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ASSESSING CONTROL BY ELEMENTS OF COMPLEX STIMULI IN DELAYED MATCHING TO SAMPLE

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A series of six experiments examined delayed identity matching-to-sample performances of subjects with mental retardation. The stimuli were either one or two simultaneously displayed forms. When the reinforcement contingencies required that only one form exert discriminative control, all subjects achieved high accuracy scores. However, accuracy scores were substantially lower when the contingencies required discriminative control by two forms, suggesting restricted stimulus control. The decline in matching accuracy appeared to reflect selective losses of conditional control by sample stimuli and shifts in control to features of the comparison stimulus displays. The experiments suggest improved techniques for assessing control by complex stimuli and for evaluating the effects of procedures that seek to broaden restricted stimulus control. The results challenge interpretations based on stimulus-generalization decrement or shared attention.

Key words: complex stimulus control, delayed matching to sample, stimulus overselectivity, restricted stimulus control, generalization decrement hypothesis, shared attention hypothesis, individuals with mental retardation

Studies of humans with mental retardation and autism often demonstrate a phenomenon termed "stimulus overselectivity" (Lovaas, Schreibman, Koegel, & Rehm, 1971) or "restricted stimulus control" (Litrownik, McInnis, Wetzel-Pritchard, & Filipelli, 1978). A common procedure for studying this phenomenon first establishes discriminative control by a complex stimulus composed of two or more elements presented simultaneously. The elements may be from the same modality (e.g., visual; Wilhelm & Lovaas, 1976) or different modalities (e.g., auditory and visual; Lovaas & Schreibman, 1971). On subsequent tests, the elements are presented separately to assess their independent control of responding. Typically, only one element of the complex exerts discriminative control; the others are apparently ignored. However, all elements tend to exert discriminative control when normally capable comparison subjects are exposed to the same procedures. Control is deemed "restricted" or "overselective" relative to these comparison subjects.

Studies of restricted stimulus control have used a variety of simple and conditional discrimination procedures. The research has shown that the phenomenon is replicable and is not specific to procedure or stimulus modality (e.g., Burke, 1991; Lovaas, Koegel, & Schreibman, 1979; Meisel, 1981; Schneider & Salzberg, 1982; Smeets, Hoogeveen, Striefel, & Lancioni, 1985). Restricted stimulus control can occur even when all stimulus complex elements are shown to be discriminable from one another before discrimination training (Dube, Kledaras, Iennaco, Stoddard, & McIlvane, 1990). Further, the tendency to display restricted control may be modifiable, at least in some cases, by arranging reinforcement contingencies that explicitly require broader control (Allen & Fuqua, 1985; Huguenin, 1985; Schreibman, Charlop, & Koegel, 1982).

The many studies in this tradition, however, have done relatively little to characterize the nature of stimulus control when it is restricted (cf. Bickel, Richmond, Bell, & Brown, 1986; Bickel, Stella, & Etzel, 1984). Also, there has been almost no effort to relate the findings to relevant studies with nonhuman subjects (e.g.,

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Born & Peterson, 1969; Reynolds, 1961). One reason for the present series of studies was to ascertain whether restricted stimulus control would be evident in a delayed identity matching-to-sample procedure with complex sample and comparison stimuli. This procedure has been used to study conceptually related phenomena in pigeons and monkeys (e.g., D'Amato & Salmon, 1984; Riley, 1984; Riley & Roitblat, 1978). For example, in one delayed matching procedure, the sample stimulus complexes consisted of superimposed form and color elements. The comparison stimuli were forms on some trials and colors on others. Because a brief delay intervened between sample removal and comparison presentation, these procedures required discriminative control by both colors and forms to obtain all reinforcers available in the situation. The typical finding is that monkeys' and pigeons' accuracy scores are significantly lower than those obtained when delayed matching requires discriminative control by a single color or form element (e.g., Cox & D'Amato, 1982; Maki & Leith, 1973; Maki & Leuin, 1972; Maki, Riley, & Leith, 1976; Richards & Bowers, 1985; Roberts & Grant, 1978).

The present series of experiments used delayed matching procedures much as they were used with the nonhuman subjects. We compared the performance of humans with mental retardation on delayed matching trials that presented either complex (two-element) or simple (one-element) form stimuli. We asked whether restricted stimulus control would be evident and how the results might compare with those from pigeons and monkeys. An inference of restricted stimulus control was made when a subject's matching accuracy showed a decrement on trials that required discriminative control by two stimulus forms, relative to accuracy scores on trials that required discriminative control by one form.

Our analyses of matching-to-sample procedures extend their prior use in the assessment of restricted stimulus control (cf. Litrownik et al., 1978; Schneider & Salzberg, 1982). Although used sparingly in this research area, these procedures may help to clarify the discriminative difficulties that lead one to infer that stimulus control is restricted (cf. Litrownik et al., 1978). We also asked whether any performance decrements on delayed matching trials could be characterized as shifts to other scores of stimulus control (Sidman, 1969). In this respect, we sought to extend the "microanalyses" of restricted stimulus control initiated by Bickel and colleagues using simple discrimination procedures (Bickel et al., 1984, 1986).

GENERAL METHOD

Subjects

Seven individuals (4 females, 3 males) with mental retardation were studied. DC, JO, EM, MM, and PA served in Experiments 1 through 5; DC, CP, and JT served in Experiment 6. Their chronological ages ranged from 17 (JO) to 76 (MM) years (M = 47). For 6 subjects, mental age scores on the Peabody Picture Vocabulary Test ranged from 3 years 8 months (JT) to 7 years 7 months (AP) (M = 5 years 6 months). A hearing impairment precluded such testing with CP. All served in prior discrimination studies but none had experienced the present procedures.

Apparatus and Setting

A Macintosh® computer with a touch-sensitive screen presented stimuli and recorded data. The screen display consisted of five white "keys" (4.5-cm squares) on a gray background. Sample stimuli appeared on the center key, and comparison stimuli appeared on the four outer keys. Sessions were conducted in a quiet area at the subject's school or institution. An experimenter, seated behind and to the subject's right, monitored all sessions.

Matching-to-Sample Procedure

Sessions occurred three times per week; each consisted of 64 trials and took about 10 min. The upper portion of Figure 1 shows the six sets of forms (about 1 cm by 1 cm) used as sample and comparison stimuli in one or more experiments, along with the alphanumeric designations that will be used to refer to specific forms within each set (A1, B1, A2, B2).

Trials began when one or two forms appeared on the center (sample) key. On simultaneous matching trials, a touch to the sample key was followed immediately by the comparison stimuli; one or two forms appeared on each of two outer keys, and the other two keys were blank. The sample remained present throughout the trial and further touches to it

