HUMAN PERFORMANCE IN CONTINGENT INFORMATION-PROCESSING TASKS

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Theoretical accounts of complex human information-processing behavior have emphasized the utilization of contingencies whereby the processing of some information directs the processing requirements of the remaining sources of uncertainty. The present investigation sought to determine how such flexible processing might be accomplished in a speeded recognition task where the relevancy of a given stimulus dimension was contingent upon the value of the stimulus on some other dimension. These contingent tasks, in which only two of the three dimensions were relevant on any one trial, were performed faster and more accurately than tasks where all three dimensions were relevant on each trial. Moreover, the speed at which a given contingent task could be performed was related to the discriminability of the dimensions that were relevant on that trial. These results provide strong support for a self-terminating, feature-testing, contingent mode of processing. The error data and repetition effects also supported the hypothesis that Ss were employing the contingent relations to achieve a classification of the stimulus. The lack of interactions between discriminability of the relevant dimensions in the contingent tasks and variations in S-R compatibility were consistent with the hypothesis that the contingencies were utilized at some stage prior to response selection.

The experimental study of choice reaction time (RT) and perceptual recognition has typically involved performance on tasks where a given source of information was either always relevant or never relevant (Posner, 1964; Smith, 1968; Treisman, 1969). Outside of the laboratory, however, information which is relevant in one situation can often be ignored in another; i.e., most information that we deal with has the status of being sometimes relevant. Obviously, the relevancy or irrelevancy of this

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information must be *contingent* upon the status of other sources of information.

The processing of contingent information is of central importance in many theoretical accounts of complex information processing (Hunt, 1962; Miller, Galanter, & Pribram, 1960; Reitman, 1965; Trabasso, Rollins, & Shaughnessy, 1971). Contingent structures are often presented diagrammatically as tree diagrams or branching flow charts or verbally referenced as “hierarchical structures.” Presumably, the functional significance of contingent (or hierarchical) structures resides in the economy which they afford in the required number or complexity of the information transformations intervening between input and output. In some sense, virtually all information-processing tasks have contingencies embedded in them in that if sources of stimulus information are sampled then an efficient system does not reexamine the already examined sources. In other words, the search among the remaining alternatives is contingent on the fact that the “critical” alternative has not, as yet, been identified. While the underlying psychological processes may be the same in the two cases, the term contingent will be used only with reference to those tasks where the processing of one source of information conveys more information about the necessity of processing remaining sources than would arise from simple elimination of that source as critical.

The present research is designed to examine the following three questions concerning the processing of contingent information. (a) Can contingent information be used to direct the course of multidimensional perceptual recognition? While it is obvious that contingent information is employed in many activities typically classified as thinking, it is not clear whether such information would be employed in the immediate classification of stimuli. (b) If contingent information is used, how is it handled? (c) At what stage in the information-processing sequence between stimulus and overt response does this processing occur?

**Experimental tasks.**—Discussion of the above three questions will be facilitated if reference is first made to a sample of the tasks employed in the experiment. The tasks used the same set of eight stimuli which were assigned to four finger-key responses: two stimuli per response (Fig. 1

![Fig. 1a. Schematic of a contingent task with color as a primary dimension (CC Set A) showing the S–R assignments for both high- and low-compatibility conditions. (1b. Schematic of a contingent task with tilt as a primary dimension (CT Set A). A serial contingent processing tree is shown above each task.)](image-url)
The eight stimuli were generated from three binary dimensions (background color, circle size, and diameter tilt). The tasks differed only in the way these eight stimuli were assigned to the four responses. In the contingent tasks, the assignment was such that the relevance of a given secondary dimension was dependent upon (or contingent upon) the value of the stimulus on a primary stimulus dimension. Figure 1a shows a contingent task where color is the primary dimension and tilt and size are secondary dimensions. If the color is green, S can respond on the basis of tilt and ignore size. If the color is red, then S can respond on the basis of size and ignore tilt. Figure 1b shows a contingent task with the same set of stimuli and responses as in Fig. 1a, but with tilt as the primary dimension. In the condensation task (Fig. 2a), all three dimensions were always relevant. In the filtering task (Fig. 2b), one of the three is always irrelevant; the other two are always relevant.

Contingent information processing.—The three tasks shown in Fig. 1 and 2 are what Posner (1964) termed information-reduction tasks in that the response information is less than the stimulus information (although Posner distinguished only be-
between filtering, which he called gating, and condensation). When relevant and irrelevant visual information are perceptually distinct or analyzable, a filtering task requires less processing time than a corresponding condensation task (Fitts & Biederman, 1965). Posner maintained that an extra transformation step is required to effect the reduction of information in the condensation task. Such a step would not be required in the filtering task where the information to be reduced is never relevant. In Posner's (1966) terms, then, the difficulty of the contingent task relative to a filtering or condensation task would depend on whether a transformation is performed on a secondary dimension on those trials when it is irrelevant.

Two studies have been explicitly concerned with RT in a contingent information-processing task (Hodge, 1959; Montague, 1965). In the Montague experiment, irrelevant information that was at other times relevant led to more errors in a contingent task than did the same amount of irrelevant (and never relevant) information in a filtering task. Montague interpreted this as indicating that "the locus of interference attributable to irrelevant information is in the response competition generated by implicit responses elicited by the nonrelevant dimensions [p. 235]." Hodge also accepted response competition as an explanation for the increase in reaction times (RTs) that occurred when the number of irrelevant, but at other times relevant, dimensions of a stimulus was increased. However, current models of information-processing behavior (e.g., Sternberg, 1969) hold that "implicit responses" occur at functionally different processing stages between input and output. It would seem desirable, therefore, to specify a more precise locus in the sequence of processing stages for the effects of sometimes relevant information. Also, as will be seen below, vastly different information-processing modes are consistent with the results of both the Hodge and Montague experiments.

