models claim that attention operates on the stimulus representation and limits the amount of information available for later processing. Another class of attention models proposed by Deutsch and Deutsch (1963) and Norman (1969) locates the selection mechanism further back in chain of processing stages. These models permit selection only after meaning has been extracted from incoming signals. Thus a memory sub-system is an integral part of these late selection models. Now models will be compared in the context of a recent experiment conducted by Murray and Hitchcock (1969).

Murray and Hitchcock used a dichotic listening task but rather than have their subjects recall an entire string of digits, they tried to reduce memory load by using a probe technique. Five pairs of digits were presented dichotically at rates of either one or two pairs per second. Following the list presentation, one of the digits from one of the two lists was repeated (probe digit) and the subject was instructed to recall the digit that had followed the probe digit in the same ear. Each ear was tested with equal probability so that on half the trials an unattended message was probed (tested). The other independent variable of interest was type of coding for the shadowed message. In the NC (not-code) condition, subjects voiced the word "the" as each pair arrived; this was aimed at preventing subvocal rehearsal. In the SC (silent-code) condition subjects were to shadow one ear by saying the digits silently to himself. Finally, in the MC (mouth-code) condition subjects silently articulated the digits with observable oral movements.

Results showed probe recall for uncoded messages to be unaffected by the type of coding used for the other message. Coded messages were recalled better than uncoded messages. When serial position probed (positions 2-5) is varied, primacy and recency effects were less pronounced for the fast presentation as compared to the slow rate although there was no difference in overall recall score for the two rates. Two ancillary experiments showed recall to improve when subjects were informed in advance which of the two messages would be probed; when subjects were required to copy the unprobed messages with ear being probed known in advance, recall of the probed message was poor.

Murray and Hitchcock interpreted their findings as supporting an auditory storage system, called echoic memory with the duration of this sensory memory trace being directly dependent upon the attention paid to the incoming stimulus material. Making a verbal response, however, as with the dichotic messages, prevents S from responding to the uncoded lists. Murray and Hitchcock argue that this is further demonstrated by comparing the results of the main experiment with those of the first subsidiary experiment where Ss knew in advance which message would be tested. Here S could totally ignore the other message, and here recall of the coded message was maximal. Subvocal coding is therefore not enough to ensure maximal recall.

The possibility remains, however, that the poorer recall in the main experiment as compared to the "know in advance" experiment is a result of Ss trying to switch attention. Murray and Hitchcock argue against this possibility by presenting data on the number of intrusions (digit recalled from wrong ear) from the uncoded into the coded lists, for the main and the "know in advance" experiments. The number of intrusions is small. For silent code (SC), mouth code (MC), and "know in advance" conditions, there were more intrusions for the fast rate than for the slow rate, although no statistical test is reported. These results may be a result of a difference in coding efficiency for fast as opposed to slow rates depending upon rehearsal strategies, as suggested by Murray and Hitchcock. This interpretation is given support by the presence of a significant rate x serial position interaction. Further, by inspection of Murray and Hitchcock's data it may be seen that greater differences (as a function of rate) in number of intrusions occurred at serial position 5 than at other positions. Therefore, it appears that a greater number of errors of intrusion occur for the most recently presented pair when presented at the fast rate.

One possible explanation of this might be to argue that coding affects not perception, but memory, by ensuring a more permanent trace. If a decay hypothesis for the echoic memory trace is assumed, then the trace should be "stronger" (in some sense) for more recently presented material. Therefore, a coded as opposed to an uncoded item should be recalled better, and the difference in recall for coded as opposed to uncoded items should increase as recall is tested from more recent or less recent items. Further, since the probe digit followed the final pair of a list after the same period of time as the inter-pair interval (i.e., one second for slow rate and a half second for the fast rate), at fast presentation rates the "echoic" or trace would be stronger or less decayed when the probe was presented than for the slow rate. In summary, this argument holds that the intrusions represent an interference between verbal short-term memory and echoic memory.

This is essentially Norman's (1968, 1969) position although Norman holds that the interaction takes place within the same memory system. Norman (1969) maintains that other theories of attention such as proposed by Broadbent (1958) and Treisman (1964), require a sensory storage system prior to attention. This has variously been called the S-system (Broadbent, 1958), preperceptual store (Turvey, 1966), and (for audition), echoic memory (Neisser, 1967). After the subject is instructed to recall a message, he is able to retrieve the contents of this storage system. However, after a long delay, the contents of this system are no longer available, since this material decays over time and/or is degraded by interference.

Norman maintains that selection operates after the analysis of incoming messages has occurred on the basis of both physical characteristics and meaning. He argues (Norman, 1969) that the meaning of a message cannot be determined without reference to memory, and if meaning is extracted from all signals, then all messages must get analyzed through permanent memory and must also be present briefly in short-term memory. The prediction follows that the subject should remember stimuli to which he has not attended, and he presents evidence which supports this prediction. Norman had subjects shadow English words presented to one ear. They were then tested for their memory of numbers which had been presented to their other ear. The results indicated that Ss were unable to recall the digits if they were required to shadow for 20 seconds before being asked to recall the digits. After immediate recall instructions, however, Ss did remember some digits. Norman interpreted these results as indicating that non-attended information gets into short-term memory, but is not transferred to long-term memory. Although the act of shadowing denies S the use of rehearsal which is deemed necessary to retain material for any length of time, the short-term memory is still operative. Thus, Norman's model of attention makes the same predictions: that coded information should be recalled better than uncoded information because the coding itself guarantees retrieval; that these differences should be greater as recall is tested from more recent to less recent items; and that at fast presentation rates more intrusions of uncoded information into coded information should occur than at slow rates.