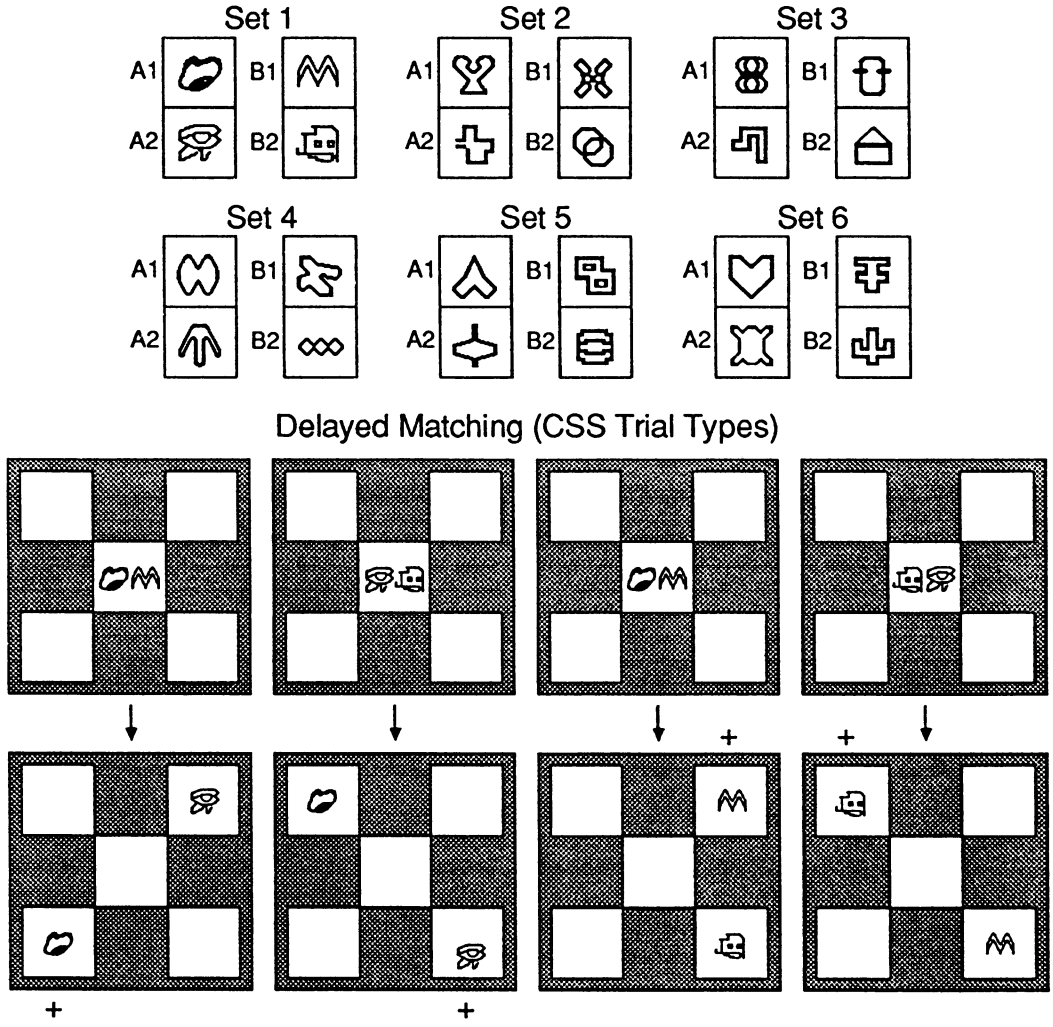

Fig. 1. At the top are six stimulus sets used in the experiments. Lower panels illustrate delayed matching with CSS trial types: matching one-element simple comparison stimuli to two-element complex sample stimuli. Trials began with a sample stimulus displayed on the center key of the display (upper row of panels). A touch to the sample removed it from the display and produced the comparisons (lower row of panels) in two of the outer keys.

had no programmed consequences. On delayed matching trials, a touch to the sample key was followed by the immediate removal of the sample forms and the presentation of the comparison forms, either immediately (0-s delay) or 1 s later (1-s delay). A touch to the positive comparison stimulus key (see below) was followed by the removal of all forms, a flashing computer screen, a melodic tune, and a 1.5-s intertrial interval with all keys blank. A touch to the negative comparison stimulus key was followed only by the removal of forms and the intertrial interval. At the end of each session, subjects received 1 penny for each correct trial. The sample and the positions of the comparisons varied unsystematically from trial to trial.

Various trial types displayed different combinations of one- and two-element (i.e., form) sample and comparison stimuli. Trial types are designated according to the three-letter system of Cox and D'Amato (1982). "S" and "C" (for "simple" and "complex") designate one- and two-element stimuli, respectively. Left-to-right order designates the sample, the positive comparison, and the negative comparison. For example, the lower portion of Figure 1 illus-

trates delayed CSS trials with stimulus Set 1. Two-element samples appear on the center key (top row), and two one-element comparisons appear on outer keys (bottom row). The positive comparison is identical to one element of the sample. An alphanumeric description of the trial shown in the first set of panels is A1B1:A1(A2), where stimuli are described in the format sample:S+(S−) (see Table 1, below). The three remaining sets of panels show A2B2:A2(A1), A1B1:B1(B2), and B2A2:B2(B1) trials. Within each stimulus set, two-element samples always consisted of either A1 and B1 or A2 and B2; the A1B2 and A2B1 combinations were never presented.

EXPERIMENT 1

Experiment 1 compared performance on four trial types: SSS trials involved one-element samples and one-element comparisons (e.g., A1:A1[A2] from Table 1); CSS trials involved two-element samples and one-element comparisons (e.g., A1B2:A1[A2]); SCC trials involved one-element samples and two-element comparisons (e.g., A1:A1B1[A2B2]); and CCC trials involved two-element samples and two-element comparisons (e.g., A1B1:A1B1[A2B2]). The primary question was whether there would be a difference in delayed matching accuracy on the four trial types. Unlike the other three types, contingencies on CSS trials required discriminative control by both sample elements on each trial to obtain the maximum available reinforcers. Subjects could not predict which of the two forms would appear as the positive comparison after the sample disappeared. SSS, SCC, and CCC trials required stimulus control by only one element—the single element presented on the first two trial types and either element on the third type. To the extent that stimulus control is restricted to one element, subjects' delayed matching accuracies should be superior on these latter three trial types compared to their accuracy scores on CSS trials.

METHOD

Table 1 shows the four trial types included in each 64-trial session; there were 16 trials each of SSS, CSS, SCC, and CCC types. Both simultaneous and delayed matching procedures were used. Figure 2 (top) illustrates some of the trials. JO was exposed to simultaneous procedures with only three different stimulus sets, each for three sessions (because of JO's low accuracy scores on simultaneous CSS trials). The other subjects were exposed to three-session blocks of both simultaneous and delayed procedures. The simultaneous procedures familiarized the subjects with the various trial types and served as a comparison condition for performance on delayed trials. To assess the generality of any observed effects, the number of stimulus sets varied across some subjects. All delays were 0 s, except for some of AP's sessions that included 1-s delays. (AP's delay was lengthened because accuracy scores in 0-s delay matching were consistently high across all trial types.)

RESULTS

Figure 3 shows accuracy scores for individual subjects calculated as the percentage of positive comparison selection for each trial type. Each data point shows the score for one trial type in one three-session block; bars indicate the range of individual session scores.

JO's simultaneous matching scores were typically very high on SSS, CCC, and SCC trials. By contrast, scores on CSS trials were substantially lower, although JO's scores improved from the second to fourth blocks of trials. For DC, EM, and MM, accuracy scores were uniformly high on all simultaneous trials. Delayed matching scores were typically high on all but CSS trials. AP's accuracy scores were high on all simultaneous and 0-s delay trials. With AP, a difference in accuracy between the CSS and other trial types was seen at 1-s delays.

Except for JO's generally improved performance across three-session blocks of trials, none of the subjects' accuracy scores on CSS trials fluctuated in any consistent manner within a particular three-session block or across the three-sessions blocks. For example, JO's average score of 79% on the first block of simultaneous CSS trials reflects consecutive scores of 88%, 75%, and 75%; JO's 92% score in the fourth block reflects scores of 94%, 88%, and 94%. Likewise, DC's average score of 75% on the first block of delayed CSS trials reflects consecutive scores of 88%, 81%, and 56%; DC's 83% score in the second block reflects scores of 69%, 94%, and 88%.

Table 1

Trial types used in experiments. Reading from left to right, a trio of uppercase letters denote the sample, positive comparison, and negative comparison for a particular trial type and whether one-element (S) or two-element (C) stimuli are involved. The alphanumeric descriptions of trial types correspond to the stimuli shown in Figure 1. Samples are denoted to the left of the colon, positive comparisons and negative comparisons (in parentheses) to the right.

