Memory search of dichotically presented lists of digits

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Subjects heard dichotically or binaurally presented digit lists followed by a binaural probe item. Instructions required attending to one list or attending to both lists at once. The task was to determine whether or not the probe had occurred among the attended items. Decision time was a linear function of the number of attended items. Responses to probes drawn from the unattended lists were slower than other negative responses. This was reflected in the intercept but not the slope of the RT/list length function.

Sternberg (1966) found that the time taken to determine if a probe item had occurred in a previously presented memory set was a linear function of the items in that set. Sternberg proposed that subjects compared the probe with an internal representation of each item in the memory set. The fact that positive and negative response functions were parallel was taken as evidence that comparison is exhaustive rather than self-terminating (ceasing once a match is obtained). After a serial comparison stage, a binary decision determines whether or not a match has been made. The sum of the durations of these stages, plus the time necessary for stimulus encoding and response execution, make up the time necessary to respond.

The Sternberg paradigm and stage analysis were applied here to a case of competing inputs. Subjects heard two spoken lists of digits; one list was presented to one ear at the same time that the second list was presented to the other ear. A single probe item followed this presentation. The subject was to determine as rapidly as possible whether or not the probe item had occurred on the ear designated as relevant (Smith & Burrows, 1974; Smith & Groen, 1974).

If the mechanisms of selective attention prevent coding of unattended material, there should be no difference between dichotic and single list conditions other than the minor effect of peripheral masking. On the other hand, if both attended and unattended words achieve representation in memory, the presence of irrelevant material may interfere with memory search. The slope of the function relating list length to response time would be greater for dichotic than for single lists. In addition, when a probe is drawn from the unattended list, we may expect frequent false positive responses. Alternatively, the subject may selectively access the

lists in memory. The lists would first be discriminated on the basis of their source (left vs. right) and, subsequently, only the relevant items would be compared with the probe. The extra processing time required to discriminate between lists would elevate response times without affecting the number of items scanned. Response times for probes drawn from the irrelevant list would not be different from response times to other negative probes, since only relevant items are searched.

METHOD

Stimuli

Stimuli were constructed from a master tape recording consisting of pairs of spoken digits. The members of a pair occurred simultaneously, one on each channel of the tape. A computer procedure had expanded or contracted each item to 250 msec. Individual lists were constructed by re-recording and splicing pairs. Each list consisted of a 250-msec warning tone (1,000 Hz) followed 600 msec later by presentation of one, two, or three pairs of digits. Presentation rate was 600 msec/pair, onset to onset. The list was followed after a 1,200-msec silent period by a binaural probe item.

Lists were assigned to four test blocks, each block consisting of 12 lists each of List Lengths 1, 2, and 3, and 16 lists of Length 4. The blocks were assigned in different orders to four stimulus tapes. Each block on a tape was randomly assigned without replacement to one of the four conditions.

Procedure

In the binaural condition (I), a single list was presented binaurally. The subject was to press a lever labeled "YES" if the probe item had occurred in the list, or a lever labeled "NO" if the probe had not occurred. For the dichotic monitor one condition (II), two lists were presented dichotically. The subject was to attend to only one ear and respond "YES" if the probe item had occurred on that ear. Subjects were informed that probe items were never drawn from the unattended list. A third condition (III) was identical to Condition II, except that half the probes were drawn from the attended and half from the unattended lists. Subjects were also informed of this fact. In a final condition (IV), subjects were to monitor both channels and respond "YES" if the probe item had occurred on either ear. Within each condition, positive and negative probes occurred equally often. For positive probes, the target item occurred in each serial portion of the list an equal number of times.

The lists were monitored from a Magnecord 1024 tape recorder through dichotic headphones. A Hunter timer/counter (Model 131c) was set to count each relay closure of a voice key (Grason-Stadler E7300-A1) monitoring one channel of the tape.

This paper is based, in part, on preliminary results reported at the Eastern Psychological Association meetings, April, 1972, Boston. The author thanks Arthur Wingfield, who sponsored this paper and takes complete editorial responsibility for it, and Anne Treisman, who supplied the time-controlled digits used in this experiment. Reprint requests may be addressed to Dennis Byrnes, University of Massachusetts, Psychology I, Boston, Massachusetts 02125.

Figure 1. Reaction times (RT) for YES responses as a function of the number of items (Condition I) or number of pairs (Conditions II, III, and IV).

Upon receipt of the closure due to the probe item, the counter pulsed the start circuit of a clock (Hunter 1520 digital reaction timer). The timing interval ended when one of the microswitch levers was depressed.