There are at least two ways in which contingent relations among dimensions might be used to influence the course of perceptual identification. The different modes depend on whether dimensions are processed sequentially or in parallel (Biederman & Checkosky, 1970; Egeth, 1966; Nickerson, 1970). A sequential mode is illustrated by the decision tree in the upper portion of Fig. 1: S might use the value of the primary dimension as the basis for selecting the relevant secondary dimension for processing. To do this, it is necessary to process the primary dimension first, select one secondary dimension for processing, and ignore the other secondary dimension. This mode implies that the primary dimension would be processed on every trial while any one secondary dimension would be processed on only those trials in which it was relevant. Such a mode of processing will be termed serial contingent processing. The utility of employing serial contingent processing arises from the savings in time when one of the secondary dimensions is not processed.

If dimensions are processed in parallel, then the contingency relations might be used to define criteria for determining when a sufficient amount of information had been extracted from the secondary dimensions for a correct response. This mode, which will be termed parallel contingent processing, would benefit S only on those trials when the processing of the primary dimension was completed before the completion of the irrelevant secondary dimension. For example, in the task shown in Fig. 1a, S would simultaneously start to process color, size, and tilt. If S determined that the color of the stimulus is red, say, then the parallel contingent mode implies that S has the capacity to initiate a successive stage of processing (e.g., response selection) as soon as he determined the size. Even though the tilt is not "known" to be irrelevant, S may continue to process it. However, the outcome of the tilt processing, even if it should come prior to the outcome of the size processing, would not influence the initiation of a successive stage.

Note that both contingent modes assume a highly flexible process in which early outcomes of processing are rapidly and efficiently utilized to influence the subsequent course of processing. Biederman and Checkosky (1970) argued for such flexi-
bility in showing that when stimuli differed on two dimensions, either of which could furnish sufficient information for a correct response, RTs were faster than when stimuli differed on only one dimension. A model compatible with this result is one in which the different dimensions are processed in parallel with a response initiated as soon as sufficient information is available. Given some variability, overlap, and independence in the distribution of times for processing each dimension, sometimes the processing for one and sometimes the processing for the other dimension would be completed first. To capitalize on this variability, S could not adopt a stopping rule based on a dimension specified prior to processing. Rather, he would have to start processing both dimensions and to initiate response selection based on whatever dimension was completed first. To capitalize on this variability, S could not adopt a stopping rule based on a dimension specified prior to processing. Rather, he would have to start processing both dimensions and to initiate response selection based on whatever dimension was completed first. To capitalize on this variability, S could not adopt a stopping rule based on a dimension specified prior to processing. Rather, he would have to start processing both dimensions and to initiate response selection based on whatever dimension was completed first.

3. All three dimensions might be processed on every trial exhaustively even when sufficient information is available from two of the dimensions to make a correct response. Both contingent modes, as well as the sequential-by-primary and sequential-by-discriminability modes, assume that a successive stage can be initiated as soon as sufficient information is available. For purposes of the present experiment, it is unnecessary to distinguish between parallel or sequential forms of exhaustive processing.

4. While the set of stimuli may be represented as being generated from several dimensions, it is not necessarily the case that S "analyzes" a stimulus into its component dimensions. Thus, S might form some internal, unitary "template" of the stimulus (visual, verbal, or abstract) in which individual features are not tested but in which the complete stimulus is the unit for input-output matching. Since the contingencies being discussed require testing features of the input, contingent processing could not be manifested if the internal representation of the stimulus was in template form.

The experimental strategy to distinguish among the various processing modes was to compare RTs from different contingent tasks where differences in discriminability (physical similarity) were interchanged between primary and secondary dimensions. To accomplish this, while using the same set of stimuli in the different tasks, the stimulus set was generated from dimensions that differed in the discriminability of their values and the contingent tasks differed in the dimension which was primary. With the tasks shown in Fig. 1 and 2, the tilt dimension was harder to discriminate than the color or size dimensions. The expected relations between RTs and primary dimension discriminability discussed below are based on the assumption that differences in RT between tasks...
reflect the number of dimensions that are processed and the difficulty in making discriminations on these dimensions.

Both exhaustive processing and template matching imply that there would be no difference in RTs between contingent tasks and condensation tasks. In both kinds of tasks, all three dimensions (or all eight templates) would be processed on every trial. The sequential-by-discriminability mode in which the dimensions were processed in order of easiest to most difficult implies that there would be no difference between a condensation task and a contingent task in which the most difficult dimension was primary (and last to be processed). In both tasks, RTs would be limited by the same third dimension to be processed. If the dimensions were processed in order of most difficult to easiest, then no difference would obtain between a contingent task and a contingent task in which the least difficult dimension was primary. Furthermore, this version of the sequential-by-discriminability mode predicts that the more difficult the discrimination of the values of the primary dimension, the faster the RTs.

The sequential-by-primary mode implies that if a contingent task had the most difficult dimension as a secondary dimension, RTs on those trials when that difficult dimension was relevant would be equal to RTs on a condensation task. For example, with the task shown in Fig. 1a, when a green stimulus is presented, S would first process its color, then its size (even when irrelevant), and finally its tilt (the most difficult dimension). Thus all three dimensions would be processed as is required in the condensation task. If the differences in discriminability are so great that there is no overlap between the component distribution of times for identifying the values on the dimension that was most difficult to discriminate and the distribution of component times of the dimension that was easier to discriminate, then the parallel contingent mode would also yield the same prediction as the sequential-by-primary mode.

The serial and parallel contingent modes can also be distinguished by means of an analysis of errors. Many models of information-processing behavior view errors as resulting from a premature termination of a sequential search or sampling process (Egeth & Smith, 1967; Fitts, 1966). Under the serial contingent mode, since the primary dimension is processed first, there would be fewer errors attributable to misidentifications of the primary dimension (primary errors) than to misidentifications of the secondary dimensions (secondary errors). Such an outcome could also be consistent with the parallel contingent mode if it is assumed that a response would tend to be initiated once the value of the primary dimension was determined. Given that RTs are related to the discriminability of the primary dimension and that there are more primary errors than secondary errors, the parallel contingent model predicts that the secondary error rate would be related to the discriminability of the primary dimension. If S starts out by processing all three dimensions simultaneously, and if the primary dimension required relatively little time to discriminate, then the processing of the secondary dimensions would tend not to be completed until after the processing of the primary dimension was completed. Now, if S initiated, on some trials, a response as soon as he determined the value of the primary dimension, then he would be likely to misidentify the value of the secondary dimension. Alternatively, if the primary dimension was difficult to discriminate, then by the time S completed the processing of the primary dimension he would be likely to have already completed the processing of the secondary dimensions. Consequently, in this latter case he would not be likely to misidentify the value of the secondary dimension. Thus the parallel contingent model predicts that there would be more secondary errors on a given dimension when that dimension is in a task with a primary dimension that is relatively easy to discriminate than when it is in a task with a primary dimension that is relatively difficult to discriminate. For example, in the tasks shown in Fig. 1, the parallel contingent model predicts that more errors would be made in misidentifying size when
it was a secondary dimension in the CC task (where a relatively easy dimension, color, is primary) than in the CT task (where a difficult dimension, tilt, is primary).