Experiment 1			
SSS trials			
A1:A1(A2)	A2:A2(A1)	B1:B1(B2)	B2:B2(B1)
CSS trials			
A1B1:A1(A2)	A2B2:A2(A1)	A1B1:B1(B2)	A2B2:B2(B1)
A1B1:A1(B2)	A2B2:A2(B1)	A1B1:B1(A2)	A2B2:B2(A1)
B1A1:A1(A2)	B2A2:A2(A1)	B1A1:B1(B2)	B2A2:B2(B1)
B1A1:A1(B2)	B2A2:A2(B1)	B1A1:B1(A2)	B2A2:B2(A1)
SCC trials			
A1:A1B1(A2B2)	A2:A2B2(A1B1)	A1:B1A1(B2A2)	A2:B2A2(B1A1)
B1:A1B1(A2B2)	B2:A2B2(A1B1)	B1:B1A1(B2A2)	B2:B2A2(B1A1)
A1:A1B2(A2B1)	A2:A2B1(A1B2)	A1:B2A1(B1A2)	A2:B1A2(B2A1)
B1:A2B1(A1B2)	B2:A1B2(A2B1)	B1:B1A2(B2A1)	B2:B2A1(B1A2)
CCC trials			
A1B1:A1B1(A2B2)	A2B2:A2B2(A1B1)	A1B1:A1B1(B2A2)	A2B2:A2B2(B1A1)
A1B1:B1A1(A2B2)	A2B2:B2A2(A1B1)	B1A1:A1B1(B2A2)	B2A2:A2B2(B1A1)
B1A1:B1A1(A2B2)	B2A2:B2A2(A1B1)	B1A1:B1A1(B2A2)	B2A2:B2A2(B1A1)
B1A1:A1B1(A2B2)	B2A2:A2B2(A1B1)	A1B1:B1A1(B2A2)	A2B2:B2A2(B1A1)
Experiment 2			
CSC trials			
A1B1:A1(A2B2)	A2B2:A2(A1B1)	A1B1:B1(B2A2)	A2B2:B2(B1A1)
B1A1:A1(A2B2)	B2A2:A2(A1B1)	B1A1:B1(B2A2)	B2A2:B2(B1A1)
A1B1:A1(B2A2)	A2B2:A2(B1A1)	A1B1:B1(A2B2)	A2B2:B2(A1B1)
B1A1:A1(B2A2)	B2A2:A2(B1A1)	B1A1:B1(A2B2)	B2A2:B2(A1B1)
CCS trials			
A1B1:A1B1(A2)	A2B2:A2B2(A1)	A1B1:B1A1(A2)	A2B2:B2A2(A1)
B1A1:A1B1(B2)	B2A2:A2B2(B1)	B1A1:B1A1(B2)	B2A2:B2A2(B1)
A1B1:A1B1(B2)	A2B2:A2B2(B1)	A1B1:B1A1(B2)	A2B2:B2A2(B1)
B1A1:A1B1(A2)	B2A2:A2B2(A1)	B1A1:B1A1(A2)	B2A2:B2A2(A1)
Experiment 3			
CCC* trials			
A1B1:A1B1(A1B2)	A2B2:A2B2(A2B1)	A1B1:A1B1(B1A2)	A2B2:A2B2(B2A1)
A1B1:A1B1(B2A1)	A2B2:A2B2(B1A2)	A1B1:A1B1(A2B1)	A2B2:A2B2(A1B2)
A1B1:B1A1(A1B2)	A2B2:B2A2(A2B1)	A1B1:B1A1(B1A2)	A2B2:B2A2(B2A1)
A1B1:B1A1(B2A1)	A2B2:B2A2(B1A2)	A1B1:B1A1(A2B1)	A2B2:B2A2(A1B2)
B1A1:A1B1(A1B2)	B2A2:A2B2(A2B1)	B1A1:A1B1(B1A2)	B2A2:A2B2(B2A1)
B1A1:A1B1(B2A1)	B2A2:A2B2(B1A2)	B1A1:A1B1(A2B1)	B2A2:A2B2(A1B2)
B1A1:B1A1(A1B2)	B2A2:B2A2(A2B1)	B1A1:B1A1(B1A2)	B2A2:B2A2(B2A1)
B1A1:B1A1(B2A1)	B2A2:B2A2(B1A2)	B1A1:B1A1(A2B1)	B2A2:B2A2(A1B2)
Experiment 5			
SCS trials			
A1:A1B1(A2)	A2:A2B2(A1)	A1:B1A1(B2)	A2:B2A2(B1)
A1:A1B1(B2)	A2:A2B2(B1)	A1:B1A1(A2)	A2:B2A2(A1)
B1:A1B1(A2)	B2:A2B2(A1)	B1:B1A1(B2)	B2:B2A2(B1)
B1:A1B1(B2)	B2:A2B2(B1)	B1:B1A1(A2)	B2:B2A2(A1)
SSC trials			
A1:A1(A2B2)	A2:A2(A1B1)	B1:B1(B2A2)	B2:B2(B1A1)
A1:A1(A2B1)	A2:A2(A1B2)	B1:B1(B2A1)	B2:B2(B1A2)
A1:A1(B2A2)	A2:A2(B1A1)	B1:B1(A2B2)	B2:B2(A1B1)
A1:A1(B1A2)	A2:A2(B2A1)	B1:B1(A1B2)	B2:B2(A2B1)

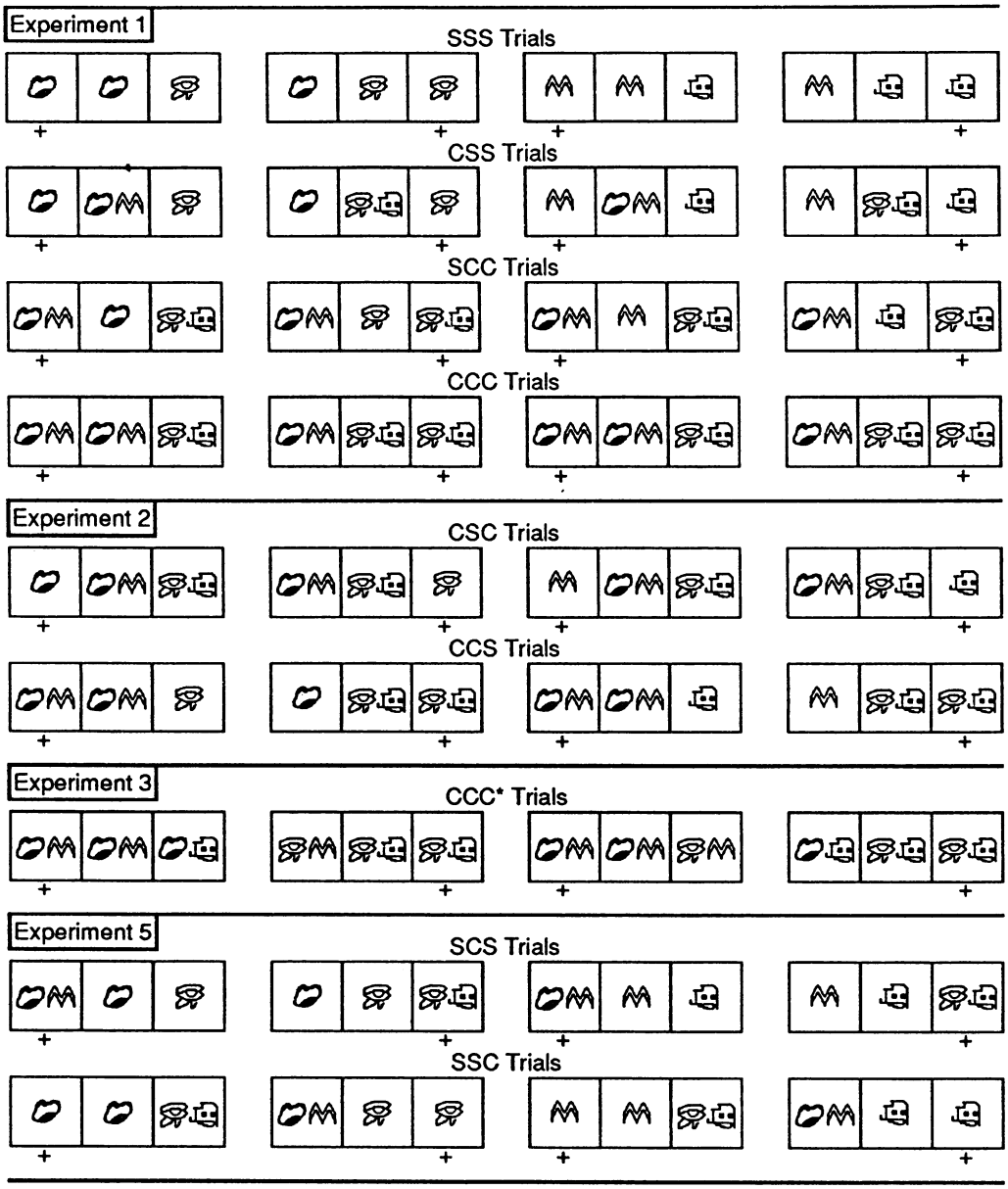

Fig. 2. Illustrative trial types (Set 1 stimuli) showing samples (center) and comparisons (sides). Actual trials involved five-key displays as shown in Figure 1.

Discussion

These results suggest that subjects' matching performances were often not controlled by both sample elements on certain CSS trials under the simultaneous (JO), 0-s delay (DC, EM, MM), and 1-s delay (AP) conditions. The conclusion of restricted stimulus control is apt because of subjects' superior performances on trials requiring delayed matching of only one stimulus element. The relatively low CSS accuracy scores cannot be attributed merely to problems matching a one-element stimulus to an identical element of a two-element stimulus; accuracy scores were high on SCC trials, which also had this requirement.

Why did JO's simultaneous CSS scores resemble the delayed CSS scores of the other

