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GENERALIZATION GRADIENTS AND STIMULUS CONTROL IN DELAYED MATCHING-TO-SAMPLE[1]

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Neurological patients were subjects in delayed visual matching-to-sample. The sample and choice stimuli were ellipses of varying size. By measuring the difference in size between the sample on a given trial and the ellipse the subject chose on that trial, gradients of differences between samples and choice stimuli could be plotted. These difference gradients broadened with increasing delays. Sharp gradients were controlled by the samples. Flat gradients were controlled by features of the choice display, independently of the samples. Intermediate gradients reflected combined control by the samples and by the choice displays.

A flat stimulus-generalization gradient may tell us simply that the stimuli specified within the continuum have failed to control the measured behavior differentially. A sharply peaked gradient may tell us that the positive or some other specified stimulus exerts precise differential control relative to the stimuli tested. These descriptive statements, involving little more than the reading of graphs, are consistent with the point of view, reviewed and amplified by Prokasy and Hall (1963), and Terrace (1966), that the stimulus generalization gradient is neither more nor less than a technique for measuring stimulus control.

This descriptive treatment, however, ignores a major implication of the position taken by Prokasy and Hall, who pointed out that the central issue is the definition of the effective stimuli:

> "What represents an important dimension of the physical event for the experimenter may not even exist as part of the effective stimulus for the subject. Similarly, the subject may perceive aspects of an experimenter event which have been ignored by, or are unknown to, the experimenter." (Prokasy and Hall, 1963, p. 312).

In these terms, one may consider a sharp gradient to mean that experimenter-specified stimuli are the effective ones, a flat gradient to mean that other stimuli are the effective ones, and an intermediate gradient to indicate that both experimenter-specified and one or more other identifiable stimuli are effective in controlling the subject's behavior. (An intermediate gradient may indicate that the experimenter-specified stimuli are effective, but that they control more than one response (Ray and Sidman, in press). The present discussion will be confined to the stimulus side of the controlling stimulus-response relation.) The assumption here is that changes of gradient shape reflect shifts in the stimuli which exert control, shifts not merely in differential control among the same stimuli, but shifts to stimuli not identified by the coordinates of the generalization curves.

The descriptive stimulus-control interpretation of the gradient assumes that only the amount of differential control within the stimuli of the test dimension changes. The flat gradient becomes peaked because (or when) the amount of differential control increases. The sharp gradient becomes less sharp because (or when) differential control decreases. An unstated assumption is that the same stimuli have

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controlled the subject's behavior both before and after the gradient changed.

Lashley and Wade (1946) interpreted the flat gradient as a failure of the subject to discriminate the relevant stimulus, and were challenged by Brown, Bilodeau, and Baron (1951) to define failure of discrimination "independently of the particular generalization reaction it is supposed to explain." The assumption that "failure to discriminate" reflects control by other stimuli makes independent definition possible. What is required is to demonstrate that the flat gradient reflects complete control by stimuli other than the ones specified by the experimenter, that the sharp gradient reflects little or no control from other sources, and that the gradient of intermediate slope is, indeed, the resultant of control shared by two or more identifiable stimuli. Such demonstrations are a major aim of the present paper.

Ray and Sidman (in press) have reported data from two monkeys, one of which gave a relatively sharp and the other, a relatively flat gradient along the dimension of line tilt. An eight-key simultaneous-discrimination procedure was used, with a different line tilt on each key. Key position, although a constant feature of the test situation and not systematically related to line tilt, was a likely alternative source of stimulus control. Indeed, both animals preferred certain key positions. It was possible to plot tilt generalization gradients separately for responses to the most-preferred key position, and for the combined responses to all other key positions. When they pressed nonpreferred keys, both animals had sharp tilt-generalization gradients. One animal's tilt gradient, however, was sharp for the preferred key position also; the other animal's tilt gradient for the preferred key was flat. The latter animal had the relatively flat overall tilt gradient. In this instance tilts, the training stimuli, and key position, a stimulus outside the training dimension, controlled each animal's responses. When key position interacted compatibly with line tilt, the overall tilt gradient was sharp; when key position exerted control that was relatively independent of line tilt, the overall tilt gradient was nearly flat.

This finding demonstrated that the slope of a generalization gradient along one stimulus dimension may be an inverse function of the amount of independent control exerted by other identifiable stimuli, even when the other stimuli are not systematically correlated with reinforcement. The term, independent, is critical. Different aspects of complex stimuli may exert either compatible (nonindependent) or incompatible (independent) control; only incompatible control will yield shallow gradients.

It is not to be expected that one will be able to identify the alternative sources of independent control which account for every observed instance of a flat or intermediate gradient. Therefore, many such demonstrations will be needed. This report will help serve that function, although it will not concern itself with factors that might influence the relative compatibility of different stimuli.

All reference in this paper is to differential control by stimuli, not to control by stimulus dimensions. Discussion of this point would lead us far afield; let it suffice to note here that the language is deliberate, stemming from the conviction that control by a whole dimension is unverifiable. Differential behavioral control may be exerted by stimuli classifiable along the same or different dimensions, but subjects respond differentially to the stimuli, not to the dimensions.

METHOD

Subjects

Although many subjects, brain-damaged and normal, have provided data on the delayed-matching procedure (*e.g.*, Rosenberger, Mohr, Stoddard, and Sidman, 1968; Sidman, Stoddard, and Mohr, 1968), only certain of the patients were affected adversely by the delays. These patients constituted a useful "preparation" for studying changes of stimulus control in individual subjects, and the data from seven of them are presented here. Although the concern here is not with brain damage *per se*, a brief description of each patient will accompany the presentation of his data.

Apparatus and Procedure

The subject sat in a small, sound-resistant room and faced a square matrix of nine translucent windows. The windows were each 2-in. square and were separated by 0.75-in. barriers. Light finger pressure on a window activated a switch mounted behind that window. Stimuli were rear-projected from slides onto the windows. The slides were punch-coded so that each could be identified by photocells that initiated appropriate electronic programming and recording signals to be correlated with the subject's responses.