Subjects were 10 graduate and undergraduate paid volunteers. Each served in four 80-min sessions on 4 consecutive days. All combinations of conditions, list lengths, and probe types occurred within each session.

RESULTS

Errors

Error rates were different across conditions, $F(3,27) = 6.64$, $p < .005$. Conditions I, II, III, and IV

received error rates of .03, .05, .10, and .08, respectively. Nine out of 10 subjects showed more false positive responses for Condition III than for any other condition.

Reaction Times (RT)

The results include only correct responses and are summarized in Figures 1 and 2. In the overall analysis, Conditions had a significant effect on RT, $F(3,27) = 28.25$, $p < .001$, as did List Length, $F(3,27) = 27.02$, $p < .001$, and Response Type, $F(1,9) = 47.38$, $p < .001$. The only significant interaction was Conditions by List Length, $F(9,81) = 7.96$, $p < .001$, reflecting the greater

Figure 2. Reaction time (RT) for NO responses as a function of the number of items (Condition I) or number of pairs (Conditions II, III, and IV).

slope of the function in Condition IV. When this condition is excluded from the analysis, the interaction is no longer significant. In this analysis, however, an interaction appears between Conditions and Response Type, $F(2,18) = 5.86$, $p < .05$, reflecting the elevation of negative responses in Condition III.

A significant linear trend underlay the List Length effect, $F(1,9) = 17.9$, $p < .005$. This linear trend interacted with Response Type, $F(1,9) = 7.0$, $p < .05$. There was no significant difference between trends for the first three conditions. Accordingly, parallel lines have been fitted to the data points in Figures 1 and 2. The regression lines for Condition IV were calculated independently of the other conditions.

For positive lists, significant effects of the serial position of the target were obtained only for List Length 4, $F(3,27) = 3.06$, $p < .05$. There were no effects of the serial positions of the target in the unattended list(III-no).

DISCUSSION

Responses to probes drawn from the unattended list (III-no) are substantially slower than other negative responses. The greatest number of errors were positive responses to probes from the unattended list. Representations of both attended and unattended words must be activated in memory.

The pattern of reaction times appears consistent with a directed entry model of memory search (Naus, 1974; Naus, Glucksberg, & Ornstein, 1972). In this model the subject uses ear-of-arrival as a cue to select the attended list for search. Unattended items, though coded into memory, are not searched. A selective search seems indicated by the fact that search rates are equal for single lists (I) and for dichotic lists with attention required to one ear only (II and III). However, if only attended items are searched, the identity of unattended items should have no effect on response time. Yet, the presence of a target from the unattended list increases RT about 100 msec regardless of list length (III-no vs. II-no).

The selection may be imperfect. In Condition III, the subject knew the probe was drawn from the unattended list on half the trials. After obtaining a match, he may have rechecked to determine whether the match was obtained from the attended or unattended list. This hypothesis predicts the same effect on positive and negative response times. Only negative response times are elevated in Condition III.

Corballis and Miller (1973) suggested that the linear relationship between list length and RT represents a sequential priming stage rather than scanning. This stage reactivates the stored representations in memory. A decision stage evaluates the memory strength of the probed item. This model has the advantage of predicting serial position effects under some conditions (more recently primed items will have greater strength), yet also accounting for the linear relationship between list length

and RT (both have been obtained by several investigators, e.g., Wingfield, 1973).

The priming model accounts for at least two of our findings. If the priming process were selective, i.e., restricted to the attended items, there would be no effect of irrelevant inputs on the slope of the RT/list length function. Irrelevant items would retain some residual strength as a result of their activation during presentation. This residual strength would make it difficult to discriminate targets in the unattended list from those in the attended list. The RT for the negative target case would be elevated relative to other negative probes.

The greater slope for positive than for negative probes is anomalous with respect to current models. The exhaustive scan model predicts equal slopes. A self-terminating model predicts that the function for negative responses will be steeper than that for positive responses. All three patterns have been reported in the literature (e.g., Aube & Murdock, 1974; Clifton & Birenbaum, 1972; Sternberg, 1966).

These results indicate that both ignored and attended items are represented in memory. Selection and limitations on processing seem more likely to occur at a stage in which stored information competes for rehearsal capacity and control of the response (cf. Wingfield & Byrnes, 1972). In addition, the results appear inconsistent with the notion that there is a serial comparison of the probe item with items in the memory set. The list length effects may be better conceptualized as a special case of rehearsal or priming.

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(Received for publication May 13, 1976.)