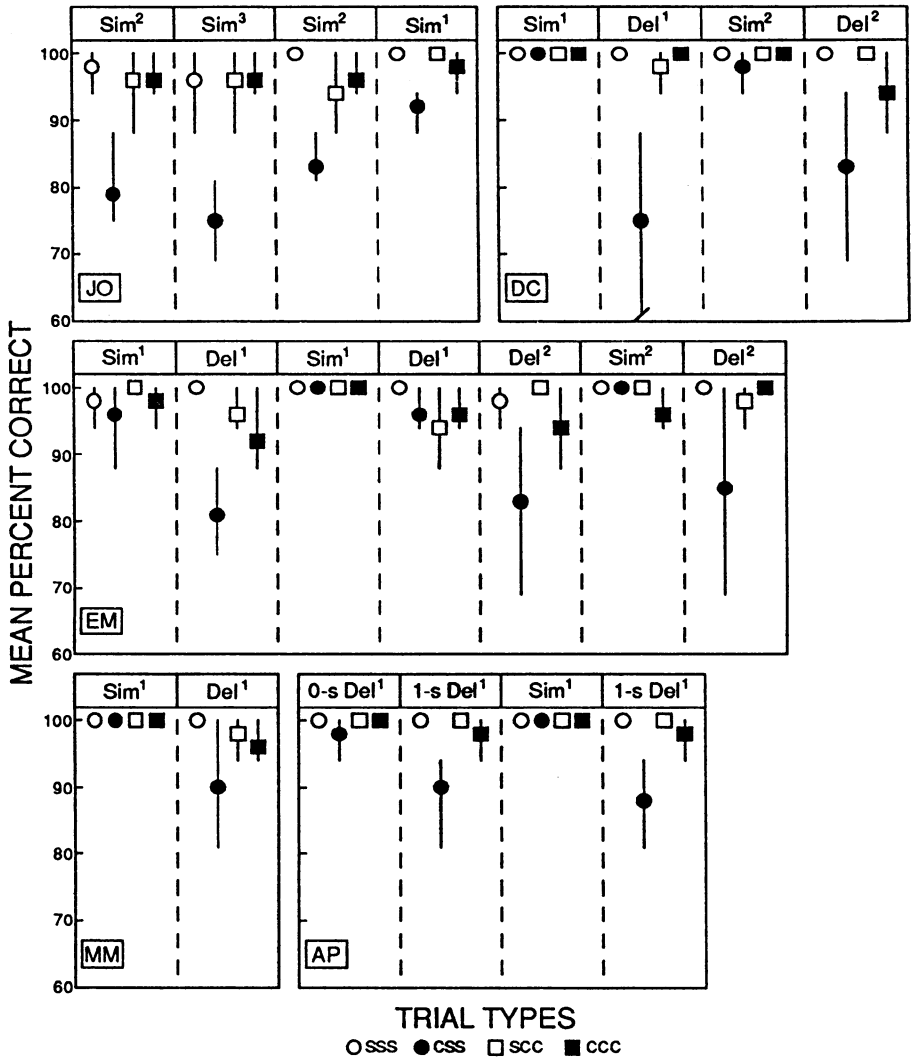

Fig. 3. Experiment 1 results. Dashed vertical lines separate three-session blocks given under simultaneous (Sim) or delayed (Del) matching conditions (the numerical superscript indicates the stimulus set used; see Figure 1). Sessions involved the four trial types listed on the abscissa. Data points reflect the mean percentage correct for a given trial type; dark vertical lines denote the range of percentages (diagonal line indicates range extends below 60%).

subjects? Limited observation of the sample is one possible reason. It seems reasonable to speculate that the other subjects also looked at only one element on their initial sample observations. If the trial was a simultaneous CSS trial, and they looked at the element that was not displayed as the positive comparison, they could shift their gaze back to the sample stimulus, look at the other element, and then make a positive comparison selection. JO may not have done this consistently. If so, JO's observing behavior on some simultaneous trials resembled that of the other subjects on delayed matching trials in that there was no reobservation of the sample. Perhaps supporting this speculation, JO's average response latency on the CSS trials was shorter (1.4 s) than any other subject's (DC, 2.0 s; EM, 2.3 s; MM, 2.5 s; and AP, 1.8 s).

EXPERIMENT 2

To assess the generality of the initial findings, the procedures of Experiment 1 were

systematically replicated. The SCC and CCC trial types were replaced by CSC and CCS trials. On CSC trials, the sample had two elements, the positive comparison had one element (identical to a sample element), and the negative comparison had two elements (neither identical to a sample element). Like CSS trials, CSC trials required discriminative control by both sample elements. Thus, if stimulus control were restricted to single elements, there should be a decrement in matching performance on both CSS and CSC trials. CCS trials displayed two sample elements, two identical positive comparison elements, and one nonidentical negative comparison element. Although these trials required control by only one of the two sample elements, they were needed to maintain conditional discrimination of one- versus two-element comparison displays. One-element comparisons were positive on CSC trials, and two-element comparisons were positive on CCS trials.

Method

The same 5 subjects served. Sessions included 64 trials, 16 each of SSS, CSS, CSC, and CCS trials (see Table 1 and Figure 2). JO received one block of three simultaneous matching sessions. The others each received at least one block each of simultaneous and delayed procedures. For AP, 1-s delays were used in these and all subsequent sessions; 0-s delays were used with the other subjects.

Results

Figure 4 shows the results. JO never selected a negative comparison on any SSS and CCS trial. Accuracy scores on CSS and CSC trials were 88% and 69%, respectively. Simultaneous scores were uniformly high for the other subjects. In delayed matching, scores on SSS and CCS trials were substantially higher than those on CSS and CSC trials. As in Experiment 1, subjects' accuracy scores on CSS and CSC trials varied unsystematically within and across three-session blocks.

Discussion

The earlier findings were replicated; lower accuracy scores were observed on trials requiring subjects to discriminate two elements, suggesting restricted stimulus control. Although the same stimulus sets were used as in Experiment 1, further experience with the procedures did not improve accuracy scores (cf. Figures 3 and 4). Note also that CSC scores were almost always lower than CSS scores for all subjects. This result suggested another possible controlling variable on CSC trials. Perhaps subjects occasionally ignored form differences and selected the (negative) comparison that had the same number of elements as the sample (cf. Cox & D'Amato, 1982). This possibility was investigated further in Experiment 5.

EXPERIMENT 3

Accurate performance on CCC trials in Experiment 1 required discriminative control by one sample element only. Experiment 3 examined a delayed CCC trial type that required control by both elements. On CCC* trials, the positive comparison had two elements that were identical to the sample; the negative comparison had one element identical and one element nonidentical. As on CSS and CSC trials in prior experiments, restricted stimulus control would predict relatively lower accuracy scores on CCC* trials.

Method

The same subjects served. Sessions included four trial types, 16 each of SSS, CSS, CCC, and CCC* (see Table 1 and Figure 2). Four subjects received both simultaneous and delayed matching sessions; DC received only simultaneous matching sessions.

Results

Figure 5 shows that simultaneous and delayed performance on all SSS and CCC trials was highly accurate. For the first time, JO achieved high accuracy scores on simultaneous CSS trials, due perhaps to more experience with the procedures. The other subjects continued their accurate performance on simultaneous CSS trials. On simultaneous CCC* trials, however, 4 subjects (JO, DC, EM, and MM) displayed relatively lower initial accuracy scores. With continued exposure to the procedures, CCC* scores improved markedly for EM and MM but not for JO and DC. In delayed matching, scores were typically lowest on CSS and CCC* trials, which required stimulus control by both sample elements. Scores

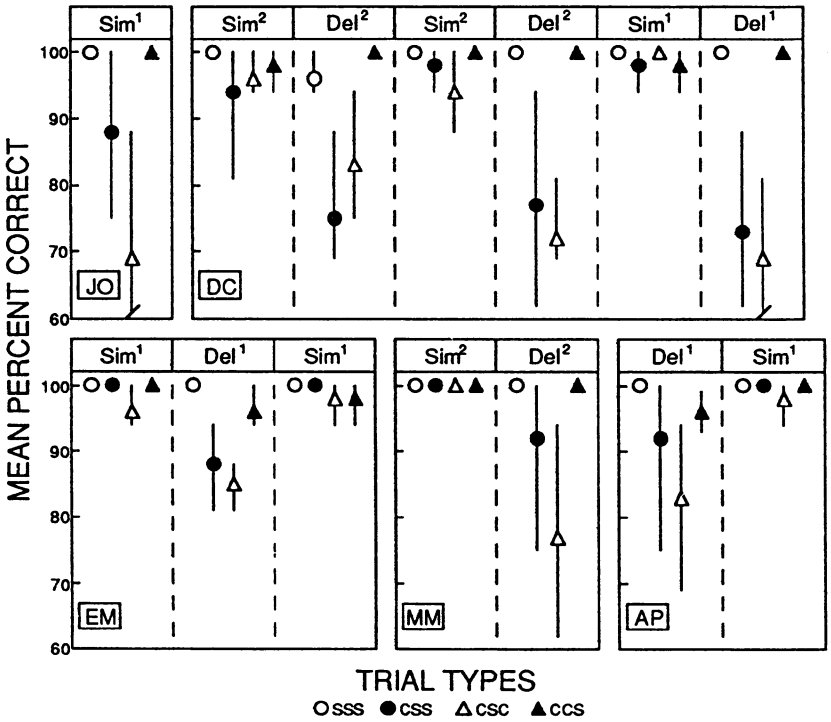

Fig. 4. Experiment 2. See Figure 3 for details.

on both trial types were comparable for JO, AP, and EM (second block). Subjects' accuracy scores on delayed CSS and CCC* trials varied unsystematically within three-session blocks.

Discussion

Subjects' difficulties with delayed CSS trials replicated prior data suggesting restricted stimulus control. Comparable difficulties on CCC* trials may also reflect problems of restricted stimulus control. Problems here, however, may stem from inadequate observation of the stimulus display, much as we speculated for JO's lower scores on CSS and CSC trials in previous experiments. In the present experiments, the subjects' relatively lower scores on simultaneous CCC* trials were likely due to their histories with the other trial types. Before Experiment 3, a comparison stimulus that had any element in common with the sample had always been the positive stimulus. On CCC* trials, however, some comparison stimuli with elements in common with the samples were negative for the first time. Therefore, additional learning was required to meet these new requirements. Evidence of learning is especially evident when one compares the first and second simultaneous matching sessions of EM and MM. The possibility of restricted control on CCC* trials was examined further in the next experiment.