Each trial began with a sample stimulus projected on the center window of the matrix; shutters, operated by rotary solenoids, kept the outer windows dark. The subject then pressed the sample window. In simultaneous matching, the sample press immediately exposed the choice stimuli on the outer windows. Then, the subject was to press the choice stimulus that matched the sample.

In delayed matching, the sample disappeared when the subject pressed it. After a delay, during which no stimuli were present, the choices appeared without the sample. Again, the subject was to press the choice stimulus which matched the (absent) sample.

When the subject matched correctly, a chimes sounded, a nickel (penny, for Subject H.M.) was delivered from an automatic dispenser, and all stimuli disappeared. After an intertrial interval of 1.5 sec, the next sample appeared on the center window. If the subject pressed an incorrect choice, the intertrial interval began without either chimes or nickel. The procedure was noncorrection.

Delay intervals were 0, (simultaneous disappearance of the sample and appearance of the choice stimuli), 8, 16, 24, 32, and 40 sec. Not all subjects were exposed to every delay. Most had 24 trials per delay, but some had 48. Some experienced the delays successively, starting with the shortest, and others were given the delays in a mixed sequence, in blocks of six trials at each delay. These variations, although not germane to the theses of this paper, will be noted. All subjects had experience with delayed-matching tasks that involved other stimuli than the ones used here, and no additional instructions were necessary. However, all were given preliminary practice at simultaneous and zero-delay matching in order to acquaint them with the stimuli of this experiment.

The stimuli were ellipses, with 1.00-in. major (horizontal) axes and minor axes of 0.17, 0.31, 0.39, 0.46, 0.61, 0.77, 0.89, and 1.00 inch. They are shown, actual size, in Fig. 1. The ellipses were not evenly spaced along any physical or subjective continuum; adjacent sizes were selected, by rough estimate, to be as easily discriminable from each other as possible. All ellipses appeared as choice stimuli on every trial, but the two extreme sizes (0.17 and 1.00) were never used as samples. Each of the remaining six ellipses appeared as a sample four (or eight) times at every delay. Consecutive trials presented different samples and different arrangements of ellipses on the outer windows.

Stimulus and Response Measurement

The ellipses can be classified along any of several dimensions, the most prominent of which are shape (ratio of minor to major axis), height (length of minor axis), and area. The specific dimension to which the subjects attended is not at issue here, and all are referred to indiscriminately as "size". It may be noted,

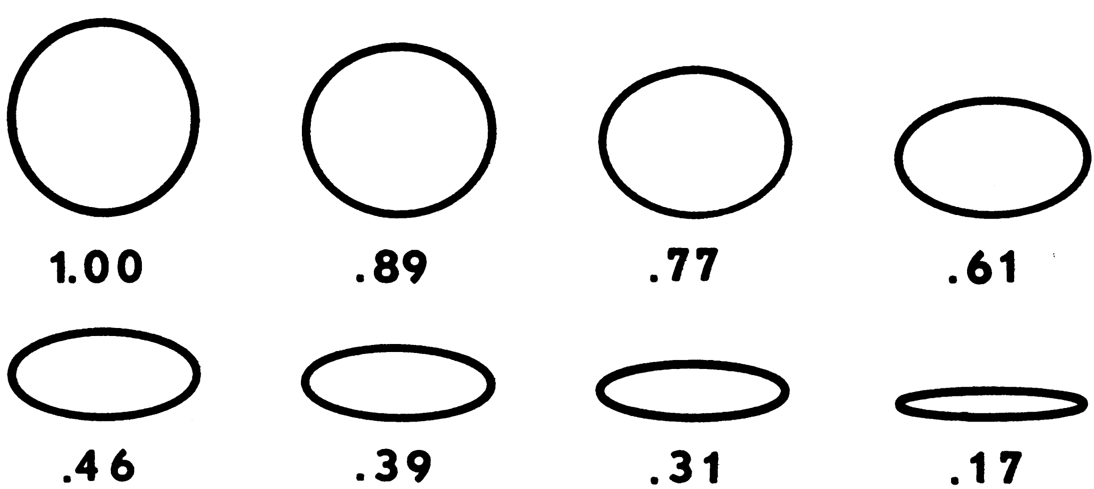

Fig. 1. The stimuli, actual size. Each is identified by its minor axis length (or the ratio of minor to major axis) in inches. The 1.00 ellipse is actually a circle.

however, that the constant 1-in. major axis makes the axis ratio and height numerically equal, and that the formula for area reduces to $\frac{\pi h}{4}$, where h is the minor axis. Therefore, area is directly proportional to height. For these reasons the ellipses have been classified in the results along the height dimension, inches.

The ellipses the subject selected from the choice display served to classify his responses. The datum of primary interest, the *gradient of sample control*, will summarize the differences between the sample ellipses and the ellipses actually chosen by the subject. To obtain the gradient of sample control each ellipse chosen was classified as a deviation from the sample, and the number of times the subject selected each deviation was recorded. If the subject matched correctly, the deviation between sample and choice was zero; if he chose, say, the 0.89 ellipse when the sample was the 0.77 ellipse, his choice was classified as a deviation of +0.12 inches; if he chose the 0.61 ellipse in response to the 0.77 sample, the deviation was −0.16 inches. Positive deviations may be regarded as overestimations of the sample size, and negative deviations as underestimations.

All deviations were not equally probable because adjacent ellipse sizes were not equally spaced, and because the size of the sample automatically restricted the range of possible deviations on a given trial. To illustrate the latter point, consider the extreme cases, with reference to Fig. 1. Suppose the sample on a given trial was the 0.89 ellipse. The only positive deviation available as a choice would be +0.11 (the 1.00 ellipse), but there would be six negative deviations from which to choose. If the sample was the 0.31 ellipse, one negative and six positive deviations would be available as choices. A middle-sized sample, *e.g.*, the 0.46 or the 0.61 ellipse, would eliminate the possibility of extremely large positive or negative deviations. Therefore, the subject had many more opportunities to select smaller than larger deviations. Because of these inequalities, the number of times the subject selected each deviation was divided by the number of opportunities available to the subject for each selection. Gradients of sample control were then plotted as choices of each deviation per opportunity.