Repetition effects.—The existence of repetition effects (e.g., Bertelson, 1963) has provided investigators of RT with another dimension to their dependent variable. Schvaneveldt and Chase (1969) have recently argued that these effects reflect processing strategies. If so, then of particular interest in the study of contingent tasks is the possibility that the magnitude of the repetition effect may be sensitive to the informational (or functional) significance of the different stimulus components. Shaffer (1965) reported a study in which he argued that repetition effects were more marked with stimuli designated as rules than with stimuli designated as signals to which rules were to be applied. The signals were two lights arranged horizontally to correspond to the spatial separation of the two index fingers. The "rule" was comprised of two intersecting bars at right angles to each other to form a "+.". When the horizontal bar was presented, a homolateral S–R mapping of signals to index fingers was defined; i.e., the left light was to be responded to with the left index finger and the right light was to be responded to with the right index finger. When the vertical bar was presented, a contralateral S–R mapping was defined.

In Shaffer's (1965) study, RTs were faster when either the rule or the signal was repeated on successive trials, but repeating the rule led to a greater facilitative effect than repeating the signal. There are some difficulties, however, in generalizing Shaffer's results. If the utility attendant upon the use of rules and concepts is to be understood in terms of their provision for efficient processing of sets of alternatives (whether these alternatives be additional features of the stimulus situation or additional S–R mappings), then Shaffer's designation of the bars as rules and the lights as signals would appear to be arbitrary: The bar conveyed as much information as the light, independently of the order in which the two stimulus elements were processed. Another difficulty in interpreting Shaffer's results is that the differences in physical characteristics of the two types of stimuli were confounded with their rule versus signal designations. A more adequate study of the use of rules in information-processing behavior would involve use of a task in which initial extraction of information from one stimulus dimension (designated as the primary or rule dimension) results in less total information processing than if some other (secondary) dimension is processed first. The contingent tasks shown in Fig. 1 meet this specification. Moreover, functional effects may be distinguished from the effects of the different physical characteristics of the stimulus dimensions by counterbalancing the dimensions assigned as rules and signals.

Shaffer's (1965) question as to the relative magnitude of the repetition effect for rules versus signals to which the rules are to be applied may be profitably asked about the performance of contingent tasks. Under the serial contingent mode, it is clear that the primary dimension would be classified as the rule and the secondary dimensions as the signals. Thus, repeating the value of the primary dimension might result in a repetition effect of greater magnitude than would be obtained if only the secondary dimension was repeated.

Locus of effects in the information-processing sequence.—In the tasks studied, two response dimensions can be identified: hand (left vs. right) and finger (index vs. middle), with the former generally leading to more potent compatibility manipulations. S–R compatibility of the contingent tasks was varied by utilizing an S–R mapping in which the value of the primary dimensions determined not only which of the two secondary dimensions was relevant but also which hand was to be used in the high-compatibility conditions. In the low-compatibility conditions, the value of the primary dimension determined neither the hand nor the finger that was to be used. These variations are shown in the lower portion of Fig. 1a and 1b. If the contingent mode of processing primarily entails a
selection of response, instead of stimulus, dimensions, then the utilization of an S-R coding in which response selection is not directly attainable from an identification of the primary dimension should reduce the facilitative effect of contingent processing. That is, there would be less evidence for a contingent mode of processing under the low-compatibility conditions. If the contingencies are utilized at some stage prior to response selection, then the effects which provide evidence for contingent processing should not interact with compatibility (Biederman & Kaplan, 1970).

By using an information-reduction task in which more than one stimulus is assigned to a single response, there are Trial $N$ to Trial $N + 1$ sequences in which different stimuli occur but in which the same response is correctly given to both. RTs from these sequences can be compared to those from sequences in which the identical stimulus is repeated on the two trials. If RTs from the latter are faster, it can be taken as evidence that processes prior to response selection are involved in the production of the repetition effect.

**Method**

**Stimuli.**—The stimuli were circles containing a diameter on a colored square background. Eight stimuli were generated from the three binary dimensions of circle size, background color, and the angular orientation of the diameter (Fig. 1). Two sets of stimuli were used so that variations in discriminability (via physical similarity) could be isolated from effects associated with the specific dimensions. The values of the size dimensions were the same in both sets, the circles were either 36.5 mm. or 29.0 mm. in diameter. The two sets differed only with respect to the discriminability of the values of the background color and diameter tilt dimensions. In one set (Set A), the colors were either green or red (Kodak Wratten Filters No. 55 and 25, respectively), and the diameters were tilted $\pm 2.25^\circ$ from the horizontal so the angular difference between the two values was only $4.5^\circ$. If the right part of the diameter was above the horizontal, it was referred to as “two o’clock.” If the left side of the diameter was above the horizontal, it was referred to as “ten o’clock.” As measured by a MacBeth Illuminometer, the background colors had a luminance of approximately 3.0 ftc. In Stimulus Set B, the colors were slightly different shades of red, with one red identical to the one used in Set A. The other red had a dominant wavelength closer to orange (Kodak Wratten Filter No. 23A) and slightly more luminance (3.5 ftc.). This color was referred to as “orange.” In Set B, the diameters were tilted $\pm 45^\circ$ from the horizontal. The angular difference between the two values in Set B was $90^\circ$ and highly discriminable.

