The Behavior Analyst 2003, 26, 195–213 No. 2 (Fall)

Stimulus Control Topography Coherence Theory: Foundations and Extensions

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Stimulus control topography refers to qualitative differences among members of a functional stimulus class. *Stimulus control topography coherence* refers to the degree of concordance between the stimulus properties specified as relevant by the individual arranging a reinforcement contingency (behavior analyst, experimenter, teacher, etc.) and the stimulus properties that come to control the behavior of the organism (experimental subject, student, etc.) that experiences those contingencies. This paper summarizes the rationale for analyses of discrimination learning outcomes in terms of stimulus control topography coherence and briefly reviews some of the foundational studies that led to this perspective. We also suggest directions for future research, including pursuit of conceptual and methodological challenges to a complete stimulus control topography coherence analysis of processes involved in discriminated and generalized operants.

Key words: stimulus control, stimulus control topography, discrimination, generalization

A little over a decade ago, an *On Terms* paper in these pages described the analytic concept termed *stimulus control topography* (SCT; McIlvane & Dube, 1992). The term refers to qualitative differences among members of a functional stimulus class. It had been introduced by Ray in 1969, and it was immediately adopted by other members of Sidman's research group at the Massachusetts General Hospital and later at the Shriver Center (e.g., Stoddard & Sidman, 1971a). Since then, the SCT concept has continued to be a useful element of the analytical verbal behavior of Shriver Center researchers. During the past decade, however, SCT has gone beyond convenient laboratory shorthand, and it is now one of the central tenets of an evolving analysis of stimulus control that we have termed *stimulus control topography coherence theory.*

Two recent publications (Dube & McIlvane, 1996; McIlvane, Serna, Dube, & Stromer, 2000) focused primarily on the application of SCT-based analyses to issues in stimulus equivalence research and emergent behavior. Our goals for the present paper are (a) to summarize the rationale for analyses of SCT coherence, (b) to briefly review selected applications of the analytic concept, and (c) to explore some avenues for future research that arise from this perspective.

Stimulus Control Topography Coherence

In the discriminated operant, SCT refers to the physical features, structural relations, and controlling properties of stimuli. SCT differentiates members of the controlling stimulus class in a manner analogous to that in which response topography differentiates members of the operative response class. Response topography distinguishes among various forms of response that produce the same measured outcome, for example, producing a reinforcer by

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This research was supported by Grants HD 033802 and HD 039816 from the National Institute of Child Health and Human Development. The contents of this paper are solely the responsibility of the authors and do not necessarily represent the official views of NICHD.

We thank Murray Sidman, Michael Davison, and Tony Nevin for stimulating many of our thoughts and apologize for any inadvertent misrepresentations or inaccuracies in our discussion of their work.

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pressing a lever with the left hand at one point in an experimental session and with the right hand at another point. SCT distinguishes among various forms of stimulus control that produce the same measured response, for example, a defined response at one moment under control of the shape of a given stimulus and at another moment under control of its location in space. The distinct response topographies may or may not be significant to the behavior analyst, depending on the objectives of the analysis (e.g., schedule control vs. response shaping). Similarly, distinct topographies of stimulus control may or may not be significant to the behavior analyst.

Ray and Sidman (1970) noted that, "All stimuli are [complex] in the sense that they have more than one dimension or aspect to which a subject might attend. To ask the experimenter to be aware of all possibilities is already, perhaps, an impossible demand" (p. 199). Nevertheless, an accurate behavioral analysis of stimulus control requires that the SCTs specified by the analyst (experimenter, teacher, etc.) must be the same as (or perfectly correlated with) those that control the behavior of the organism under study (experimental subject, student, etc.). We introduced the term *SCT coherence* to refer to the degree of concordance between the stimulus properties that control the behavior of the behavior analyst and those that control the behavior of the organism (McIlvane et al., 2000).

Coherence theory applies most clearly at a molecular level of behavior analysis (Bickel & Etzel, 1985; Ray & Sidman, 1970; cf. Baum, 2002). The theory assumes that the behavioral stream can be divided into discrete operant analytical units and that only one SCT occurs on any given unit instance (just as only one response topography can be emitted at any given moment in time). For example, consider the interpretation of accuracy scores in a simple discrimination procedure. At one extreme, chance scores indicate that the reinforcement contingencies have captured one or more SCTs that are not specified as relevant by the experimenter or teacher. At the other extreme, perfect or near-perfect accuracy scores suggest a high degree of SCT coherence. The controlling stimuli are either those specified by the experimenter or unspecified, highly correlated stimuli (e.g., Stikeleather & Sidman, 1990).