Other classifications of stimulus control will be described in conjunction with the results.

RESULTS

Subject H.M.

H.M., male, age 41, had undergone radical bilateral excision of temporal-lobe structures 12 years earlier. Since then, he has been severely amnesic (Scoville and Milner, 1957; Milner, 1966; Milner, Corkin, and Teuber, 1968). The presentation of H.M.'s ellipse matching data will set the pattern to be followed with the other subjects.

Sample control. Solid curves in the left column of Fig. 2 show gradients of control by the sample stimuli at each delay. The point above zero on each abscissa represents correct choices (zero deviation in size from the sample). Points at the left of zero represent choices of ellipses increasingly smaller than the samples (negative deviations). Points at the right of zero represent choices of ellipses increasingly larger than the samples (positive deviations).

The simultaneous-matching gradient shows relatively sharp sample control. Seventy-seven per cent of the choices were correct, and most of the few incorrect choices were ellipses slightly smaller than the samples.

Control by the samples diminished with increasing delays. Although negative deviations (underestimations) predominated at 0- and 8-sec delays, H.M. shifted to overestimation at 16-sec delays. At 32-sec delays his choices per opportunity were spread relatively evenly from zero to the largest positive deviations.

Choice control. Was the change from a sharply peaked to a broad gradient accompanied by a shift in stimulus control from sample size to other stimuli? H.M.'s sample-control gradient at 32 sec suggested that he might have been selecting large ellipses indiscriminately, regardless of the sample size. Therefore, his choices were classified as absolute ellipse sizes, without reference to the samples, and were expressed as relative frequencies (number of choices/number of trials). The choice gradients in the center column of Fig. 2 show how frequently he selected each ellipse at each delay.

In simultaneous matching, H.M.'s choices were relatively evenly distributed among the six ellipses that were also used as samples, as was to be expected from his accurate performance. But with increasing delays, choice preferences developed. At 8- and 16-sec delays, H.M. preferred the middle-sized ellipses, but he shifted to larger choices at 24 and 32 sec. The choice display came to exert some control over his behavior.

"Control by the choice display" was, of course, involved even in accurate sample matching. The term, choice control, used here in a more restricted sense, may refer to any property of the choice display *except* the relation of the choice ellipses to the sample on a given trial.

Did control by the choice display influence the shape of the sample-control gradient? This possibility was evaluated by assuming that the subject's choices were actually independent of the samples. Such an assumption, if true, would require that the subject distribute his choices among the samples strictly in proportion to the relative frequency of each choice. For example, suppose H.M. had selected the circle (1.00 ellipse) on 50% of the trials at a given delay. If his choices were, in fact, independent of the sample sizes, he would have selected the circle on 50% of the presentations of each sample. Similarly, the relative frequency of each choice ellipse (center column) would determine its frequency of occurrence in response to each of the samples.

Theoretical sample-control gradients, based on the assumption that the choice display exerted control independently of the samples, were plotted. These are the dotted curves in the left column of Fig. 2. Because they depend on the actual distribution of the subject's choices among the various ellipses, the theoretical gradients differ from delay to delay and from subject to subject.

If the assumption of independent choice control were valid, the theoretical (dotted) and actual (solid) sample-control gradients would coincide. As was to be expected, the two curves for simultaneous matching were quite different. H.M. selected zero deviations much more often, and large positive and negative deviations much less often, than the assumption of independent choice-control predicted. But with increasing delays, the actual sample-control gradient conformed more closely to the prediction. Relatively complete sample control in simultaneous matching shifted to relatively complete control by the choice stimuli at 32-sec delays.

It should be pointed out that the experimental procedures and methods of data analysis do not, by themselves, artificially deter-

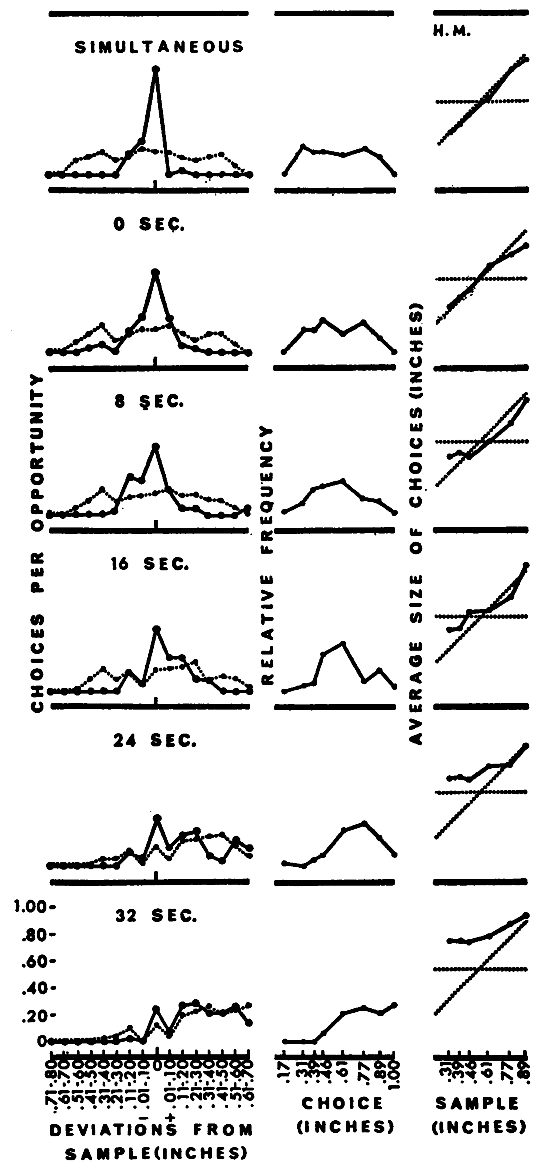

Fig. 2. H.M.'s actual sample-control gradients (solid curves in left column), choice gradients (center column), theoretical sample-control gradients (dotted curves in left column), and interaction analysis (right column), as described in the text. Delay intervals are consistent across rows. All ordinates have the same numerical scales, indicated at the lower left, but the numbers represent different variables in each column, as indicated by the ordinate labels. On the left-column abscissa, deviations from the samples have been grouped into classes 0.1-in. wide. This subject experienced the delays in ascending order and had 48 trials at each delay.