The circles and the diameters appeared as white outlines on the colored square; the color was therefore visible in the interior of the circle. The colored background squares were 50.8 mm. on a side. Stimuli were presented by a multiunit projection apparatus which permitted the independent display of two slides on each trial (Myklebust, 1966): one for background color and the other for a particular circle size-diameter tilt combination. The images from the two slides were superimposed on a ground-glass screen approximately 71 cm. from S’s eyes. The circles were centered within the background square.

To ascertain the relative discriminability of the different dimensions, six Ss performed two choice RT tasks in which one of the dimensions was relevant and the other two dimensions were held constant. The stimuli from Set A were used with three Ss; the other three Ss had Set B stimuli. In both cases, mean RTs were fastest when size was the relevant dimension. In Set A, color was faster than tilt. In Set B, tilt was faster than color.

**Responses.**—A response consisted of the depression of one of four piano-like microswitch keys arranged so as to correspond to the natural placement of the middle and index fingers of the left and right hands (see Fitts, 1966, Fig. 2 for a diagram of the response panel).

**Procedure.**—The procedure insured that S learned the assignment of stimuli to responses. A card with a facsimile of the eight patterns, labeled and arranged according to the correct S-R pairings, remained directly in front of S’s response panel throughout an 8-min. instruction period and the first block of 128 trials. The S was told the rules for performing the contingencies, e.g., “if the pattern is green, then you need only consider the diameter tilt to determine which key is correct,” or for performing the filtering, e.g., “only the size and the color need be considered to perform correctly; the diameter tilt may be ignored.” A 3-min. period was allotted for S to study the card after these instructions were given. After this study period, the eight stimuli were projected and the values on the three dimensions were identified verbally by E. An experimental session consisted of five blocks of 128 trials. The first block was termed a “practice block,” and S was encouraged to strive for accuracy while committing the task to memory. A verbal ready signal initiated each block. The task was self-paced; patterns remained displayed until S made a response. Simultaneous with the offset of the pattern, a 6.4-mm. fixation cross would appear at the position occupied by the center of the circle. The interval after a response and before the next stimulus was 2 sec. During this time, one of six feedback lights would flash indicating whether the response was correct or incorrect and whether it was fast, intermediate, or slow.
The condensation task is symbolized by "COND." Table 1 also shows the S-R assignments of the 10 tasks of Set B with the one modification that "O" for orange be substituted for "G" for green. (While the differences between the diameter tilts were not the same in the two sets, the "two o'clock" and "ten o'clock" labels need not be changed since they correctly designate the quadrants of the upper portion of the diameters for both sets.)

Eight stimuli were assigned to four responses in all 10 tasks represented in Table 1. The low-compatibility contingent tasks were derived from their high-compatibility counterparts by switching the stimuli assigned to the index fingers.

**Design.**—The Ss were assigned to 1 of the 10 tasks within a set. The 6 contingent tasks comprise a mixed design with two between-group variables and three within-S variables. The two between-group variables were compatibility (high vs. low) and primary dimension (color vs. size vs. tilt). One of the three within-S variables was the relative discriminability (high vs. low) of the relevant secondary dimension. The other two within-S variables were those for repetition effects. One of these variables was whether the value of the primary dimension changed from Trial N to Trial N + 1, the other was whether none, one, or both secondary dimensions changed value from Trial N to Trial N + 1.

The data of the filtering tasks were analyzed in a manner analogous to the contingent task analysis. In this analysis, it was assumed that the "primary" dimension was the one that determined which hand would be used, and the "secondary" dimension was the one that determined which finger would be used. A hand variable (left vs. right) was substituted in the filtering task analysis for the within-task discriminability variable in the contingent task analysis. A filter criteria were 375 and 525 msec for the filtering and contingent tasks and 600 and 800 msec for the condensation tasks. A pilot study revealed that the speed criteria specified for the contingent and filtering tasks would be unattainable in the condensation tasks. After each block, there was a 2-min. rest interval during which S was given a score sheet indicating the number of times he received each of the six feedback lights on the preceding block.

The Ss were instructed to strive for accuracy rather than speed on the practice block but after that to "go fast enough so that about 5 per cent of your responses are in error." The S was reminded of this if his error rate exceeded 25%.

To reduce visual and auditory distraction, S sat in a dimly lit room and wore earphones into which white noise was fed. The earphones were part of an intercom system which enabled E and S to communicate from their separate rooms.

Stimulus sequences were presented by a punch-tape system. A different sequence was used for each block. The sequences were generated so that each of the eight stimuli appeared eight times in both halves of each block. The 64 possible Trial N to Trial N + 1 stimulus pairs yielded approximately equal frequencies of the 16 possible Trial N to Trial N + 1 response pairs.

**Tasks.**—There were 10 tasks within each stimulus set: 6 of the 10 tasks were contingent tasks, 3 were filtering tasks and 1 was a condensation task. Table 1 shows the S-R assignments for the 10 tasks of Set A. Contingent tasks are symbolized by an initial "C" followed by the letter indicating the dimension which is primary: "C" for color, "S" for size, and "T" for tilt. The last letter, "H" or "L," indicates whether the task was high or low, respectively, in compatibility. Thus "CSL" indicates a contingent task with the size dimension as primary and which was low in compatibility. Filtering tasks are symbolized by an initial "F" followed by the letter indicating the dimension which was to be ignored. Thus "FC" refers to a filtering task in which color was the irrelevant dimension (tilt and size, therefore, would be the relevant dimensions).
bility was assigned to the right hand in five out of six tasks, both the filtering tasks and the low-
compatibility contingent tasks provided a control for hand effects.

Subjects.—The Ss were 188 University of Michigan undergraduate and graduate students who volunteered for paid participation. Ten Ss were assigned to each of the three filtering and six contingent tasks in Set A and in Set B. Four Ss were assigned to each condensation task in each set. An equal number of males and females was assigned to each task.