An additional explanation of these intrusions is also possible. Treisman (1964) suggested that messages to which S does not attend are attenuated, so that for a dichotically presented pair of messages the attended message (signal) is more intense than the unattended message (noise). If this is so, and if material in echoic memory is less likely to be retrieved as the period between presentation and recall increases, then the signal-to-noise ratio should be less for recently presented messages than for messages presented earlier. Implicit in this argument is the assumption that both signal and noise decay at the same rate. From this position it may also be predicted that for more recent items there should be more intrusions from the unattended to the attended channel. In addition, at fast rates of presentation, more intrusions should occur since there has been less time for decay of the two signals. Treisman proposed that selection reflected a hierarchy of tests, the lowest test being an analysis based upon gross physical characteristics of the message such as pitch and intensity. She proposed on the basis of empirical findings (Treisman, 1964), that the initial selection of messages occurred at this low level of processing and that only later in processing did an analysis of meaning occur. From this position additional predictions regarding intrusions of unattended material into recall of attended material may be made which do not follow from Norman's model. More intrusions of items from the unattended to the attended ear should occur when the messages consist of similar sounding words than when they are different sounding; in addition, this should be more likely to occur at the fast, rather than slow rates of presentation, since, as argued above, at slow rates the effects of attenuation should be more marked. Also of interest are the effects of semantic relationships between the attended and unattended messages. If higher order tests are necessary to analyze meaning, then these tests should take more time than the gross physical analyses. Posner and Mitchell (1967) have demonstrated in several experiments that "same" responses for two physically identical visual stimuli were 70 to 100 msec faster than "same" responses to pairs of stimuli having only the same name. These studies clearly suggest that Ss can respond faster on the basis of physical characteristics than they can on the basis of higher order characteristics such as meaning. To the extent that more time is available for these higher order tests at slow rates of presentation, as opposed to fast rates, then intrusions from the unattended to the attended message should be more likely for synonyms at the slow rate, than at the fast rate, since there is enough time between items to allow an analysis based upon meaning. These additional predictions seem to be inconsistent with the view that interference occurs within a single short-term storage system. If items in short term memory are stored on the bases of meaning rather than on the basis of sensory factors such as duration, pitch, intensity, i.e., gross physical features, as seems to be indicated by evidence reported by Miller (1956), Norman (1966), and Waugh and Norman (1965), and if attended and unattended information are both held in this same system, then intrusions across channels should occur not on the basis of sound, but instead on the basis of meaning.

METHODS

Word Experiment

Dichotic stimulus tapes were prepared using a minicomputer system developed in this project (Knight & Kantowitz, 1973). This article is included in the appendix and gives a detailed description of the computer method. The following is a simplified description of the system and its advantages.

The typical non-computerized procedure for construction of dichotic tapes (e.g., Murray & Hitchcock, 1969) first records one channel on a stereo tape recorder, perhaps in time to a metronome. The second channel is then recorded manually so that synchronization depends upon the skill of the recordist. A visual check is then made by running the tape and displaying both channels on an oscilloscope. This crude procedure yields large and variable onset asynchronies. Other mechanized approaches require either large computers or special purpose equipment. The present procedure requires only a small minicomputer (8K of memory) which is a great advantage since such computers are becoming more and more common in the psychological laboratory.

The system can be used by an operator with no special technical training. It operates in two stages. In Stage 1 monaural words are digitized, adjusted to a fixed preset length and stored. In Stage 2 pairs of adjusted words are recorded on audio tape. The tapes used in this experiment had onset asynchronies less than 100 microsecs and intensity of 70 db SPL $\pm$ 1 db.

Words were common one-syllable words selected from Thorndike-Lorge frequency categories AA and A. These were recorded by a phonetician (standard American dialect) and then processed by computer. Word length was set to 400 msec. Dichotic tapes were recorded directly from the computer onto a Revox-A-77 tape recorder which was later used to present dichotic lists to subjects.

Two groups of 16 female undergraduate subjects were used. One group had lists presented at a Fast rate (2 word pairs/sec) and the other had a Slow rate (1 pair/sec).

A trial consisted of five dichotic word-pairs preceded by a monaural burst of white noise. Figure 1 shows a schematic rendering of a trial. After the last word pair, another noise burst was presented binaurally. This was followed by a binaural probe word, which had appeared previously in one of the five dichotic pairs. Subjects were given 10 sec to write down the word which followed the probe word in the same ear as the probe word. Thus, for example, if the five pairs were 12, 34, 56, 78, 90, where digits 13579 occurred in the left ear and digits 24680 occurred in the right ear, and the probe was the digit 3, a correct response would have been the digit 5.

Four test tapes of 56 trials were used. The first 8 trials of each tape were for practice and used only digits. The remaining 48 trials