mine the predictability of one gradient from the other. There are only two extreme constraints: Only if the subject always chooses the same ellipse will the sample-control gradient necessarily be predictable from the choice preferences; only if the subject always chooses the correct matching ellipse will the choice gradient be completely determined. At the other extremes, even a flat choice gradient may be accompanied by either a sharp or a flat sample-control gradient; or a flat sample-control gradient may be accompanied by either a sharp or a flat choice gradient. If the actual and predicted sample-control gradients were flat and identical, but the choice gradients were flat also, then, of course, it could not be said that the choice display determined the shape of the sample-control gradient. In that instance, neither samples nor choices could be said to control the subject's behavior. Thus, before asking if the choice gradient determined the shape of the sample-control gradient, it was necessary to show that choice preferences did exist.

Although H.M.'s choice preferences became more pronounced, at least up to 16-sec delays, and the area between theoretical and actual sample-control gradients decreased steadily, the correspondence between theoretical and actual gradients was never complete. Even at 32 sec, accurate choices (zero deviations) occurred slightly more often than was predicted from the choice preferences. The inference to be drawn is that both sources of control contributed to the shape of the sample-control gradients, but that the relative contribution of each varied as a function of the delay interval.

Combined control. Having established that the actual controlling stimuli shifted as the sample-control gradients broadened, and that both sources of control contributed to the shape of the intermediate gradients, it becomes relevant to inquire more precisely into the nature of the combined control over the subject's behavior.

To evaluate the combined control by sample sizes and choice displays, the average size of the ellipses chosen by the subject was determined for each sample separately. The solid curves in the right column of Fig. 2 show the average choice size as a function of the sample size at each delay.

If the average size of the subject's choices was completely determined by the samples, without bias toward over- or underestimation, the solid curve would coincide with the diagonal dotted line, as it did fairly closely in simultaneous matching. Here, H.M. slightly underestimated 0.89 and 0.61 sample ellipses. At zero delay, he underestimated the 0.89 and 0.77 samples.

If the average choice was controlled by the samples but was inaccurate, the solid curve would be parallel to, but displaced from the diagonal dotted line. For example, at 8-sec delays H.M. slightly underestimated the four largest sample ellipses, but the slope of the curve indicated that his average choices were related to these samples.

If the subject's selections were unrelated to the samples, and were, instead, completely determined by stimuli in the choice display, the solid curve would be horizontal. Its location relative to the horizontal dotted line would depend on the size of the preferred choices. (The horizontal dotted line is located at the median of the choice-ellipse sizes.) Control by the choice display began to develop at 8-sec delays; when the samples were 0.31, 0.39, and 0.46 ellipses, the average size of H.M.'s choices remained constant and just below the median.

Slopes between the diagonal line and the horizontal reflect combined sample and choice control, the steepness of the curve indicating which source of control predominated. H.M.'s curves changed in slope from 45 degrees to near-horizontal with increasing delays, indicating a shift from exclusive sample control at simultaneous matching, to combined sample and choice control at intermediate delays, and to nearly exclusive choice control at 32 sec.

Combined control by samples and choices is demonstrated not only by intermediate linear slopes, but by nonlinear curves also. It is tempting to interpret the right-column, 8-sec curve, as showing that features of the choice display completely determined the subject's responses to the smallest samples; that the sample sizes completely determined his responses to the largest samples; and that only when the data were averaged over all samples, as in the left column, did the two sources of control seem to combine. The averaging process in the left column did, indeed, hide the varying degrees of control by different samples, but it would not be correct to say that either choice or sample control was complete at any *one* sample size. The evaluation of stimulus control always requires measurement of responses to at least two stimuli. If lines were drawn from the average choice at each of the smallest samples to the average choice at each of the largest samples, the steep slopes would show considerable differential control within each small-large pair. The 0.31 sample, for example, exerted no differential control with respect to the 0.46 sample, but considerable differential control when measured against the 0.89 sample. An accurate interpretation of the 8-sec curve in the right column is that there was no differential sample control among the three smallest samples, relative to each other; nearly maximum differential sample control among the four largest samples, relative to each other; and combined sample and choice-display control within all small-large sample pairs. Thus, choice or sample control which varies with sample size demonstrates an interaction between the two sources of control, and produces a nonlinear curve in the righthand column.

At 16-sec delays the slope became shallow between the 0.46 and the 0.77 ellipses, indicating that sample sizes within this range were beginning to lose differential control, relative to each other. The trend continued until, at 32-sec delays, there was no longer any sign of exclusive differential sample control. All samples were overestimated, and the shallow overall slope revealed all pairs of samples to exert either no differential control at all or to share control with the choice display. The small residue of combined control is consistent with the nonindependence of the choice control which was revealed by the comparison of actual and predicted gradients in the left column.

Summary of H.M.'s data. Sample-control gradients became broader with increasing delays (solid curves in left column). Choice preferences developed (center column) as sample control deteriorated. Choice control became increasingly independent of the samples at longer delays, and the sample-control gradients became more predictable from the choice preferences alone (comparison of dotted and solid curves in the left column). Exclusive sample control shifted to combined sample and choice control (right column) when the initially sharp sample-control gradient assumed intermediate slopes. Combined control faded into nearly independent choice control as the gradient approached the horizontal.

Data from other patients will demonstrate that the findings are not confined to any particular neurological condition. Furthermore, not all patients preferred the same ellipses, nor were their forms of combined sample and choice control identical. These variations will demonstrate that the phenomena are not artifacts of the ellipse series or other constant aspects of the experimental procedure.

Subject J.B.

J.B., male, age 51, had been left unconscious after a physical assault, and was found to have a large mass lesion deep in the left postero-frontal-temporal region. An intracerebral clot was surgically removed. His oral speech was severely impaired, but he had no obvious memory disturbance. The present data were obtained 3 yr after he suffered the lesion.