Data analysis.—For each S in the contingent tasks, an 8 × 8 matrix of mean RTs of correct responses on Trial N + 1 to all 64 possible stimulus shifts from Trial N to Trial N + 1 was constructed from the last three blocks of 128 trials. The first RT from each block was discarded because it had no immediate antecedent. A mean of the four means of the RTs to a particular value of the primary dimension on Trial N + 1 was computed. Thus the 8 × 8 matrix was collapsed into an 8 × 2 data matrix by ignoring differences in RTs between the four stimuli having the same value on the primary dimension on Trial N + 1. The 16 means were the data points used, after log transformation, in the analysis of variance. Each of the 16 means represented one combination of treatment levels in a 2 × 2 × 4 within-S factorial design in which the first variable was the relative discriminability of the secondary dimension that was relevant on Trial N + 1; the second variable was whether the primary dimension changed from Trial N to Trial N + 1;

Fig. 3. Trial N to N + 1 stimulus sequences showing categorization of stimulus changes for analysis of repetition effects. (Example is from Contingent Task CC (Set A) with color as primary dimension. Irrel. and rel. refer to changes in value(s) of secondary dimensions with respect to their status on Trial N + 1. Prim. refers to changes in value of primary dimension.)
and the third variable was the change from Trial $N$ to Trial $N + 1$ in the values of the secondary dimensions. There were four levels of this last variable: (a) both secondary dimensions had the same value on Trial $N + 1$ as they had on Trial $N$, (b) the irrelevant secondary dimension on Trial $N + 1$ changed its value from Trial $N$, but the relevant secondary dimension did not change value, (c) the relevant secondary dimension on Trial $N + 1$ changed its value from Trial $N$ but the irrelevant secondary dimension did not change value, and (d) both secondary dimensions changed value from the preceding trial. These categories are illustrated in Fig. 3.

RESULTS

Tasks.—Figure 4 shows that the task differences were relatively stable over practice. The condensation tasks were clearly the slowest in both sets (and also had the highest error rates). In general the contingent tasks were next in difficulty and the filtering tasks were easiest. The one exception to this is the FS task which was more difficult than most of the contingent tasks in both sets. Performance on this task was more comparable to the CTL task than to the filtering tasks.

Discriminability.—Figures 5 and 6 show that the orderings of the means of the contingent tasks were generally consistent with the orderings based on the discriminability of their primary dimensions. The differences among primary dimensions were highly significant, $F (2, 54) = 42.91, p < .001$, and $20.19, p < .001$, for Sets A and B, respectively. The exceptions to the orderings based on primary dimension
discriminability were that CCH was faster than CSH in Set A and that CCL was faster than CTL in Set B. Differences in RTs among the filtering tasks were also highly reliable, $F(2, 27) = 12.16, p < .001$, and $23.94, p < .001$, for Sets A and B, respectively. Within both sets, the ordering of RTs for the filtering tasks was consistent with the discriminability of the relevant dimensions.

Fig. 5. Mean correct RTs as a function of pairs of relevant dimensions (one primary and one secondary) from the last three 128-trial blocks for the high-compatibility contingent tasks. (Code in upper left-hand corner specifies the contingent task of the pair: $C =$ color primary, $CS =$ size primary, $CT =$ tilt primary. Dashed lines show corresponding RTs, matched by fingers, from filtering tasks with the same relevant dimensions.)

Fig. 6. Mean correct RTs as a function of pairs of relevant dimensions (one primary and one secondary) from the last three 128-trial blocks for the low-compatibility contingent tasks. (Code in upper left-hand corner specifies the contingent task of the pair: $CC =$ color primary, $CS =$ size primary, $CT =$ tilt primary. Dashed lines show corresponding RTs, matched by fingers, from filtering tasks with the same relevant dimensions.)
Figures 5 and 6 show mean RTs grouped in terms of the pair of dimensions that were relevant on that trial. In the contingent tasks in Set A, RTs from those trials when the more discriminable secondary dimension was relevant averaged 95 msec faster than RTs from those trials when the less discriminable secondary dimension was relevant, $F(1, 54) = 38.06, p < .001$. In Set B, this difference was 148 msec., $F(1, 54) = 97.89, p < .001$. It should be noted that when the least discriminable dimensions were relevant, i.e., tilt and color, RTs were still considerably faster than RTs on the condensation task (Fig. 4).

**Compatibility.**—In all cases, the low-compatibility tasks had longer RTs than the corresponding high-compatibility tasks (Fig. 4). In Set A, this main effect of compatibility fell short of significance, $F(1, 54) = 3.91, .05 < p < .10$, but is significant in Set B, $F(1, 54) = 20.49, p < .001$. The relatively large difference of 261 msec. between the CTH and CTL tasks in Set B resulted in a significant Primary Dimension X Compatibility interaction, $F(2, 54) = 5.74, p < .001$. In both sets, the $F$ ratios for the Compatibility X Secondary Dimension Discriminability interaction were less than 1.00. This indicates that the above-mentioned main
effect of secondary dimension discriminability in the high-compatibility tasks cannot be attributed to a left- versus right-hand effect.

Repetition effects.—The pattern of repetition effects was similar in the two sets as is shown in Fig. 7 and 8. In the contingent tasks, RTs averaged 130 msec longer when the primary dimension changed value from the preceding trial than when its value was repeated, $F(1, 54) = 164.49, p < .001$, in Set A, and 169.76, $p < .001$, in Set B. In the high-compatibility contingent tasks, such changes were confounded with hand changes. However, hand changes are insufficient to account for the effect since there was only a negligible increase in RTs when hand changes occurred in the FT and FC filtering tasks (Fig. 9 and 10). (The apparent exception is with FS which will be discussed later.) Moreover, the magnitude of the effect was approximately the same in the low- as in the high-compatibility contingent tasks; the Primary Value Change X Compatibility interactions were not significant, $F(1, 54) = 1.99$ in Set A and 2.46 in Set B. In the low-compatibility tasks, hand changes were required on only half of the trials when the primary dimension changed value. RTs from these trials were indistinguishable from RTs when the primary dimension changed value and a hand change was not required.

When only an irrelevant dimension changed value from Trial $N$ to Trial $N + 1$, RTs were longer than when the stimulus was repeated on successive trials. In both cases, repetition of the response was required. The magnitude of this repetition effect was directly related to the discriminability of the irrelevant dimension that changed value and it occurred in both the contingent and the filtering tasks (Fig. 7, 8, 9, and 10).