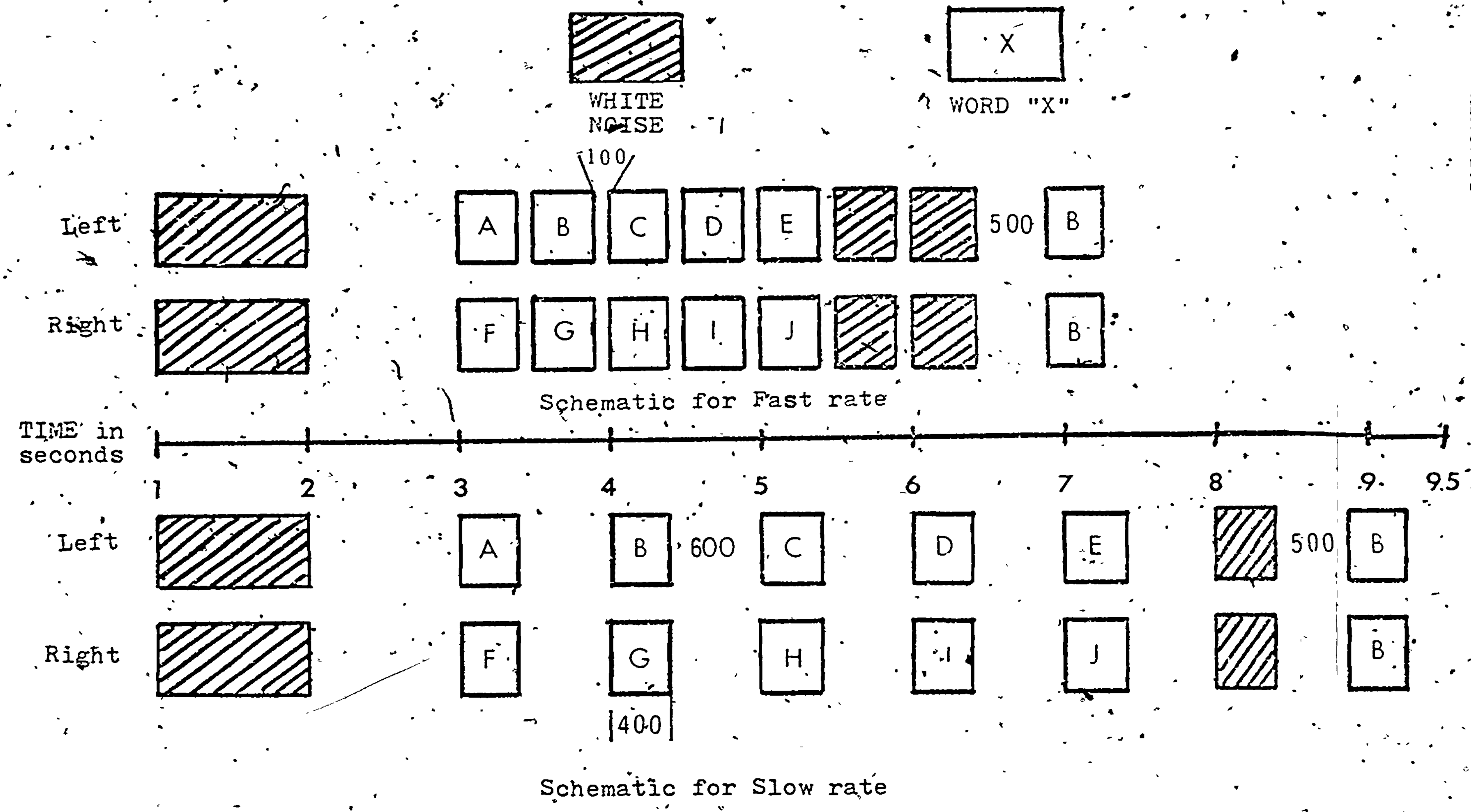

Figure 1. Trial schematics for Fast and Slow presentation rates.

used word pairs which exhibited one of four types of relationship: Terminal (T)-both words shared the same final phoneme, e.g., GAIN-RAIN; Initial (I)-both words shared the same first phoneme, e.g., VAGUE-VASE; Associates (A)-both dichotic words were high-frequency associates, e.g., NIGHT-DAY; Synonyms (S) each word in a dichotic pair was a synonym of the other, e.g., WIDE-BROAD. The type of relationship used, i.e., T, I, A, or S, remained constant for 48 trials. On 24 trials the preceding monaural, white noise, warning signal occurred on the left ear, indicating that subjects should attend to the left ear. However, no vocalization (shadowing) was required. On half of these 24 trials, the probe word was drawn from the right (unattended) ear and on half from the attended ear. On the remaining 24 trials, the right ear was attended with probes again being drawn 12 times from each ear. During each of these 12 trials, each serial position was probed 3 times; note that since the last serial position could not be probed (since nothing followed it) only four serial positions could be tested.

Subjects were tested in groups of four. Each subject sat in his own booth and could not communicate with other subjects. A $5 bonus was given to the subject who recalled the greatest number of correct attended-channel words. Instructions noted that the unattended channel would be tested also. (See Appendix I.)

Tone Experiment

Stimulus tapes for this experiment were prepared by the Hybrid Computing Facility of Wright-Patterson Air Force Base. A standard signal detection task with .50 signal probability, 1 khz sinusoidal tone, and a signal/noise ratio of 16 db was recorded on one channel. Signal duration was .5 sec. Digit lists were recorded on the other channel. White noise and digits commenced simultaneously. The signal, when it appeared, occurred exactly in the middle of the digit list. Digits were presented at a rate of 2/sec.

Sixty-nine subjects tested for normal hearing participated in all four experimental treatments. In the divided attention (DA) condition, subjects were required to attend to both digit and signal-detection tasks. Three DA conditions had list lengths of two, six and ten digits. In a control (C) or concentrated attention condition, a six-digit list was presented but subjects were instructed to ignore the digits and to attend only to the signal-detection task. At the end of each trial, subjects first reported the presence or absence of the tone and gave a confidence rating on a four-point scale; then, for DA conditions they wrote down the digits in the order in which the digits occurred on that trial. Each condition consisted of 30 trials.

RESULTS

Word Experiment

Four dependent variables proved interesting: number of intrusions, number of correct responses, number of errors from attended ear, number of errors from unattended ear. Number of external errors and number of null responses although examined were not useful indicants.

Intrusions.— An intrusion is defined as a response from the correct serial position but incorrect channel. Thus, if a trial had digit pairs of 12, 34, 56, 78, 90 and 3 was the probe digit, 6 would be an intrusion. Table 1 contains intrusions for each list relationship as a function of presentation rate. While more intrusions occurred at the Slow rate, this effect was not statisticall reliable, F $(1,28) = 1.85$, $p > .05$. Effects of list relationship were significant, F $(3,84) = 26.13$, $p < .001$. While all lists differed at the .01 level of significance by Newman-Keuls test (except S vs. A at .05 level), a contrast comparing acoustic lists (T and I) with semantic lists (S and A) revealed significantly more intrusions for acoustic lists, F $(1,84) = 98.38$, $p < .001$. Of greatest importance is the interaction between presentation rate and list relationship, F $(3,84) = 3.56$, $p < .05$. While acoustic lists were unaffected by rate, more intrusions occurred at the Slow rate for semantic lists. This result supports the attenuation model of Treisman. At the Fast rate only acoustic tests can be performed but at the Slow rate, semantic tests can also be performed.

As was expected, significantly more intrusions (668 vs. 360) occurred when the unattended channel was probed, F $(1,28) = 44.42$, $p < .001$. Intrusions generally increased with serial position: 150, 204, 371, 303, F $(3,84) = 3.10$, $p < .05$. A contrast comparing the first two and last two serial positions was significant, F $(1,84) = 96.52$, $p < .001$, indicating more intrusions for later serial positions. Number of intrusions for each list relationship, for attended and unattended channels, is displayed in Figure 2 as a function of probe serial position, i.e., serial position one means that the intrusion occurred in the second pair of words. These curves are pooled over Fast and Slow rates, since no rate X serial position interaction was obtained, F $(3,84) = 2.64$, $p < .05$, contrary to the findings of Murray and Hitchcock (1969). This implies that attention does not affect memory by ensuring a more permanent trace but instead effect perception at the time of input. The finding of Murray and Hitchcock of more intrusions for the most recently presented pair at the Fast rate, is most likely an artifact of the unequal delay between the probe digit and the last dichotic pair presented which was confounded with rate. In the present study, this interval was constant (1.5 sec) for both rates (see Figure 1). In the present experiment, intrusions do not appear to result from an interference between echoic and verbal short-term memories. In Figure 2, there is a decrease in the number of intrusions for the last serial position relative to the third serial position (although there are still more intrusions than for the first serial position) for most lists; an exception is the rise in intrusions for the A and T lists when probed on the unattended channel. The possibility that serial position three did not benefit from either recency or primacy short-term memory effects may account for the intrusion rate peaks at this serial position. The significant three-way interaction (list type X attended-unattended channel X serial position), F $(9,252) = 8.69$, $p < .001$, may largely be attributed to the failure to find an intrusion rate peak for semantically related lists when the unattended channel was probed.