Sample control. The solid curves in the left column of Fig. 3 show a sharp deterioration of sample control upon the change from simultaneous to zero-delay matching. J.B.'s choices

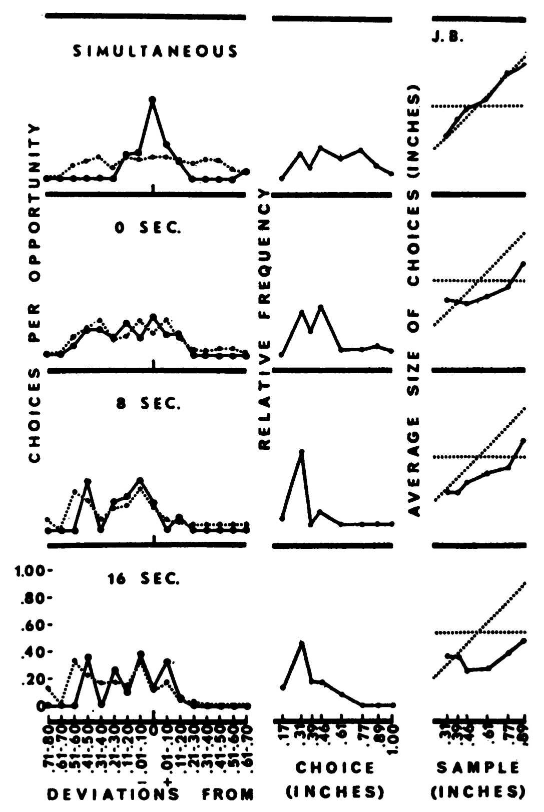

Fig. 3. Subject J.B.'s data, like Fig. 2 except that he had 48 trials each at simultaneous and zero delay, and 24 trials at 8 and 16 sec.

were predominantly ellipses smaller than the samples (negative deviations) at delays of 0, 8, and 16 sec. Even at 16-sec delays, however, he avoided the extreme negative deviations.

Choice control. When sample control deteriorated, J.B. developed a preference for small ellipses (center column of Fig. 3).

At delays of 0 to 16 sec, the theoretical sample-control gradients (dotted curves in the left column), computed from the choice frequencies alone, predicted the actual gradients fairly closely. Differences between the two gradients were inconsistent, except for the theoretical overestimation of the number of large negative deviations at 8 and 16 sec, and of large positive deviations at 0 and 8 sec.

Combined control. Nearly exclusive sample control was apparent in simultaneous matching (right column of Fig. 3).

In zero-delay matching, the horizontal slope from 0.31 to 0.46 samples shows choice control within this range. The 0.77 and 0.89 samples showed exclusive but inaccurate differential sample control. All other pairs of samples revealed combined sample and choice control.

Even though the choice preference sharpened at 8-sec delays, control by the choices became less independent of the samples, as indicated by the somewhat steeper slope of the 8-sec curve in the right column. Although sample control increased, it was still inaccurate (underestimation). This is consistent with the peak at small negative deviations in the 8-sec sample-control gradient, and with the excess of actual over predicted deviations at and near the peak.

At 16-sec delays control by the small choices predominated, with a remnant of exclusive but inaccurate differential sample control within the largest samples.

Although J.B. preferred small ellipses and H.M. (Fig. 2) preferred large ellipses, choice control was strongest in both subjects within the range of small samples. Therefore, no consistent correlation need exist between the range of ellipse sizes preferred by the subject and the sample range within which choice control predominates.

Subject S.J.K.

S.J.K., male, age 20, suffered a concussion in an automobile accident, followed by a period of amnesia which eventually became restricted to the events immediately before the accident. The present data were obtained when the general amnesia had almost completely disappeared.

Sample control. The gradients of sample control were relatively sharp at all delays (left column of Fig. 4), but from 0 to 40 sec the peak shifted to the right, indicating slight overestimation of the sample sizes.

Choice control. Evidence of choice control was present from 0 to 40 sec (middle column) but, as might have been expected from the relatively sharp sample-control gradients, choice control proved only a poor predictor of the sample-control gradients. Differences between predicted and actual gradients, shown only at 40-sec delays, were similar at all delays.

Combined control. Choice control was evident within the range of the smallest sample

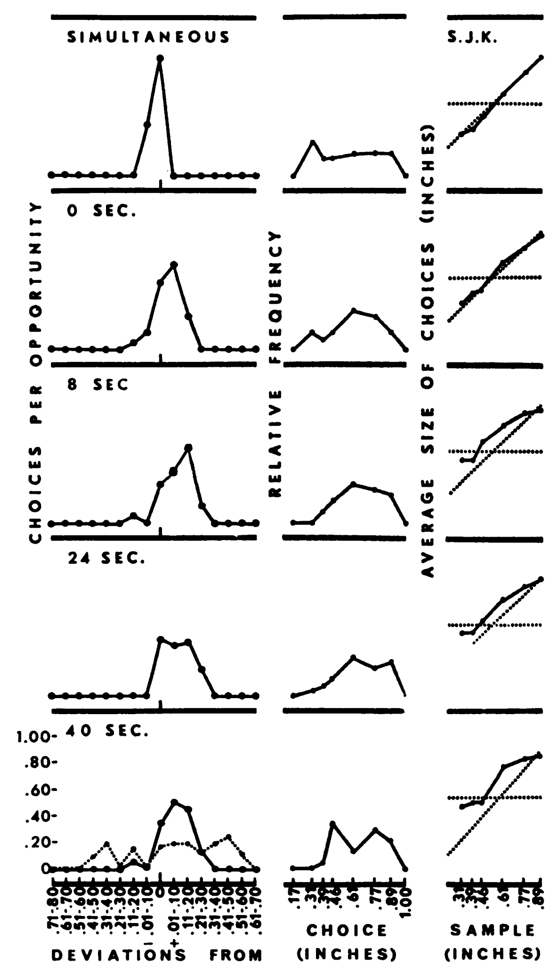

Fig. 4. Subject S.J.K., like Fig. 2, except that he had 24 trials at each delay.

ellipses (right column; 8, 24, and 40-sec delays), but the steepness of the curves indicated that S.J.K.'s behavior was almost completely controlled by the samples, with some tendency toward overestimation. Even though S.J.K.'s choice preferences at 8, 24, and 40 sec (middle column) were at least as sharp as H.M.'s at 40 sec (Fig. 2), S.J.K.'s choice control was clearly less independent of the samples; hence, his choice gradients had less influence on the shape of his sample-control gradients.