EXPERIMENT 4

Experiment 4 asked if accuracy on CCC* and CSS trials would improve if their numbers were increased relative to trials that required discriminative control by one sample element.

Method

All 5 subjects continued. In Phase 1, sessions consisted of 32 CCC and 32 CCC* trials. DC received simultaneous procedures only; the others received both simultaneous and delayed matching procedures. In Phase 2, sessions included 32 SCC and 32 CSS trials; all subjects received both simultaneous and delayed matching procedures.

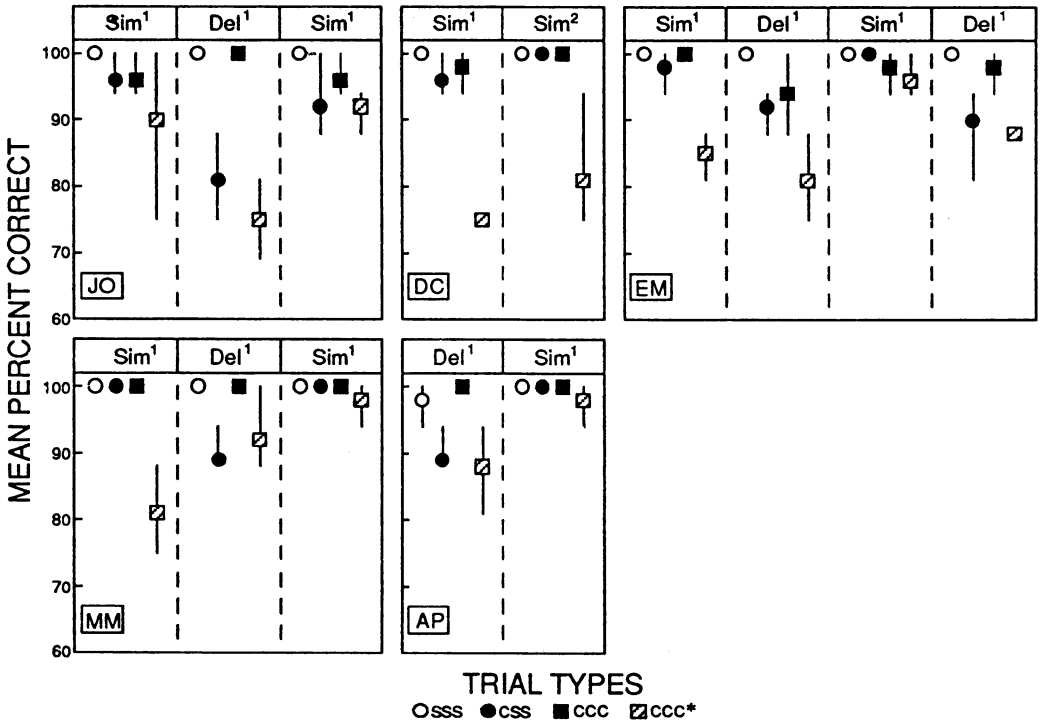

Fig. 5. Experiment 3. See Figure 3 for details.

Results

Figure 6 shows the results. During Phase 1, accuracy on CCC trials was typically superior to that on CCC* trials. During Phase 2, accuracy on SCC trials was typically superior to that on CSS trials. In both cases, the difference was most pronounced in the delayed matching sessions. Within-block trends of subjects' accuracy scores on CCC* and CSS trials varied unsystematically.

Discussion

Increasing the relative proportions of trials that required discrimination of both sample elements did not lead to high accuracy on these trials in delayed (or simultaneous for DC) matching. Relatively lower accuracy scores on CSS and CCC* trials persisted despite the subjects' growing experience with the procedures and several variations in the circumstances of testing. As assessed by the present methods, the modification of restricted stimulus control may require something more than mere prolonged exposure to the contingencies.

EXPERIMENT 5

In Experiment 2, recall that performance on CSC trials was inferior to that on CSS trials, perhaps reflecting the identity in number of elements between the CSC sample and negative comparison rather than restricted stimulus control per se. Experiment 5 explored this possibility by scheduling both CSC and SCS trial types. On SCS trials, the sample had one element, the positive comparison had one element identical to the sample and one nonidentical element, and the negative comparison had one nonidentical element. If subjects sometimes matched number of elements rather than form, then error rate on these trials should be higher than those on trials that did not place identity of number and form in conflict (cf. Roberts & Grant, 1978).

Method

All 5 subjects continued. Sessions consisted of 16 trials each of SCS, SSC, CSC, and CCS types (see Table 1 and Figure 2). On CCS and SSC trials, the sample and positive com-

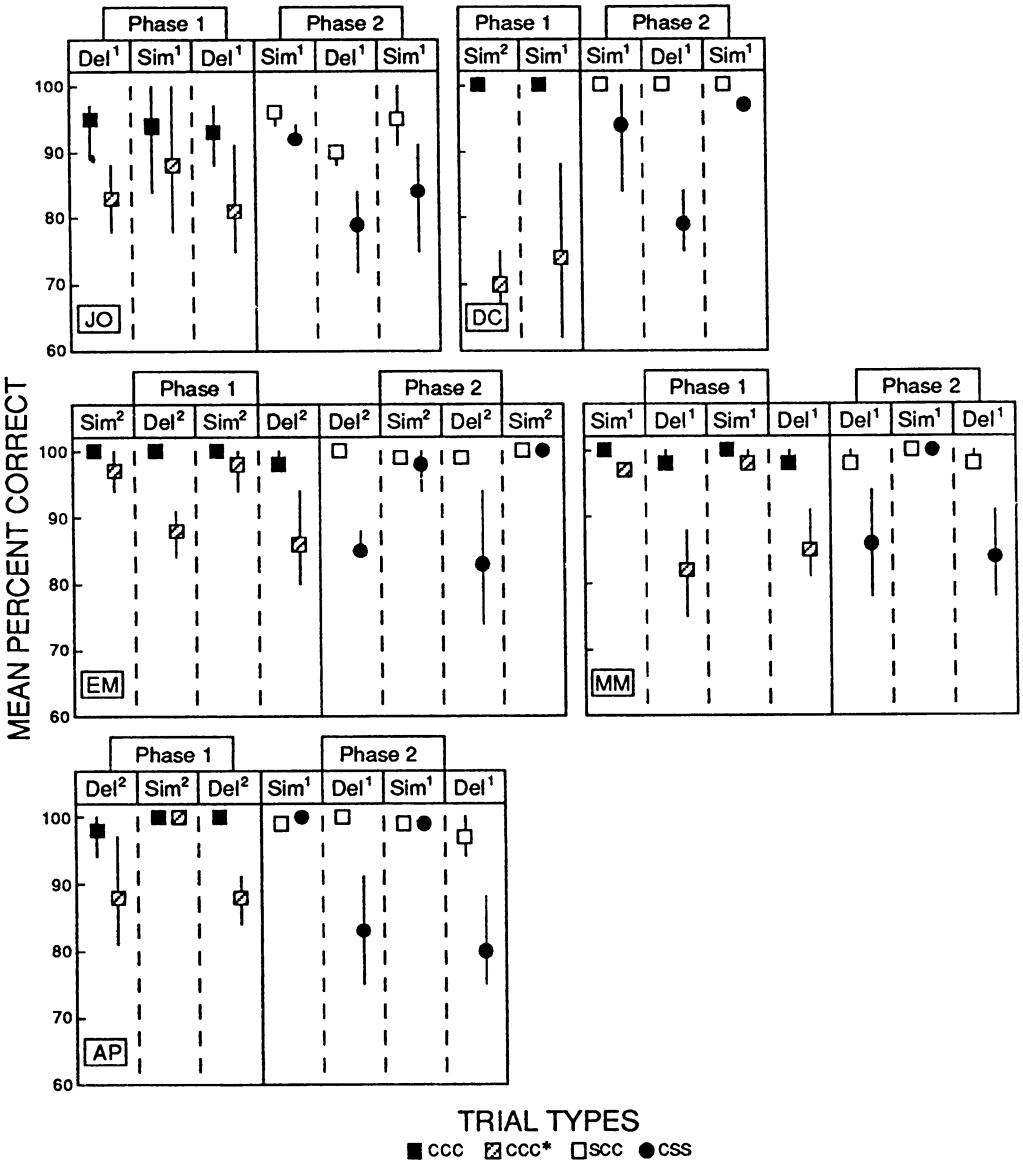

Fig. 6. Experiment 4. See Figure 3 for details.

parison were identical in both form and number of elements. They also served to balance the reinforcement contingencies. Without them, a one-element comparison would always have been the positive comparison for two-element samples and vice versa. All subjects received both simultaneous and delayed matching conditions with one stimulus set.