Table 1

Number of Intrusion Errors for each List Type as a Function of Presentation Rate

	List Type				
	S	A	T	I	Σ
Presentation Rate					
Fast	68	89	147	182	486
Slow	103	129	148	162	542
Σ	171	218	215	344	

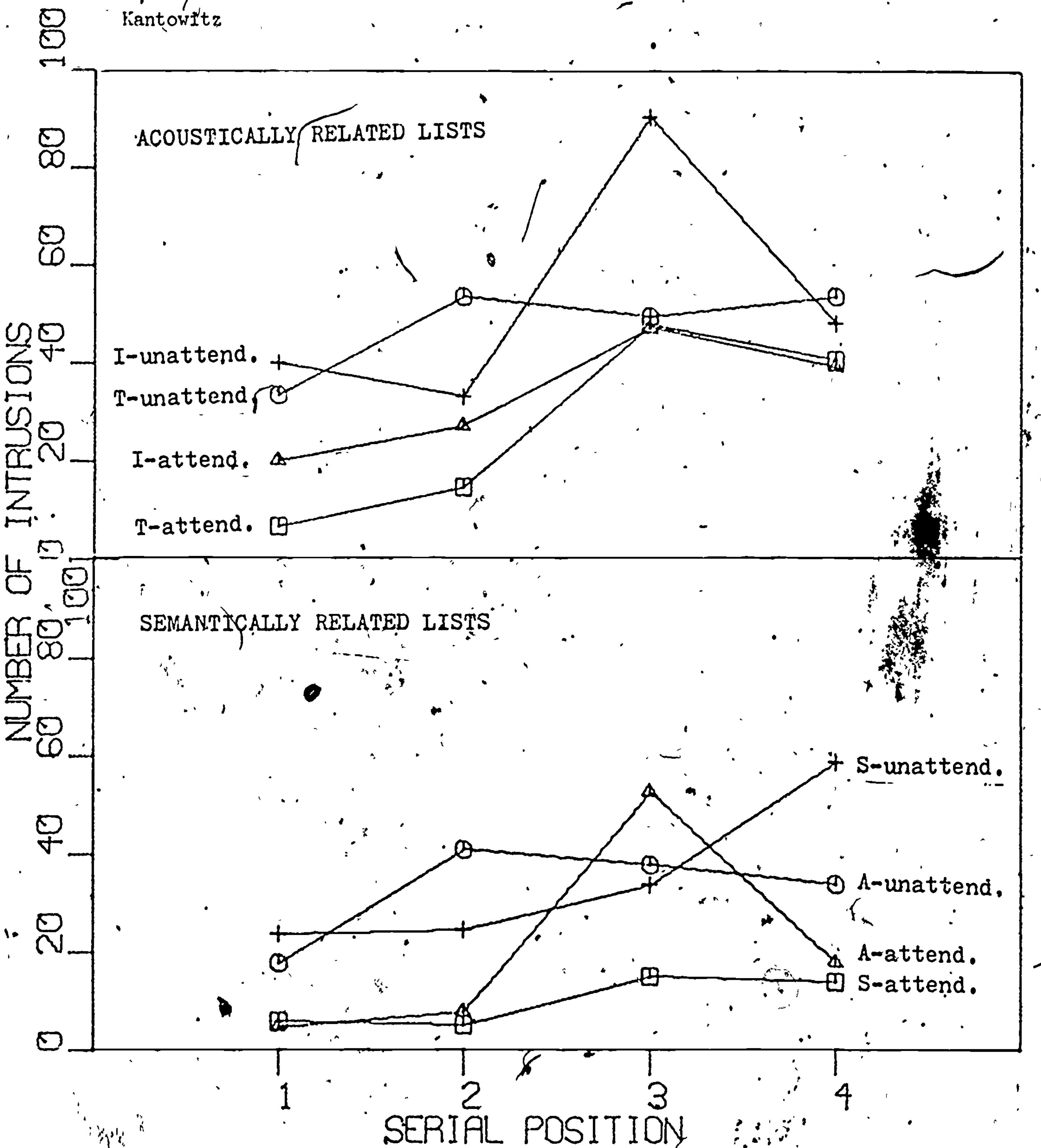

Figure 2. Serial position effect for intrusions as a function of List type and Attended vs. Unattended channels.

Correct responses.— A correct response is defined as the word following the probe word in the same channel, e.g., if digit pairs 12, 34, 56, 78, 90 were presented and 3 was the probe digit, 5 would be the correct response. The overall proportion of correct responses was quite low (.24). This is a joint effect of the task difficulty and the use of experimentally naive subjects with little practice in dichotic listening. Many studies of dichotic listening have used small numbers of extremely well-practiced subjects. Since a major aim of this study was the investigation of intrusion errors, a large number of unpracticed subjects was used.

No difference was found in the number of correct responses as a function of presentation rate with 752 correct responses for the Slow rate and 745 for the Fast rate, F (1,28) < 1.0. Since the time from offset of the last (fifth) word-pair to probe onset was equated for both rates (see Figure 1), this result implies that overall, neglecting serial position effects, the greater inter-pair delay at the Slow rate was counteracted by rehearsal during presentation. Correct responses were fewest for the S list (305) while the A list (416) had the best performance, and the acoustic list relationships were intermediate (T:395, I:381), F (3,84) = 9.38, p < .001. Newman-Keuls test showed the S list to be reliably poorer than all other lists (p < .01), while A, T, and I lists did not differ at the .05 level of significance. No interaction between presentation rate and list relationship was obtained, F (3,84) < 1. Performance improved for later serial positions as expected (272, 300, 395, 500), F (3,84) = 35.56, p < .001. The interaction between presentation rate and serial position is shown in Table 2. The Fast rate produced better performance at the first two serial positions, while the Slow rate was better for the two terminal positions, F (3,84) = 3.06, p < .05. This result was true for all four list relationships. One explanation of this finding could be a relatively greater loss of item information in the Slow rate. Performance is poorer at the early serial positions because the subject is less likely to recall early items and instead recalls (incorrectly) a later item from the attended channel. However, this loss of early items is beneficial at later serial positions since the weakened early items do not interfere with later items so that correct recall improves.