Subject V.C.C.

V.C.C., female, age 60, suffered a cerebral infarction, affecting the distribution of the left middle cerebral artery. She was aphasic, with no obvious memory disorder. The present data were obtained one month after the stroke.

Sample control. The solid curves in the left column of Fig. 5 show the peak of V.C.C.'s sample-control gradient shifting gradually toward larger positive deviations with increasing delays. As the peak shifted, the gradient broadened. A suggestion of sample control remained at 24 sec, where the subject never selected extremely large positive or negative deviations.

Choice control. The center column of Fig. 5 shows the development of a relatively sharp choice gradient, peaked at the 0.61 ellipse. With increasing delays, theoretical sample-control gradients, computed from choice frequencies alone (dotted curves in the left column), accounted more completely for the actual gradients. Theoretical gradients, however, consistently underestimated actual choices per opportunity at the shifting peaks.

Combined control. At zero delays, differential sample control predominated between sample pairs that included the largest and smallest ellipses (right column of Fig. 5), but the slope of the curve in the middle range of sample sizes revealed combined sample and choice control within that range.

The interaction between sample and choice control was similar at 8-sec delays except for the subject's tendency to choose larger ellipses in response to smaller samples at the low end of the sample-size range.

At 16-sec delays, the trend which began at 0 sec became more pronounced. Nearly exclusive differential sample control remained between ellipses at the extreme ends of the curve, although it was inaccurate (overestimation) at small sample sizes. But the combined control that occurred within the middle range of sample sizes at shorter delays shifted to choice control at 16 sec; the curve became flat in the middle range of samples.

Exclusive but inaccurate differential sample control remained at 24-sec delays only between the smallest sample ellipses. Otherwise, the choice display exerted nearly complete control. Thus, control by the small samples, which took the form of consistent overestimation, was largely responsible for the discrepancy between the actual and theoretical gradients at 24 sec in the left column.

There was more sample control at 16-sec than at 24-sec delays, even though V.C.C.'s choice gradient was sharper at 16 sec. This again illustrates the principle that the sample-control gradient is a function not simply of

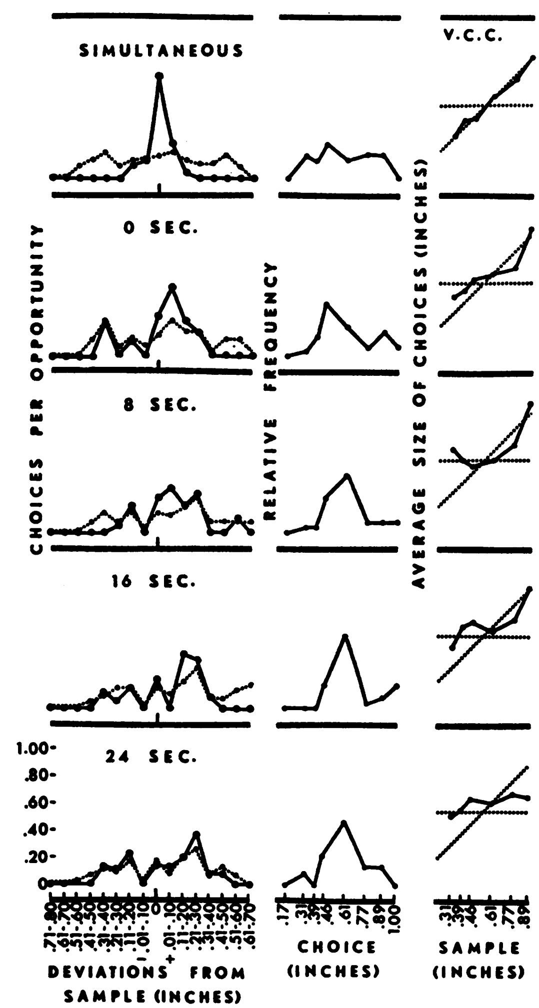

Fig. 5. Subject V.C.C., like Fig. 4.

concurrent choice control, but also of the degree to which choice control is independent of the samples.

V.C.C.'s data revealed the strongest choice control when preferred ellipses were also the samples. This type of interaction between sample and choice control was similar to that of J.B. (Fig. 3), except that J.B. preferred small ellipses and V.C.C. preferred middle-sized ellipses. In contrast, H.M. (Fig. 2) showed strongest control by the choices when nonpreferred ellipses were the samples.

Subjects E.J.R., M.D., and E.T.T.

These patients were nearly-classic examples of Korsakoff's disease, and showed the severe memory disturbance characteristic of this disorder. E.J.R. and M.D. were female, age 48 and 57, respectively. E.T.T., male, was 59 yr of age. Their data, shown in Fig. 6, 7, and 8, are intended to serve the following functions: A. Replication of the findings already described; B. Controls for the order in which the delays were presented. Unlike the previous subjects, who experienced the delays in ascending order, these subjects were given the mixed sequence (see Method); C. Controls for disease category; D. To illustrate certain additional features of the data analysis and interpretation.

These subjects, particularly M.D. (Fig. 7), were somewhat more variable than the others, possibly because of the mixed scheduling of the delays. All sample-control gradients, however, deteriorated with increasing delays (solid curves in the left columns). All subjects displayed choice preferences (middle columns) when the sample-control gradients broadened. Sample-control gradients were more strongly determined by the choice gradients as a function of increasing delays (comparison of solid and dotted curves in the left columns). For all subjects, combined control emerged from exclusive sample control as the delays lengthened, and became exclusive or nearly exclusive choice control at those delays that were the longest.