Results

As Figure 7 shows, the main finding was that CSC accuracy scores were relatively lower than those on the other three trial types. This was true on both simultaneous and delayed trials for JO and only on delayed trials for the other subjects. Within-block trends of subjects'

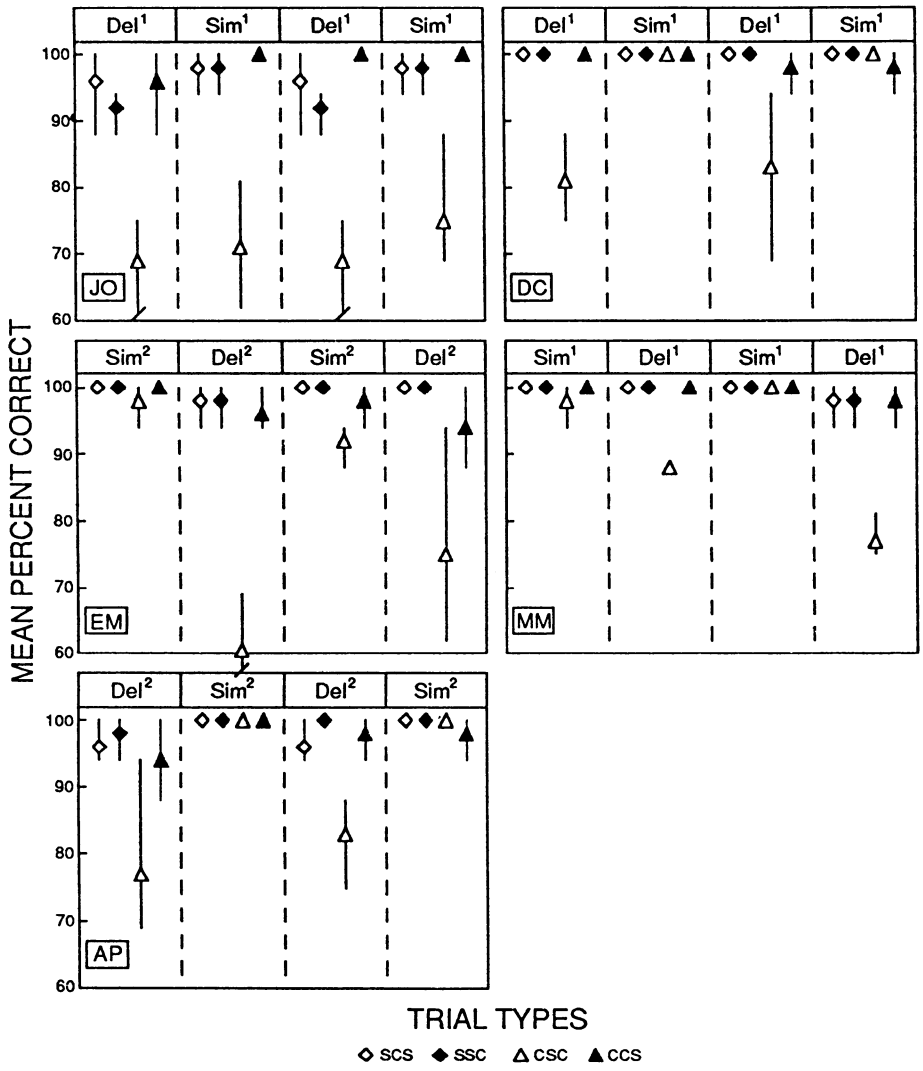

Fig. 7. Experiment 5 (EM's plot was 60%). See Figure 3 for details.

accuracy scores on CSC trials varied unsystematically.

Discussion

These results were generally consistent with those of previous experiments. Accuracy scores were relatively lower on CSC trials that required stimulus control by two sample elements, supporting an inference of restricted stimulus control. As in Experiment 2, JO's difficulties on these trials may have involved inadequate observing behavior during simultaneous matching. The asymmetrically high SCS scores suggest either that (a) the number of elements did not compete with the identity of form for control of matching selections or (b) competition occurred only on CSC trials.

EXPERIMENT 6

Experiment 6 investigated the determinants of relatively low accuracy scores on trials that required discrimination of two sample elements. In Experiments 1 through 5, these trials made up only 25% to 50% of the total trials in each test session. On up to 75% of the trials, therefore, the reinforcement contingencies required discrimination of only one sample el-

ement. Was the relatively lower accuracy on trials that required discrimination of two elements due to interspersing such trials among trials that required only one-element sample control? Experiment 6 asked this question by presenting CSS trials only. The resulting uniform baseline and larger number of trials also set the stage for a microanalysis of the data to clarify further the nature of restricted stimulus control on CSS trials (cf. Bickel et al., 1984, 1986).

Method

Subjects were DC and 2 new ones (CP and JT). The first and second sessions scheduled 64 simultaneous and 0-s delay SSS trials, respectively, with Set 3 stimuli (Figure 1). In the third session, delayed SSS trials assessed visual discrimination of two stimulus sets that would be used in subsequent test sessions. The test sets were Sets 1 and 2 for CP, Sets 2 and 6 for JT, and Sets 4 and 5 for DC (Figure 1). Only 12 trials with each set were scheduled to limit experience with these stimuli on trials that required only one-element sample control. These trials were interspersed among 40 trials with the Set 3 stimuli. Test sessions included 64 CSS trials only. During these sessions, subjects were given blocks of three to five sessions of simultaneous and delayed matching with the test stimuli.

Results

Accuracy scores for CP and JT averaged 97% and 100% for DC during the three initial sessions involving only SSS trials. The test data shown in Figure 8 largely replicate previous findings with CSS trials; accuracy scores were typically lower on delayed trials than on simultaneous trials. Accuracy levels on delayed trials varied: They were low to intermediate (CP and JT, Set 6), stable intermediate (JT, Set 2; DC, Set 4), and high (DC, Set 5). For DC, the stimulus set was clearly a variable; scores with Set 5 were always higher than those with Set 4.

Figure 9 shows a more detailed analysis of delayed CSS performance. This analysis includes the five delayed matching sessions with Set 2 stimuli (Del^2) for CP and JT (Sessions 11 through 15 and 1 through 5, respectively), and the first five sessions with Set 4 (Del^4) for DC (Sessions 1 through 5). Bars show the number of positive comparison selections for

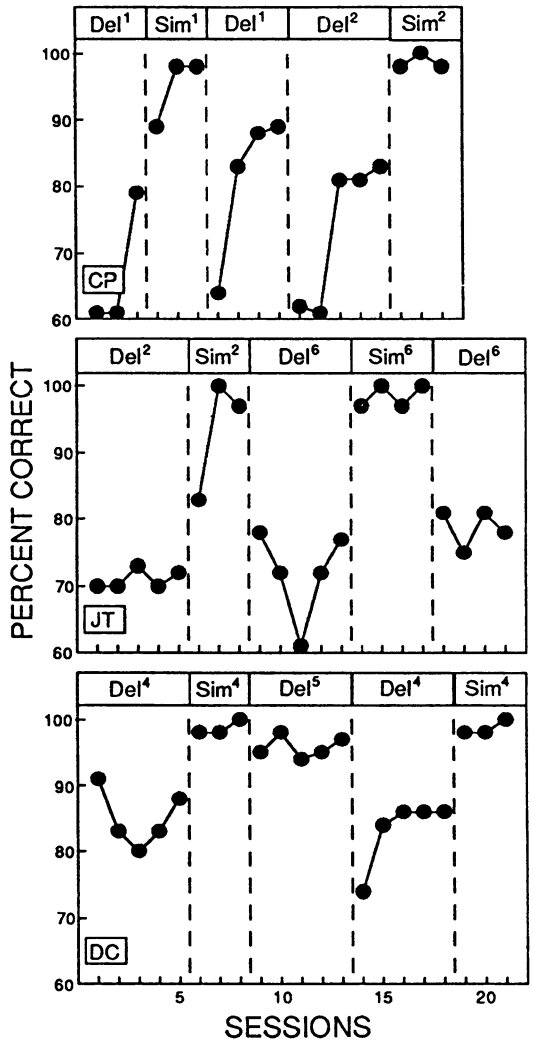

Fig. 8. Experiment 6 results involving CSS trial types.

each of the eight trials that made up each 64-trial session (ignoring element and comparison position differences). Two-element samples are shown to the left and comparison displays across the top; parentheses indicate the negative comparison on each type of trial.