As expected, more correct responses were made when the attended channel (1087 corrects), rather than the unattended channel (410 corrects), was probed, F (1,28) = 118.81, p < .001. However, this attended-unattended channel effect interacted with List type as shown in Table 3, F (3,84) = 20.20, p < .001. It can be seen from this table that probing the unattended channel was far more detrimental to performance when semantically, rather than acoustically, related word-pairs were presented.

Figure 3 shows that performance improved much less rapidly at terminal serial positions when the unattended, rather than the attended, channel was probed, F (3,84) = 4.57, p < .01. This finding suggests that subjects continued to process echoically stored information from only the attended channel following list presentation. Since the echoic trace of recent serial positions is most salient, the bias toward continued attended

Table 2

Serial Position Effects on Number of Corrects as a Function of Presentation Rate

	Probe 1	Serial 2	Position 3	4	$\overline{X}$	
Slow	119	161	207	265	118.0	752/4
Fast	153	169	188	235	186.3	745/4
$\overline{X}$	136.0	165.0	197.5	250.0		

Table 3

List Effects on Number of Corrects as a Function of Probing the Unattended and Attended Channel

	List Type					
	Semantic Lists			Acoustic Lists		
Channel Probed	S	A	$\bar{X}$semantic	T	I	$\bar{X}$acoustic
Attended	263	332	297.5	237	255	246
Unattended	42	84	63	158	126	142

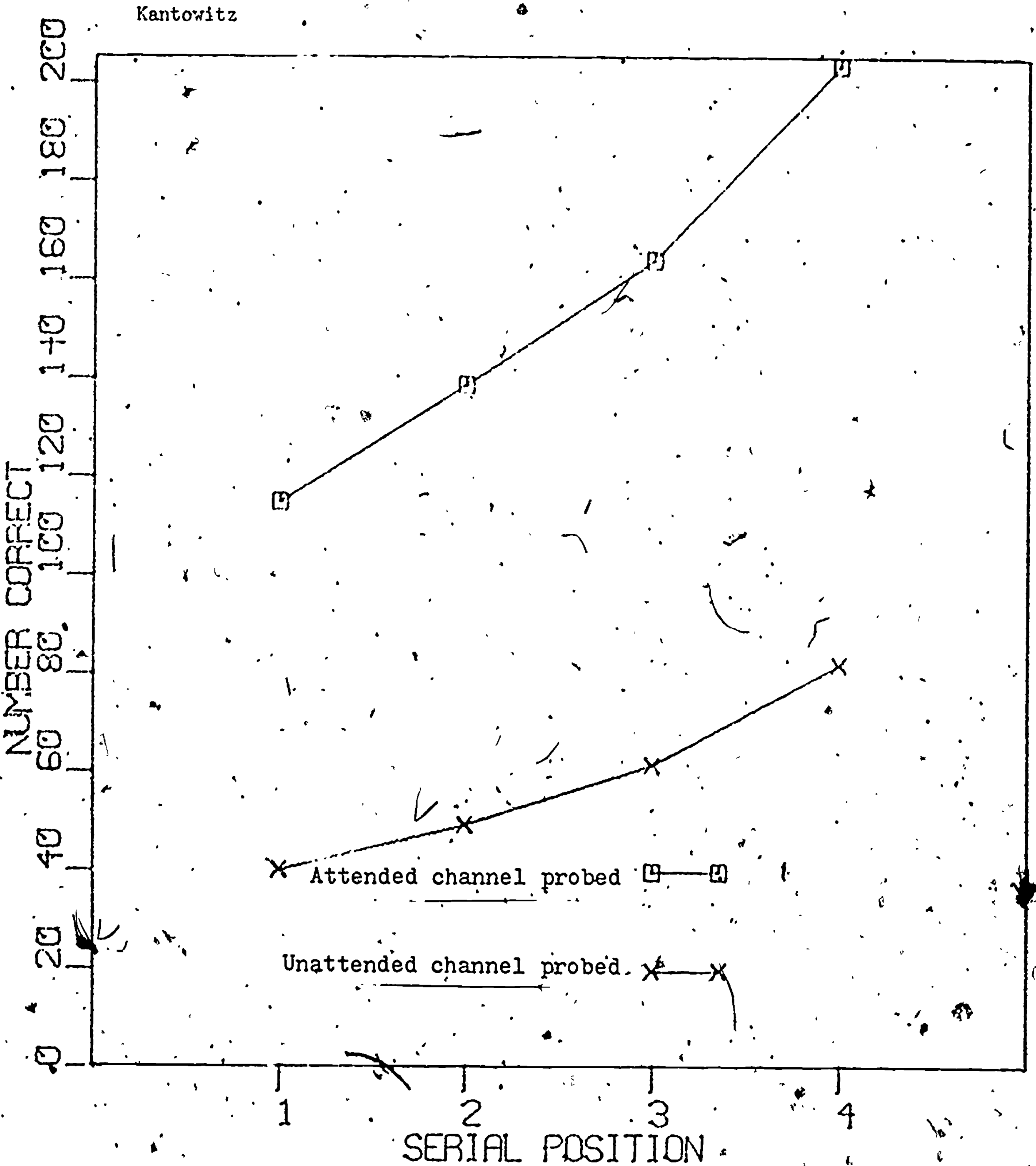

Figure 3. Serial position effect for correct responses from Attended and Unattended channels.

channel processing should produce the greatest attended channel advantage at final serial positions.