Errors.—Each contingent task error was classified in terms of (a) whether the error could be attributed to an incorrect identification of the value of the primary dimension, of the secondary dimension, or of both, and (b) whether the secondary dimension which was relevant on the trial in which the error was made was high or low in discriminability. For example, in the high-compatible CC task in Set A (Fig. 1), if a small green two o'clock stimulus was presented and $S$ responded with the left index finger, then the error was classified as a secondary error because a misidentification of the value of the relevant secondary dimension would have resulted in that...
response. If S responded with his right index finger, then the error was classified as primary because if S has misidentified the primary dimension, he would have responded on the basis of size. Errors that involved misidentifications of both the primary and the irrelevant secondary dimensions (S would have made this type of error if he had responded with his right middle finger) constituted only 6.5% of the total number of errors and were therefore omitted from the following analysis.

Table 2 shows the mean error frequencies for the last three blocks of 128 trials for the two-way classification of primary dimension and compatibility for both sets of contingent tasks. Within both sets there were significantly more secondary than primary errors: F (1, 54) = 51.90, p < .001 for Set A, and F (1, 54) = 27.81, p < .001, for Set B. The error rates were also related to the discriminability of the different dimensions. Of the 1,738 primary and secondary errors in Set A, 409 involved misidentifica-

### Table 2

**Mean Secondary and Primary Error Frequencies as a Function of Primary Dimension, Compatibility, and Secondary Dimension Discriminability for the Contingent Tasks of High and Low Compatibility in Sets A and B**

<table>
<thead>
<tr>
<th>Task</th>
<th>Low discriminability</th>
<th>High discriminability</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sec.</td>
<td>Pri.</td>
<td>Sec.</td>
</tr>
<tr>
<td>Set A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High compatibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>15.0</td>
<td>3.6</td>
<td>9.9</td>
</tr>
<tr>
<td>CS</td>
<td>13.2</td>
<td>1.1</td>
<td>12.0</td>
</tr>
<tr>
<td>CT</td>
<td>12.4</td>
<td>6.7</td>
<td>7.7</td>
</tr>
<tr>
<td>X</td>
<td>13.5</td>
<td>3.8</td>
<td>9.9</td>
</tr>
<tr>
<td>Low compatibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>12.9</td>
<td>6.0</td>
<td>4.5</td>
</tr>
<tr>
<td>CS</td>
<td>6.8</td>
<td>2.2</td>
<td>10.8</td>
</tr>
<tr>
<td>CT</td>
<td>7.7</td>
<td>9.9</td>
<td>11.0</td>
</tr>
<tr>
<td>X</td>
<td>9.2</td>
<td>6.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Set B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High compatibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>9.2</td>
<td>15.8</td>
<td>6.8</td>
</tr>
<tr>
<td>CS</td>
<td>17.9</td>
<td>2.6</td>
<td>10.2</td>
</tr>
<tr>
<td>CT</td>
<td>22.2</td>
<td>2.2</td>
<td>7.9</td>
</tr>
<tr>
<td>X</td>
<td>16.4</td>
<td>6.9</td>
<td>8.3</td>
</tr>
<tr>
<td>Low compatibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>6.7</td>
<td>9.1</td>
<td>3.2</td>
</tr>
<tr>
<td>CS</td>
<td>14.3</td>
<td>5.0</td>
<td>4.7</td>
</tr>
<tr>
<td>CT</td>
<td>14.1</td>
<td>6.8</td>
<td>5.0</td>
</tr>
<tr>
<td>X</td>
<td>11.7</td>
<td>7.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Note.—CC = color primary, CS = size primary, CT = tilt primary.

### Table 3

**Mean Primary and Secondary Error Frequencies as a Function of Dimension Discriminability**

<table>
<thead>
<tr>
<th>Error type</th>
<th>Relative discriminability of misidentified dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easy</td>
</tr>
<tr>
<td>Primary</td>
<td>4.8</td>
</tr>
<tr>
<td>Secondary</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Note.—Size was the easiest dimension to discriminate in both stimulus sets. In Set A, color was intermediate in discrimination difficulty and tilt was most difficult; in Set B, tilt was intermediate in discrimination difficulty and color was most difficult.

### Discussion

**Modes of processing.—**The results strongly support a self-terminating, feature-testing, contingent mode of processing. The differences among contingent tasks differing in primary dimension discriminability, as well as between contingent and condensation tasks, support a self-terminating, feature-testing mode rather than a template matching or exhaustive process. The sequential-by-discriminability mode is inconsistent with the finding that tasks with a primary dimension lowest in discriminability (CT in Set A and CC in Set B) were faster...
than the condensation tasks. When the dimensions that were lowest in discriminability were secondary and relevant, RTs were still faster than the condensation tasks. This result is not consistent with the sequential-by-primary mode.

If it is assumed that the component time distributions of the three dimensions were less than perfectly correlated and did not overlap, then the parallel contingent model would predict that there would be no difference in RTs in tasks in which the least discriminable dimension was relevant. Thus when the least discriminable dimension was secondary and relevant or primary in the contingent tasks, then RTs should have been equal to the RTs in the condensation tasks. In these cases, RTs would be determined by the dimension that was slowest to process. However, the condensation tasks were considerably slower than these contingent task RTs. In fact, even if there was some overlap in the component times, so that occasionally the condensation task would be limited by the more discriminable dimension, it would be difficult to produce a difference as large as 100 msec. between the condensation and these contingent tasks. It seems plausible, therefore, that the sequential contingent mode provides a more accurate description of S's processing.

A mode that is consistent with all the above results is the sequential contingent mode. The contingent modes are also consistent with the finding that more errors were attributable to misidentification of the value of the relevant secondary dimension, rather than of the primary dimension, although this result is also consistent with the sequential-by-primary mode. Given that RTs were related to the discriminability of the primary dimension and that there were more primary errors than secondary errors, the failure to find any appreciable effect of primary dimension discriminability on secondary error rates is evidence against parallel contingent processing. The small difference that was found was in a direction opposite to that expected from the parallel model. The finding that repetition effects were related to the primary-secondary status of the dimensions is additional evidence for the functional significance of the contingent relations.