E.J.R.'s choice gradient at zero delay (Fig. 6, center column) was sharply bimodal. Yet, the corresponding sample-control gradient was markedly peaked. Similarly, M.D.'s bimodal choice gradient at 24-sec delays (Fig. 7) was correlated with a pronounced, though displaced, peak in the corresponding sample-control gradient. However, at delays of 32 and 40 sec, M.D.'s bimodal choice gradients were correlated with relatively weak sample control. These observations demonstrate once again that in the absence of specific and complete choice control, or of perfect sample control, it is not possible to reconstruct one gradient by knowing the other. The type of interaction between the two sources of control becomes the determining factor, and the interaction is a feature of the individual subject's behavior, not of the analytic methods.

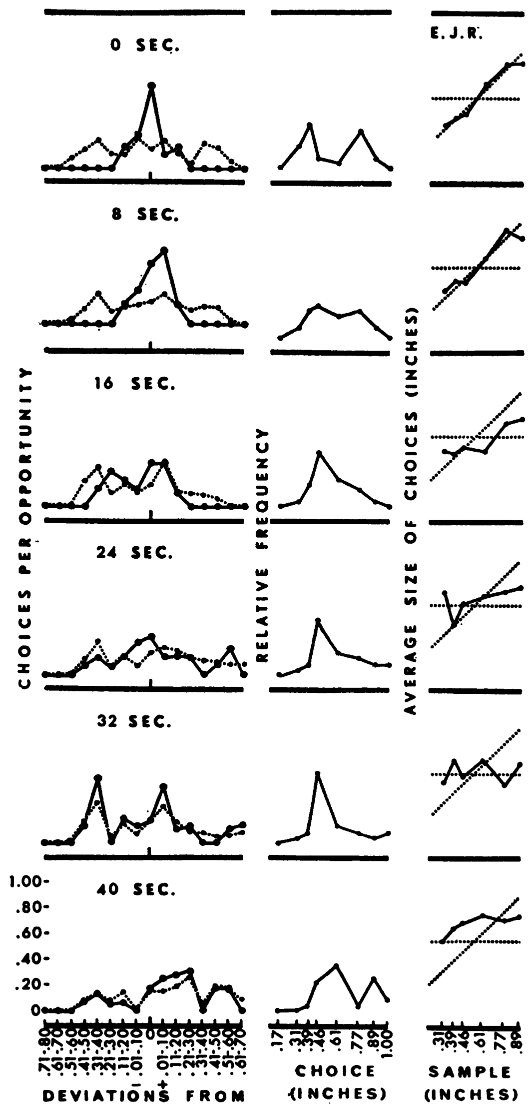

Fig. 6. Subject E.J.R. experienced the mixed sequence of delays and had 24 trials at each. Her simultaneous matching, not shown here, was only slightly better than the zero-delay performance.

DISCUSSION

Two sources of stimulus control were identified in delayed matching-to-sample. One source was the sample stimuli. The other was the choice display. With increasing delays, behavioral control shifted from the samples to the choice displays, independently of the samples. Sharply peaked gradients of sample control were shown to reflect nearly exclusive control of the subjects' behavior by the sample stimuli. Broad gradients of sample control reflected nearly exclusive control by the choice displays. Intermediate sample-control gradients resulted when samples and choice displays combined to control the subjects' behavior.

These data are not consistent with the view that the same stimuli control a subject's behavior both before and after a change in gradient shape, and that the new gradient only reflects shifting differential control among stimuli of the test dimension. Rather, the data demonstrate that gradient changes are accompanied by shifts to new sources of stimulus control. Furthermore, the greater the independence of the new sources of control, the more they de-

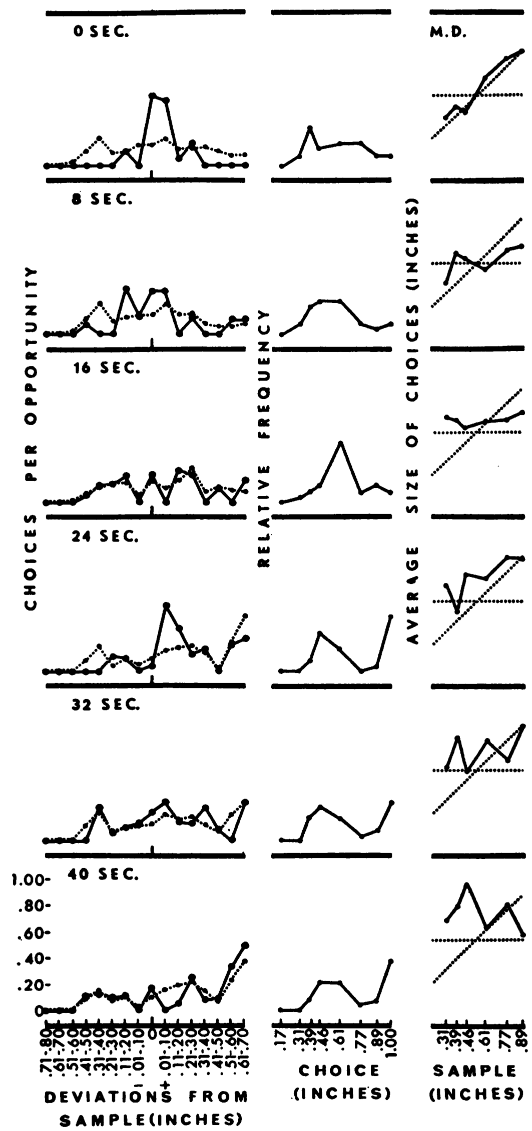

Fig. 7. Subject M.D., like Fig. 6.