A Presentation rate X List type X Attended-unattended channel interaction is shown in Table 4, F (3,84) = 3.29, $p < .05$. Two principal effects are evident in Table 4. First, there is a greater difference between attended and unattended channel performance when semantically related word-pairs (Lists S and A), rather than acoustically related pairs (Lists T and I), were presented. Second, Presentation rate had little consistent effect upon acoustic list performance but did influence semantic list performance. For semantic lists (S and A), fast presentation rate was superior to slow presentation rate when the attended channel was probed. When the unattended channel was probed, the converse obtained: performance at the slow presentation rate was superior. This reversal may be understood in terms of the effects of unattended channel processing. When the unattended channel was probed, any unattended channel processing would have been beneficial. Such unattended channel processing is minimized by fast presentation. However, when the attended channel was probed, any unattended channel processing was probably disruptive since increased load would be placed on perceptual and memory systems. The failure to find a similar rate effect among acoustic list conditions may reflect the relative simplicity of acoustic filtering processes: the same degree of acoustic filtering was possible at both fast and slow presentation rates. Thus, the interaction depicted in Table 4 supports a hierarchical filtering system as proposed by Treisman (1969).

As when intrusions were analyzed, an interaction between List type, Attended-unattended channel, and Serial position was found for correct responses. This interaction, shown in Figure 4 was statistically significant, F (9,252) = 4.53, $p < .001$. Unlike the intrusion data, correct recalls showed no peak at central serial positions but increased with serial position for all conditions other than terminally acoustically similar (T) lists, when the attended channel was probed. Furthermore, it appears that the serial position effect is unusually small when semantically related lists were probed on the unattended channel.

Errors from attended channel. An error from the attended channel (EAC) is defined as an item, other than the correct item, or an intrusion from the ear which was monitored by the subject regardless of which ear was probed, e.g., if the digit pairs were 12, 34, 56, 78, 90 and the probe was 3 or 4 and the left (odd-digit) ear was to be attended, then EAC would be the digits 1, 7 or 9. The greatest number of such errors occurred for Synonyms (485), followed by Associates (478), Terminal (321) and Initial (313) lists, F (3,84) = 20.95, $p < .001$. More EACs occurred when the unattended channel was probed (986) than when the attended channel was probed (611), F (1,28) = 49.66, $p < .001$. This result was true for all list relationships, except T lists for which equal EACs were produced. This can be attributed to a response bias for the attended channel with subjects tending to respond from the attended channel more often than from the unattended channel regardless of which channel was probed. An interaction between rate and serial position, F (3,84) = 3.00, $p < .05$, is the inverse

Table 4

List Effects on Number of Corrects as a Function of: 1) Probing the Attended and Unattended Channel and: 2) Presentation Rate

		List Type					
		Semantic Lists			Acoustic Lists		
	Channel Probed	S	A	$\overline{X}_{semantic}$	T	I	$\overline{X}_{acoustic}$
Slow Presentation Rate	Attended	123	162	142.5	111	137	124
	Unattended	27	54	40.5	82	56	69
Fast Presentation Rate	Attended	140	170	155	126	118	122
	Unattended	15	30	22.5	76	70	73

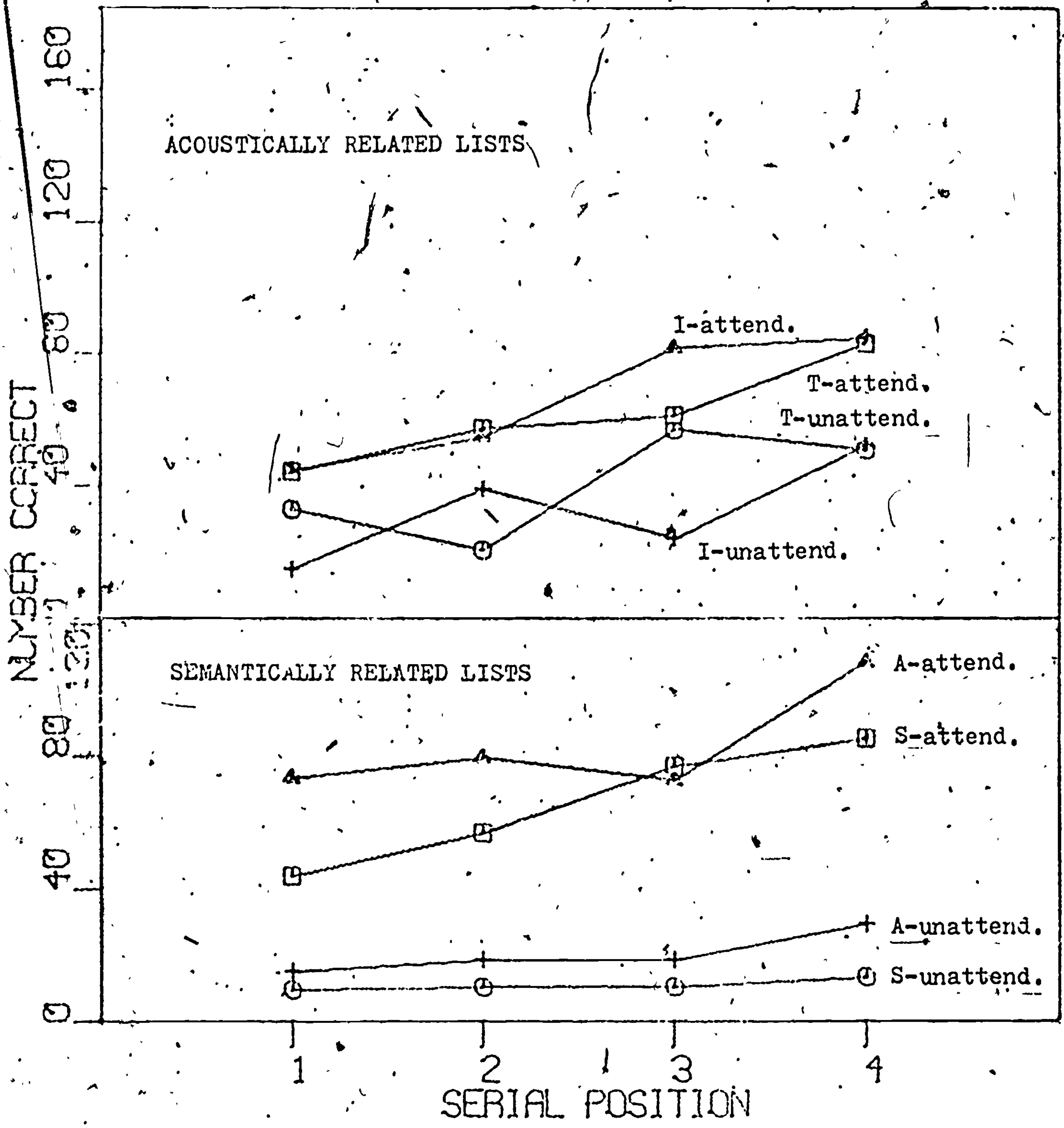

Figure 4. Serial position effect for correct responses as a function of List type and Attended vs. Unattended channel.

of this interaction for correct responses.