Some additional comment is required, however, concerning those between-task comparisons that were inconsistent with the discriminability orderings derived from the data of the two-choice and filtering tasks. In discussing differences in performance attributable to differences in the dimensions that were processed, the primary emphasis has been on the discriminability (physical similarity) of the dimensions as the factor responsible for these differences in RT. While the reversal in difficulty of the CC and the CT tasks between Sets A and B indicated that physical similarity was operative in establishing differences among the contingent tasks, it is likely that other factors were also operative in producing differences among the contingent tasks within a set.

Under the general rubric of "codability," two factors, presumably operating relatively independently of physical similarity, deserve discussion. The first is related to the role played (or reflected) by specific language habits on performance in these tasks. There was much consistency among Ss in the order in which they identified the values of a dimensionalized pattern when they were asked to describe it. These orders typically corresponded to the most frequently occurring adjectival orders in the language. Such natural language stereotypes are illustrated when people tend to say BIG RED HOUSE rather than RED BIG HOUSE. In describing the stimuli used in these experiments, Ss would typically mention the value of the size dimension first, the value of the color dimension second, and the value of the tilt dimension last. Thus a stimulus was most often described as LARGE, GREEN, TWO O'CLOCK or SMALL, RED, TEN O'CLOCK, and rarely as TWO O'CLOCK, LARGE, GREEN OR RED, TEN O'CLOCK, SMALL. If these natural language orderings influenced the order in which dimensions were identified in these experiments, the sequence determined by the contingent mode of processing in the CS tasks, where size would be identified first, would be most consistent with the language sequence. The serial contingent mode of processing in the CT tasks would involve a sequence of identifications that would be most incompatible with the language sequence in that tilt was to be identified first. If the degree of correspondence between the adjectival sequence and the sequence determined by the contingent mode of processing determined the amount of interference (or facilitation) that would be produced from language habits (or some factor reflected by language habits), then the CT task would suffer maximal interference and the CS task the least interference. The CC task would be intermediate. This argument is supported by an examination of Fig. 5 and 6 which show that when size and tilt or color and tilt were
the relevant dimensions in the CT tasks, RTs were longer than when these pairs of dimensions were relevant in the CS or CC tasks, respectively. When color and size were the relevant dimensions, the prediction of RTs on the basis of the adjectival ordering is that RTs would be longer in the CC than in the CS task. This is contrary to the results shown in Fig. 5 and 6, but a direct comparison in this case is difficult to make in that when size was the relevant secondary dimension in the CC task, the right hand was used, while in the CS task, when color was the relevant secondary dimension, the left hand was used.

The second factor arises from difficulty in utilizing different S-R assignments or differences in S-R compatibility (Fitts & Seeger, 1953). Specifically, in the high-compatibility CT tasks and the FC tasks, it was possible to “code” the tilt dimension as a pointer in that the lower part of the diameter was in the portion of the circle which corresponded to the hand that was to be used in responding. For example, in the ten o’clock position, the lower portion of the diameter was in the right part of the circle and in some tasks the diameter was in the 10 o’clock position when the right hand was to be used. Some Ss who were assigned to these tasks reported that they employed such a coding scheme. It is possible that the extremely poor performance shown by Ss in the FS and low-compatibility FT groups was a result of their inability to use such a pointing code in processing the information from the tilt dimension. This explanation can resolve two inconsistencies in the ordering of the tasks determined on the basis of the discriminability of the relevant dimensions and the proportion of the time that they were relevant: (a) In the low-compatibility contingent tasks of Set B, CT results in longer RTs than CC even though in the high-compatibility conditions of that set CT is faster than CC (Fig. 4); and (b) in Set A, the difference in discriminability between the size and color dimensions was slight, but a sizable difference occurred between the FC (in which size and tilt were relevant) and the FS (in which color and tilt were relevant) tasks (Fig. 4). In the former filtering task, the tilt dimension was assigned in the more compatible “pointing” fashion, while in the latter task no consistent pointing code could be used since each hand had both tilt values assigned to it. If only discriminability was operative, then the difference between the FC and FS tasks would have been less than the difference between the FC and FT tasks since there was a comparatively large difference between the discriminability of the color and tilt dimensions.

The evidence for serial contingent processing would appear to be at variance with the evidence for parallel processing of multidimensional stimuli reported in other studies (Biederman & Checkosky, 1970; Hawkins, 1969). One possible resolution of this discrepancy is that the serial versus parallel modes represent an option available to the processor. In the present experiment, the instructions and/or contingent correlations could have induced a serial mode. Another possibility, stressed by Garner and Felfody (1970), is that the manner of processing a dimensionalized set of stimuli may depend on the specific stimulus dimensions used to generate the set. Following Shepard (1964) and Lockhead (1966), they distinguish between integral (or unanalyzable) and non-integral (or analyzable) stimulus dimensions, “the distinction phenomenologically being between dimensions which can be pulled apart, seen as unrelated, or analyzable, and those which cannot be analyzed but somehow are perceived as single dimensions. [Garner & Felfody, 1970, p. 225]." In a recent series of experiments, Garner and his associates (Felfody & Garner, 1971; Garner, 1970; Garner & Felfody, 1970) have argued that stimuli generated from integral dimensions typically yield results (e.g., redundancy gains) that have been interpreted as parallel processing, while nonintegral dimensions typically yield results that are consistent with serial processing. In the present experiment, the stimulus dimensions were most likely non-integral. Clearly, the diameter tilt was analyzable from the circle size or the background color. Since the appearance of the color was that of the background square and not that of the circle, it too was analyzable from the circle. Given these stimulus dimensions, it is not unexpected, from Garner’s (1970) position, that serial processing would occur. According to Garner’s integrality hypothesis, however, contingent processing should not be evidenced when identifying stimuli generated from integral dimensions (e.g., sizes and colors of shapes). This prediction awaits future test. The evidence supporting the serial contingent mode of processing bears some relevance to the taxonomic system proposed by Posner (1964, 1966). In Posner’s (1966) system, an issue was whether transformations were performed on sometimes relevant infor-
mation on trials when that information was not relevant. The shorter RTs in the contingent than in the condensation tasks may be regarded as evidence that such transformations were not (always) performed. However, the contingent tasks required more processing time than the filtering tasks. If transformations were not performed on the information from an irrelevant secondary dimension, then what is accounting for this additional time? One possibility is that time was required to "switch attention" from the primary to the secondary dimension. Such an explanation has been employed in the analysis of dichotic listening studies (Broadbent, 1958). Assume that this "switching time" is independent of the discriminability of the dimensions being processed. The difference in processing time between matched (for discriminability and responses) contingent and filtering tasks would be constant. It is, unfortunately, very difficult to employ such a "subtraction method" since, as discussed previously, discriminability might not have been the only factor determining differences in RTs. It is not surprising, therefore, that the relevant comparisons shown in Fig. 5 and 6 are not consistent on this point. Another possibility is that the sometimes relevant information, when it is not relevant, is "attenuated" but not filtered. Such an explanation has been advanced by Treisman (1964a, 1964b) to account for the effects of information from an irrelevant source during dichotic listening. Treisman's (1964a, 1964b) model would imply that stimulus identification in these tasks is dependent upon activation of one of six internal representations. These units correspond to the six stimulus values. The activation threshold of these units varies as a function of various task conditions and S's experience. In the contingent tasks, the units corresponding to the values of the primary dimension would have the lowest threshold. When one of these primary units is activated, the thresholds for the units corresponding to the relevant secondary dimensions would be lowered. For example, the two primary units for the CC task in Set A corresponded to the red and green values. If the "red unit" were activated, the threshold for the two units corresponding to the tilt values would be lowered. If the "green unit" were activated, the thresholds for the units corresponding to the size values would be lowered. This notion of a sequential facilitation between units has been employed by Treisman in her analysis of dichotic listening to speech (1964a).