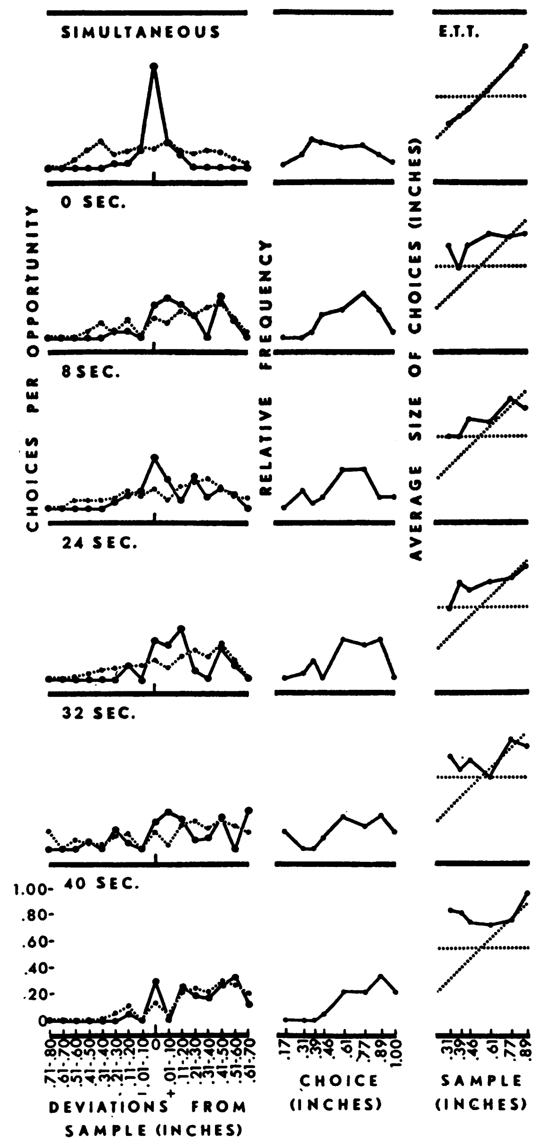

Fig. 8. Subject E.T.T., like Fig. 6 and 7. His 16-sec delay performance, omitted here, was like the one at 24 sec.

termine the shape of the gradient along the original dimension.

Although a major purpose of this paper was to demonstrate that the shape of the sample-control gradient was a function of combined control from two sources, that purpose, once accomplished, diminished in importance. Intermediate and flat gradients became exposed as devices for masking multiple sources of control. The masking was accomplished by inaccurate experimenter-specification of the relevant stimuli and by averaging across them. It then became of greater importance to separate out the several sources. When this was done, various patterns of control were revealed. In some instances, samples or choice displays exerted nearly exclusive control over the subject's responses. In other instances, samples and choices exerted joint control; the subject selected the preferred choices when they were within a certain range of size deviations from the sample. Intermediate between exclusive and joint control were instances in which the average choice was invariant within one range of sample sizes, but within another range was determined either by the samples alone or by samples and choices combined.

The present data do not answer the question: does combined, or even joint, control refer to simultaneous action of both stimuli? The alternative possibility is that one stimulus or the other, sample or choice display, actually exerted exclusive control on any given trial but that the pooling of data over several trials masked fluctuations from trial to trial. By presenting all choice stimuli to the subject simultaneously, the amount of information gained from each response was increased, and the number of trials necessary for the averaging process was greatly reduced (Ray and Sidman, in press). But until methods are devised that permit identification of the controlling stimulus after the subject has responded only once, the problem of simultaneous *vs.* exclusive but fluctuating control will be answerable only by theoretical inference (*e.g.*, Cross, 1965*a*).

Although control by the samples was consistent with the reinforcement contingencies, the development of control by the choice display was not predictable on behavioral or logical grounds. It might easily have proven impossible to discover any source of control to account for the intermediate and flat gradients. Competing control might have shifted so frequently among several sources other than samples or choice displays as to be unidentifiable; or the experimenter simply might not have been aware of all the possibilities. In this experiment there were undoubtedly sources of control besides those selected for analysis. A relatively obvious candidate was key position. Some patients (none in this report at the time these experiments were done) have, in fact, preferred keys on the left or right side of the matrix. Three-way control by samples, choices, and key positions, however, could not be evaluated because of the small number of trials.

These considerations emphasize that the identification of alternative sources of stimulus control remains a problem of empirical discovery. Failures do not disprove the existence of such control. The very absence of a theoretical basis for evaluating negative evidence, however, requires that there be many confirmatory demonstrations. Competing control of the individual subject's behavior by several aspects of complex stimuli has been identified in simple discriminations, matching, and oddity (*e.g.*, Blough, 1963; Cumming and Berryman, 1965; Ferster and Hammer, 1966; Harlow, 1950; Jenkins, 1965; Johnson and Cumming, 1968; Revesz, 1925; Shepard, 1964; Sidman and Stoddard, 1967; Skinner, 1965). The rules by which reinforced unidimensional stimuli may combine to produce multidimensional control have been investigated (*e.g.*, Atkinson, Calfee, Sommer, Jeffrey, and Shoemaker, 1964; Butter, 1963; Cross, 1965*a*, *b;* Johnson, 1966; Shepard, 1964; White, 1958). However, apart from the present data, there has been only one demonstration (Ray and Sidman, in press) that an experimentally irrelevant gradient of stimulus control can influence the shape of a gradient along another stimulus dimension, and that the extent of its influence is related to the type of interaction between the two gradients. The number of such demonstrations required for the stimulus-control interpretation of the generalization gradient to be accepted will be a matter of individual preference.

It should not be inferred that the development of control by the choice display was responsible for the breakdown of sample control. The suggestion has been presented elsewhere, on independent grounds, that stimulus control other than that intended by the experimenter develops as a result of factors which render the subject unable to respond in concordance with the scheduled contingencies (Sidman and Stoddard, 1966, 1967; Stoddard and Sidman, 1967). Here, the increasing delays, interposed between sample disappearance and presentation of the choice stimuli, were directly responsible for the loss of sample control over the subject's choice responses. The development of control by the choice display must be considered a consequence, not a cause, of the deterioration of sample control.

Although choice control did not initiate the breakdown of sample control, it did contribute to the shape of the sample-control gradients once the latter began to broaden. Furthermore, because choice control was not systematically reinforced, its gradient shape and its interaction with sample control varied, even among subjects who showed markedly similar changes in their sample-control gradients, and among subjects with the same neurological diagnosis.

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