Errors from unattended channel.-- An error from the unattended channel (EUC) is similarly defined as an incorrect item drawn from the unmonitored channel; in the example above EUCs would be the digits 2, 8 or 0. The only finding of interest (Table 5) was a reduction in EUCs as presentation rate increased when the unattended channel was probed, $F\ (1,28) = 4.70$, $p < .05$.

Tone Experiment

Figure 5 shows ROC functions for each of the four attention conditions pooled over subjects. It is clear that d' changes with condition. However, to avoid parametric and pooling assumptions, an additional analysis was performed. The area under the ROC function was separately calculated for each subject and condition and these data were then analyzed. The mean area under the ROC function was .95 for the control condition, .93 for the 2-digit DA condition, .92 for the 6-digit condition and .73 for the 10-digit condition, $F\ (3,204) = 117$, $p < .001$. Thus, tone detectability decreased with increasing digit load.

Mean recall scores, for ordered and free recall are shown in Table 6. For serial recall, effects of digit-list length, $F\ (2,136) = 153$, and tone presence vs. absence, $F\ (1,68) = 23.69$ were both significant at the .001 level, as was their interaction, $F\ (2,136) = 22.74$. While recall performance was independent of tone/no-tone trials for both 2- and 6-digit DA conditions, performance was better in no-tone trials for the 10-digit DA condition. For free recall similar, albeit weaker, effects were also observed. Effects of list length, $F\ (2,136) = 913$, $p < .001$ were again significant, although tone presence vs. absence just missed significance at the .95 level, $F\ (1,68) = 3.49$, $.1 > p > .05$. However, their interaction was again significant, $F\ (2,136) = 3.17$, $p < .05$, due to improved performance on no-tone trials at the 10-digit, DA condition. Thus, while digit load had a clear effect upon tone detectability, which was most evident for the 10-digit DA condition, a reciprocal effect upon digit recall was observed for the most difficult digit condition. Although serial recall scores which require both order and item information were more sensitive than free recall scores which require only item information, effects were similar for both measures.

CONCLUSIONS

The two studies reported herein used dichotic stimulus tapes generated by computer. Such precisely generated stimuli remove many of the artifacts in previous research in this area so that more confidence may be placed in these present results.

Results of both experiments were more compatible with early-selection models of attention than with late-selection models. In the word experiment, the dependence of semantic intrusions upon presentation rate coupled with the independence of acoustic intrusions from presentation rate, supports

Table 5

Effects of Presentation Rate on Number of Errors from Unattended Channel (EUCs) as a Function of Probing Attended and Unattended Channels

Channel Probed	Presentation Rate: Slow	Fast	$\bar{X}$
Attended	176	138	157
Unattended	182	136	159
$\bar{X}$	179	137	