CP's accuracy scores for the five Del^2 sessions in Figure 9 ranged from 61% to 83% (Figure 8). The score for the first session (Session 11) was 62%. In this session, Figure 9 shows that on A1B1:A1(A2) and A1B1:A1(B2) trials (i.e., A1B1 sample, A1 positive comparison, A2 or B2 negative comparison), A1 was selected on five of eight and six of eight trials, respectively (top row, far left bar in the two

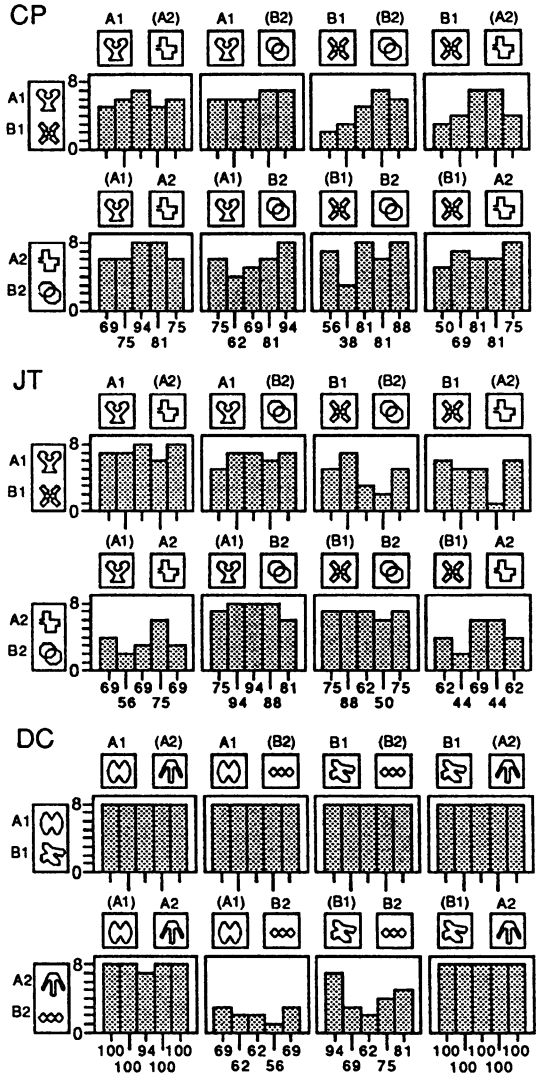

Fig. 9. Analysis of delayed matching performances in Experiment 6: the Del[2] conditions for CP and JT and the initial Del[4] condition for DC (see Figure 8). The panels for each subject represent the eight possible trial types among the complex sample stimuli (left column) and the pairs of simple comparison stimuli (top rows). Alphanumeric notations without parentheses denote positive comparisons; each bar shows the number of times (out of eight) that a positive comparison was selected during each of five sessions. The numbers below each subject's set of panels reflect percentages of conditional selections of comparisons across sessions.

left panels). By contrast, on A1B1:B1(B2) and A1B1:B1(A2) trials, B1 was selected on only two of eight and three of eight trials, respectively (top row, left bar in the right two panels). When A2B2 was the sample, scores with the A2 positive comparison were six of eight and five of eight (bottom row, left bar in the two end panels); when B2 was the positive comparison, however, scores were six of eight and seven of eight (bottom row, left bar in the middle panels). To summarize the Session 11 data, when A1, B1, A2, and B2 were the positive comparisons, they were selected on 69% (11 of 16), 31% (5 of 16), 69% (11 of 16), and 81% (13 of 16) of the trials, respectively. The 62% overall session accuracy score thus averages a wide range of scores that varied according to the identity of the positive comparison stimulus.

Further examples of variation related to different comparison combinations can be seen by inspecting the numbers below the second row of panels for each subject. These numbers give the percentage of positive comparison selection on trials that displayed each of the four possible comparison combinations (A1/A2, A1/B2, B1/B2, and B1/A2). They serve to index the degree of conditional control by the A1B1 and A2B2 samples over selections made to each comparison display. Perfect conditional control would be shown by 100% scores (or 0% scores, if the subject consistently selected the negative comparison). No conditional control by the sample over comparison selection would be shown by scores near 50%. Intermediate scores could indicate either sample control of selections of stimuli other than the comparisons (e.g., position) or mixed control by samples and features of the comparison display (cf. McIlvane, 1992; Sidman, 1980).

Consider, for example, CP's Session 11 performance. Conditional control scores were 69% (A1/A2), 75% (A1/B2), 56% (B1/B2), and 50% (B1/A2). Corresponding scores in Session 15 were 75%, 94%, 88%, and 75%, respectively. These data indicate that much of the improvement in overall accuracy in Sessions 11 through 15 can be attributed to the development of conditional control over selections to comparison displays that included B1.

The analysis of JT's performance with the same Set 2 stimuli shows a different pattern. JT's accuracy scores in Sessions 1 through 5 were consistent, ranging from 70% to 73% (Figure 8). Figure 9 shows that performance varied greatly on different types of trials. Conditional control scores were consistently higher on trials in which A1 and B2 were the positive comparisons and relatively lower when A2 and

B1 were positive. The stimulus preferences were not exclusive, however. The latter two stimuli were selected on many trials, including some in which A1 and B2 were positive comparisons. Overall, JT's intermediate accuracy scores and the analysis of individual trial data suggest a mixture of conditional control by the sample on some trials and nonconditional stimulus preferences on others.

Results with DC show yet another pattern of stimulus control. Accuracy scores with Set 4 stimuli in the first five sessions ranged from 80% to 91% (Figure 8). The analysis in Figure 9 reveals almost perfect conditional control by samples when A2 was present in the comparison display (M = 99%). Conditional control scores were low, however, on the other trial types. Note the relatively lower scores on trials that had the A1/B2 and B1/B2 comparison displays (M = 70%). Note also that these low scores could have resulted if DC tended to avoid B2 whenever it was displayed (a nonconditional stimulus preference).

Discussion

Together, these results indicate that imperfect CSS performance need not be due to interspersing such trials in an equal or greater number of trials that required only one-element control. The new subjects in particular had minimal experience with these trials, and their performance was no better and arguably worse than that seen with the subjects in the preceding experiments. We do not know, of course, whether further limiting (or eliminating) experience with one-element trials would change the outcome. We speculate that it would not, however, given that many other studies have shown restricted stimulus control with similar subject populations without providing one-element experience.

The analysis presented in Figure 9 clearly shows that the errors on delayed CSS trials were not equally distributed across trial types. Rather, they appeared to reflect mixtures of conditional control by the samples and nonconditional control by features of the comparison displays (cf. Sidman, 1969). This analysis complements prior microanalyses of restricted stimulus control (Bickel et al., 1984, 1986). For example, Bickel et al. (1986) reported that features of the stimulus displays also controlled choice responding in humans' simple discrimination. In one instance, the selection of a particular stimulus element was conditionally controlled by the presence of another stimulus in the test display. These studies and the present one illustrate several alternative sources of control that may underlie profiles of restricted stimulus control in simple discrimination and matching-to-sample procedures.

GENERAL DISCUSSION

This series of experiments examined simultaneous and delayed matching-to-sample performances of individuals with mental retardation. The experiments made within-subject comparisons of performance on trials with one- or two-element samples. Accuracy scores on simultaneous trials were typically high. High scores were also typical on delayed trials with one-element samples (SSS, SCC, SCS, and SSC trials). Scores on delayed trials with two-element samples depended on the trial type. High scores (90% to 100% positive comparison selections) were typical on CCC and CCS trials in which control by one element was sufficient. Intermediate scores (>75% and <90%) were typical on CSS, CSC, and CCC* trials in which control by two sample elements was required to maximize reinforcement.

The high accuracy scores on certain delayed matching trials and intermediate scores on other trials indicate that subjects' comparison selections were controlled by only one sample element on each trial. On one-element sample trials, high accuracy resulted because subjects' comparison selections were controlled by that element. On two-element trials, accuracy depended on the requirements of the trial type. CCC and CCS trial contingencies required discriminative control by either one of the elements to assure reinforcement. Subjects met these requirements well. CCC*, CSS, and CSC trial contingencies required discriminative control by both elements to assure reinforcement. Subjects met these requirements less well.

Intermediate delayed matching scores (i.e., near 75%) probably reflected the average of (a) near 100% selections on trials in which the element that gained control appeared as the positive comparison and (b) near 50% selections when the element that did not gain control appeared as the positive comparison. Because all stimulus elements appeared with about equal frequency, the averaged overall

accuracy score was approximately 75% (Sidman, 1980). The fact that many intermediate scores were higher (80% to 90%), however, suggests that both elements gained discriminative control on some trials.

Relevance to Previous Studies with Human Subjects

Our findings are consistent with past reports of stimulus overselectivity or restricted stimulus control in humans with developmental limitations. Our subjects' behavior often appeared to be controlled by only one element of a two-element sample stimulus. For 2 subjects (JO and DC), the phenomenon was evident in both simultaneous and delayed matching to sample. For other subjects, it was evident only in delayed matching. These findings seem directly relevant to the literature on overselectivity and restricted stimulus control. One major concern, for example, is whether the phenomenon of restricted stimulus control reflects problems in observing, remembering, or some other more subtle aspect of stimulus control (e.g., Litrownik et al., 1978).