Repetition effects.—A change in the value of the primary dimension resulted in longer RTs than did a change in the value of the relevant secondary dimension. This confirms Shaffer's (1965) finding that repetition effects for rules were of greater magnitude than repetition effects for signals to which the rules were to be applied. The present data confirm Shaffer's interpretation, but without the uncertainty as to which dimension was "primary" and which "secondary."

The difference in the magnitudes of the repetition effects for changes in the values of the two types of dimensions cannot be attributed to differences in the kind of response changes that they required. It will be recalled that in the high-compatibility contingent tasks a primary value change required a hand change. However, since differences in the magnitude of repetition effects for primary value changes versus secondary value changes also occurred in the low-compatibility tasks, where primary value changes did not always entail hand changes, then differences in the response changes that were required cannot be responsible for the effect. Moreover, in the FT and FC filtering tasks, which were similar to the high-compatibility contingent tasks with respect to the confounding of primary and secondary value changes with hand and finger changes, repetition effects of different magnitudes for the two types of response changes did not occur. It would thus appear that this difference in the magnitude of the repetition effects for primary and secondary dimensions, or to use Shaffer's (1965) terminology, for rules and signals, is specific to these functional variables rather than to differences in response dimensions.

An additional finding was that a primary value change eliminated any concomitant repetition effects attributable to changes in the values of the secondary dimensions. In other words, when the primary dimension in a contingent task changed value, the increment in RT which occurred as a result of this change was unaffected by simultaneous changes in the values of the secondary dimensions.

The repetition effects were largely associated with stimulus variables. RTs were lengthened when an irrelevant dimension changed value in the absence of changes in the values of any of the other dimensions and, therefore, in the
absence of response changes.\(^8\) That these repetition effects occurred in the filtering tasks, where the irrelevant dimension was never relevant, and, moreover, the magnitudes of these repetition effects were associated with the discriminability of the irrelevant dimension that changed value, adds additional support to the interpretation that at least part of the repetition effect must be attributed to variables that have their effect prior to response selection.

The one task that showed hand-change repetition effects was the FS task. Unlike the FC and FT filtering tasks, changes in the value of the primary dimension in the FS task resulted in longer RTs than those obtained when the secondary dimension changed value. A possible explanation for this discrepancy is that the color dimension in the FS task was employed in a manner similar to the way in which the primary dimensions were used in the contingent tasks. It was previously mentioned that in the FS task, \(S\) was unable to utilize a coding scheme for the tilt dimension such that the lower portion of the diameter would point to the appropriate hand. In the FS task, the coding was such that the value of the color dimension could be used to determine whether the upper or the lower portion of the diameter was pointing to the appropriate finger. Thus, when the color was green, the left hand was to be used and the lower portion of the diameter correctly pointed to the appropriate finger. When the color was red, the upper portion correctly pointed to the appropriate finger to be used on the right hand.

The finding that repetition effects can be attributed to stimulus and functional variations rather than response variations is not consistent with Williams' (1966) and Bertelson's (1963) response interpretation of the repetition effect. As such, the repetition effect holds promise of being a relatively sensitive dependent variable with which to study the effects of variations of task structure and input variables on information-processing behavior, as was implied by the recent work of Schvaneveldt and Chase (1969).

*Locus of effects in the information-processing sequence.*—The third general problem of this experiment was the specification of the locus of the use of contingencies in information handling. With the exception of the CT task in Set B, the low-compatibility conditions manifested similar orderings and repetition effects to the high-compatibility contingent tasks. If the utilization of the contingencies was dependent upon a direct selection of response dimensions, then their utility should have been reduced in the low-compatibility conditions and consequently the differences among the contingent tasks should have been decreased. That this did not obtain is evidence that these rules were being employed in stages prior to that involved in the selection of responses. The results of the compatibility variable were, therefore, consistent with the results of the repetition effect.

In ruling out response selection and execution effects as the locus of the contingent processing, caution must be exercised before effects are attributed to perceptual processes. Given the adjectival order and coding effects, and the independence in the error data of dimension discriminability and error type, it is quite likely that the contingencies were not affecting stimulus preprocessing or an initial read-in stage but, instead, were involved in a more central stage. While a number of paradigms are now available for the specification of effects at preprocessing or response selection stages (Sternberg, 1969), the middle ground is still relatively unexplored. It has been 14 yr. since Broadbent (1958) proposed his information-flow model and the difficulty still remains of conceptualizing the functions of the channel, although how information gets selected for it has come under intense investigation (Treisman, 1969). In fact, it is still not clear to what degree the channel should be conceptualized in terms of (a) a set of general stages (or transformations) whose mode of operation (but not duration) is relatively independent of the to-be-processed information and, (b) a set of events specific to the to-be-processed information.

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