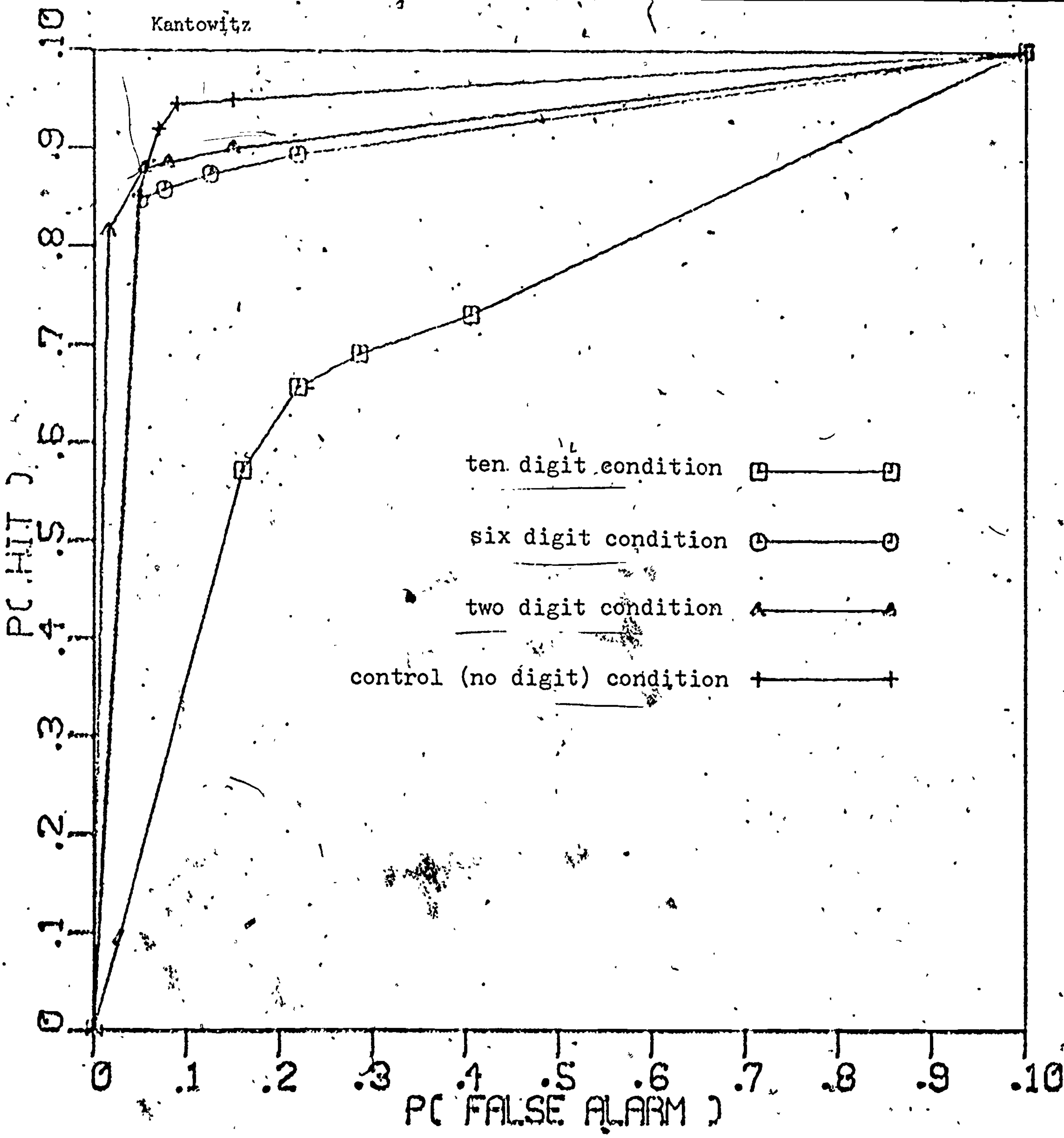

Figure 5. Receiver Operating Characteristics (R.O.C.s) as a function of opposite ear digit load.

Table 6

Mean Correctly Recalled Digits

Serial Recall

Number of Digits to be Recalled

	2	6	10	$\overline{X}$
Tone Present	2.00	5.13	4.49	3.87
Tone Absent	1.99	5.16	4.99	4.05

Free Recall

Number of Digits to be Recalled

	2	6	10	$\overline{X}$
Tone Present	2.00	5.68	7.41	5.03
Tone Absent	1.99	5.70	7.55	5.08

Treisman's model of a hierarchical set of tests imposed upon incoming stimulus material. Since attended and unattended information is maintained in the same system according to late-selection models, intrusions should not be based upon acoustic relations but should occur more frequently for semantically related words since, according to this model meaning is extracted before attentional limitations are imposed. Indeed, the opposite outcome was obtained with considerably more intrusions for acoustic lists even at the Slow presentation rate.

In the tone experiment, the early-selection model was again supported. Increasing digit-load resulted in poorer signal detection. Since the tone was reported before digit recall, this outcome cannot be attributed to memory decrement during digit recall, a criticism which could be applied to the Broadbent and Gregory (1963) study. However, it could be argued that within a trial presentation, a correctly detected tone could be forgotten while the rest of the digit string was presented. The concentrated attention condition involved a 6-digit string and resulted in better signal detection than the 6-digit DA condition; however, this difference although statistically reliable was small. The major decrement was observed in the 10-digit DA condition in which tone report was delayed for one sec more than in the 6-digit condition. While it is rather unlikely that memory for a correctly detected tone could decay so rapidly during this additional one second, such a possibility cannot be dismissed outright. It is much more likely that the deficit is due to perceptual, as opposed to memorial, processes occurring during stimulus input. Support for this position was obtained in the digit recall scores. For both free and ordered recall, performance in the 10-digit DA condition was worse for trials on which a signal tone had been presented. Since tone presentation was randomized, subject had no way of discovering a tone presentation prior to tone occurrence. In the 2- and 6-digit DA conditions, dual-task load was sufficiently low so that subjects could both detect the tone with a high degree of accuracy and also recall the digits quite accurately. However, in the 10-digit DA condition, processing of the tone (when it occurred) caused attenuation of the digit message on the other ear. This effect was more pronounced for ordered recall and this outcome is in agreement with a suggestion of Dornic (1973) that order information is stored in a "lower storage mechanism" which is primarily echoic in nature with items being linked by their physical features and order of occurrence rather than being stored in relation to their meaning. The additional attentional demands of tone processing interfere with the entry of items into this primitive echoic memory. Such an interpretation has an interesting implication for Treisman's model: active utilization of an analyzer (e.g., tone detector) is more attention demanding than the maintenance of the analyzer in a ready state. As was noted by Dornic (1973) such a "lower storage" is more compatible with early-selection than late-selection models of attention.

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APPENDIX I

Instructions

You are about to participate in an experiment designed to study how well people can pay attention under distracting circumstances. The experiment will consist of several blocks of 56 trials. You will be given short rest breaks between each block of trials. The first eight trials of each block will be for practice.

At the start of each trial you will hear a one-second burst of noise in only one ear. The side of the noise burst tells you which side you should listen closely to during the upcoming trial. For instance, if you heard a burst of noise in the left ear, then you should pay attention to words presented in the left ear during the next trial.

Shortly after the noise burst five pairs of words will be presented to you. In each pair of words, one word will be presented to your left ear and one word will be presented to your right ear. You should listen to words on the side indicated by the first noise burst.

After the five word-pairs have been presented, another burst of noise will be given to tell you the presentation is over.

Shortly thereafter you will hear a single word. It will be presented in both ears. This word will be one which you just heard among the five word-pairs.

Your task in this experiment is to recall the word which followed this test word during the presentation period. You will have ten seconds to write down your answer before the next trial starts. For instance, if you heard 1, 2, 3, 4, 5 in the left ear and the test word was 2, then you should write down 3 as your answer. Similarly, if you heard 2, 4, 6, 8, 10 in the right ear and the test word was 6, then you should write down 8.

We would also like to know how confident you are in your answer. Next to your answer write down a number from 1 to 5, 5 meaning very confident; 1 meaning least confident.

Most of the time the test word will come from the side you were instructed to attend to. Sometimes the test word will come from the other side. However, your score will be based ONLY upon trials where the attended ear is tested. If the test did happen to be from the unattended side, however, you would still, if possible, write down the word from the unattended side which followed the test word.

It is only fair that good performance be rewarded. Therefore, subjects in each experimental condition who achieve the highest scores will be given a five dollar bonus. Remember that your score will depend only upon your ability to recall words from the side indicated by the initial noise burst.

Appendix I (Continued)
Instructions

Even though the other side is occasionally tested, this will not be used in determining your performance since we are primarily interested in how well you can focus your attention on a specified speech signal.

In order that we may notify the high scoring subjects, please write down on the top of the scoring sheet a mailing address at which you can be reached during the next two months. Winners will be notified during this period.

If you have difficulty hearing the signals, feel tired, or otherwise unable to continue, please indicate this to the experimenter at the end of a trial block. The words you will hear have been generated by computer and therefore sound slightly metallic. However, they are common English words and, with a little practice, you should be able to understand them well. If you have any questions, please ask the experimenter now.