For our subjects who had intermediate scores in 0-s delay but not in simultaneous matching, one interpretation might be that they observed both elements but remembered only one. Although our data do not refute this explanation, we think it more likely that they observed only one stimulus element. The lowered delayed matching scores may have resulted because the procedure removed the sample display before the comparison stimuli were presented. This also removed the opportunity to look again at the sample if the element observed initially was not present in the comparison display. Results for AP, however, may be consistent with failure to remember one of two observed sample elements. Recall that simultaneous and 0-s delay scores were both high, suggesting that AP was capable of observing two elements on every trial, and, on 0-s delay trials, remembering them for the short time that it took to erase the sample elements and present the comparisons. The fact that intermediate accuracy was obtained only with the 1-s delay suggests that AP may indeed have forgotten a sample element on some trials.

The matching-to-sample procedures used in the present study appear to have certain methodological advantages over those used in typical studies of restricted stimulus control. As noted earlier, many studies established discriminative control by a stimulus complex composed of two or more elements and then assessed control by elements alone. When an element or elements did not exert stimulus control, the result might have been due to any of several factors. For example, the stimulus complex might have functioned as a compound, not a multielement complex. The traditional view of a stimulus compound predicts that the elements do not exert independent control; the discriminative performance established during training depends upon all aspects of the stimulus complex remaining intact (cf. Carter & Werner, 1978; Cumming & Berryman, 1965). Alternatively, the lack of separate element control could reflect a problem of observing or remembering. Matching-to-sample methods can potentially clarify these matters.

The present study appears noteworthy in at least two aspects of its methodology. First, although matching-to-sample procedures have been used previously to study restricted stimulus control (Litrownik et al., 1978; Schneider & Salzberg, 1982), only one other study (Dube et al., 1990) has done so in the context of verified generalized identity matching of all test elements. This method shows that subjects can discriminate the elements from one another and permits isolating problems in discrimination acquisition per se from those of observing and remembering.

The second noteworthy aspect of our procedures is the use of discrete forms as elements of complex sample and comparison stimuli. Although discrete forms have been used in previous studies of restricted stimulus control (e.g., Wilhelm & Lovaas, 1976), all used simple discrimination procedures. The use of forms in matching to sample, as in the present study, raises a number of further questions about conditional control by complex stimuli in subjects with developmental limitations. One can easily ask, for example, about how spatial contiguity of elements affects control by complex stimuli (e.g., Rincover & Ducharme, 1987). The methods also lend themselves readily to questions about whether the discrete elements of a complex controlling stimulus become members of functional or equivalence classes (Stromer & Mackay, 1990, in press-a, in press-b; Stromer & Stromer, 1990a, 1990b).

Another concern is the need to understand

better the circumstances under which restricted stimulus control does and does not occur. Several studies have reported that it can be reduced or eliminated merely by exposing subjects to contingencies that require the subject to discriminate two or more elements of complex stimuli (Allen & Fuqua, 1985; Koegel & Schreibman, 1977; Schreibman et al., 1982; cf. Huguenin, 1985; Huguenin & Touchette, 1980). In our study, however, protracted exposure to CSS trials across several problems did not always result in discriminative control by multiple elements. Moreover, extended exposure did not improve performance on CCC* trials, which appear directly analogous to procedures reported to reduce restricted stimulus control.

The differences in outcome between our study and those cited above could be due to the influence of any of several variables. For example, relative to the other studies, ours presented more stimuli and trial types during training. Also, our procedures required true conditional discrimination in which the positive and negative functions of stimuli varied from trial to trial; the procedures of the other studies required only simple discriminative control by stimulus compounds (see Dube, McIlvane, & Green, 1992, for further discussion of the relevant issues). Conceivably, training in baseline of less stimulus variability and functional complexity may be necessary to achieve the intervention effects reported.

Relevance to Previous Studies with Nonhuman Subjects

Aspects of our findings are also consistent with those reported previously in studies with pigeons and monkeys: Delayed matching scores were generally lower on CSS trials than on SSS trials, and delayed matching CSS scores were lower than simultaneous matching scores (Cox & D'Amato, 1982; Maki & Leith, 1973; Maki & Leuin, 1972; Maki et al., 1976; Richards & Bowers, 1985; Roberts & Grant, 1978). We also observed generally lower matching accuracy on two other trial types that required the subject to discriminate two sample elements, CSC and CCC* trials. These results are also consistent with findings reported in studies with nonhuman subjects (e.g., Cox & D'Amato, 1982; Maki et al., 1976; Roberts & Grant, 1978).

The studies with nonhumans have led to several efforts to develop a theoretical account of diminished accuracy on trials requiring delayed matching of one- or two-element comparisons to a two-element sample. At least two major accounts have been offered. One has been termed the "generalization decrement" hypothesis (Cox & D'Amato, 1982; Maki et al., 1976). This account assumes that sample stimuli function as unitary entities (i.e., compound stimuli) in the control of behavior. The account notes that CSS trials require the subject to match a one-element comparison to a nonidentical two-element sample. Accurate CSS matching depends, therefore, on primary stimulus generalization. The account suggests that delayed CSS accuracy scores are lower relative to SSS scores because generalization is incomplete.

The other major account has been termed the "shared attention" hypothesis (Maki & Leith, 1973; Maki et al., 1976). This hypothesis suggests that the subject treats sample elements of the stimulus complex as separate elements, not as a compound. The account also asserts that the subject has a limited capacity for discrimination of the elements of complex stimuli. The capacity is adequate for one-element samples; however, the capacity is taxed with two-element samples. Attention is divided "either by rapid switching of attention between the two elements or by allocating a portion of the total processing capacity to each element, resulting in poorer performance" (Riley, 1984, p. 335).

To what extent do these accounts apply to our results? The generalization decrement hypothesis provides a plausible explanation of aspects of our data (e.g., subjects' difficulties on CSS trials). There are certain problems, however. For one, our subjects' high accuracy scores on SCC trials indicate that they were capable of matching a two-element comparison to a nonidentical one-element sample. To hold to the generalization decrement account, therefore, one must argue that primary stimulus generalization is not required to match a one-element sample with a comparison composed of one identical and one nonidentical element. Another problem is the relatively less accurate performance on CCC* trials. If two-element samples functioned as unitary compound stimuli, as suggested by the generalization decrement account, then one must explain why subjects failed to match them reliably with identical

two-element positive comparisons. Further, the fact that negative comparisons were often selected on CCC* trials, but not on CCC trials, supports an interpretation of control by the element common to the sample—an interpretation that does not seem consistent with compound sample stimulus control.

The shared attention account might seem applicable to our data. Subjects typically had relatively lower accuracy scores on trials that required discriminative control (i.e., to divide attention between) by two sample elements. This account also presents certain problems, however. For example, it is not clear whether the account admits the possibility that further experience with the procedures can lead to increases in the limited capacity of an organism to come under the control of more than one sample element. We did observe some instances of within- and across-problem improvement in accuracy, particularly in Experiment 6.

It is not clear whether the shared attention account would predict certain findings of our microanalysis of the data in Experiment 6. On its face, shared attention formulations seem to predict not only intermediate overall accuracy scores but also intermediate scores on individual trial types. If attention were somehow divided more or less equally between the elements on every trial or switched rapidly back and forth between elements depending on individual trial outcomes (i.e., "win-stay, lose-shift"), then one might expect comparable intermediate scores on all trial types within a single session and across sessions. None of our subjects produced this pattern of results. If switching occurred less frequently, one might expect comparable intermediate trial type accuracies when the results of several sessions were averaged. CP's data might be interpretable in these terms. Data from DC and JT, however, do not appear to be consistent with the shared attention account, at least as articulated with respect to studies with nonhuman subjects. Their accuracy scores were high and generally stable on certain trial types and at chance (25% to 75%) levels and relatively unstable on others.

These data appear to indicate trial-to-trial shifts among different stimulus control topographies (cf. McIlvane & Dube, 1992; Sidman, 1969). Conditional control by two-element samples sometimes was and sometimes was not restricted to particular elements, and sometimes shifts to nonconditional control by particular comparison displays were evident. The data support Sidman's (1980) contention that exclusive reliance on a general measure such as accuracy "can generate erroneous conclusions about the extent to which the controlling relations are those specified by the experimenter" (p. 285). Bickel and colleagues articulated a similar position with respect to analyses of restricted stimulus control (Bickel et al., 1984, 1986).

Whether nonhuman subjects will show the response patterns observed in Experiment 6 is not known. Although certain global analyses by trial types have been reported (e.g., Maki et al., 1976; Roberts & Grant, 1978), microanalyses comparable to ours have not yet been conducted. If comparable data resulted from such an analysis of nonhumans' performance, the shared attention account might be elaborated to incorporate the additional findings. If different data resulted, however, one could point to subject differences as an important variable. Another variable may be stimulus differences; we used combinations of forms as complex stimuli, whereas studies with nonhumans typically used hue-line combinations. Nonetheless, further microanalyses will help to clarify the nature of restricted stimulus control and will contribute to the development of methods to broaden control by complex stimuli.

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