Regarding SCT stability, we see no compelling logical reason to assume that the SCT remains consistent from one moment to the next, and there is much evidence that it does not (see below). Intermediate accuracy scores may result when both specified and unspecified SCTs have been established and both occur with some frequency greater than zero within a measured performance (e.g., an experimental session). Although Sidman (1980) made this general point many years ago, SCT coherence theory extends and involves some reformulation of his perspectives.

Multiple SCTs may become established because the stimuli in experimental or teaching situations have multiple dimensions or features such as shape, size, color, location, and so forth, as noted in the Ray and Sidman (1970) passage quoted above. This potential has long been acknowledged in discrimination learning, as in, for example, Harlow's (1950) proposal that learning requires the elimination of competing error factors, statistical sampling theory (Estes, 1959), hypothesis testing (Levine, 1965), or the Zeaman and House (1979) multistage attentional theory, in which the initial stage of discrimination acquisition is learning to attend to the relevant stimulus dimension among multiple possibilities.

The SCT model differs from earlier formulations in that multiple topographies are seen to coexist at different, perhaps relatively stable, frequencies within the same baseline. Frequency of occurrence is influenced by variables such as inherent or acquired salience of the targeted stimulus features and dimensions or their associated schedules of reinforcement. These influences will be considered more completely below.

A Brief Research Summary

Here, we will summarize selected research studies that have influenced the development of SCT coherence theory. In other publications (e.g., Dube & McIlvane, 1996; McIlvane et al., 2000), we have applied coherence principles in accounts of so-called relational stimulus control, addressing the current interest of behavior analysts in the theoretical analysis of stimulus equivalence and related phenomenon (e.g., Hayes, Barnes-Holmes, & Roche, 2001; Sidman, 1994). SCT coherence analysis has a considerably broader scope, however, a point that has been so far insufficiently developed in our published accounts. We take this opportunity to emphasize that SCT coherence theory applies not merely to stimulus equivalence or to conditional discrimination but rather to the description of the discriminated operant more generally. We will begin by reviewing some of the foundational studies that led us to our current research perspectives. Then, we will describe some conceptual and methodological challenges that are being addressed via ongoing and planned studies.

Multiple SCTs. Our point concerning SCT frequency within a given baseline was first illustrated by Ray (1969). Rhesus monkeys were trained to perform a simultaneous left–right discrimination task with red and green stimuli displayed on the response keys, then with vertical and horizontal lines, and finally with compatible compound stimuli in which the lines were superimposed on the colors that controlled the same responses. After these original discriminations were established, subjects were presented with line–color "conflict compounds" in which the reinforcement contingencies were unchanged for one set of stimuli but were reversed for the other set of stimuli (e.g., colors reversed but lines unchanged). Conflict compounds disrupted discrimination initially, but the conflict-compound discrimination was quickly acquired. When performance was accurate with the conflict-compound stimuli, test trials presented the line and color stimuli separately. The results on trials with the nonreversed stimuli showed that stimulus control continued as in the original training (as expected, because the relevant contingencies did not change during conflict-compound training). Results on trials with the reversed stimuli, however, also showed stimulus control consistent with the original training. These procedures—conflict-compound training immediately followed by individual-stimulus testing—were replicated many times within the study, and stimulus control on test trials typically remained consistent with the original discriminations for all stimuli. Ray concluded that the conflict-compound contingencies changed the frequency with which some of the original controlling stimulus–response relations occurred, but did not alter their topography. That is, when performance was accurate with conflict compounds, the frequency of stimulus control by the reversed stimuli fell to zero or near zero, but the SCT remained unchanged. Other studies that reached the same conclusion include Huguenin and Touchette (1980) and Stoddard and Sidman (1971a).

Multiple SCTs with one nominal stimulus dimension. Among studies showing lack of coherence between experimenter-specified and actual controlling stimuli, it is instructive to review those in which researchers designed stimulus sets to isolate control by experimenter-specified stimuli and stimulus dimensions. As background, much research in the middle years of the 20th century sought to understand processes involved in generalization along stimulus dimensions. Line orientation was used extensively in such research. In a typical experiment, for example, vertical (90°) and horizontal

(0°) lines were first established as S+ and S−, respectively. Thereafter, line stimuli were varied (e.g., 85°, 80°, 75°, etc.) to assess excitatory or inhibitory control along the dimension of orientation. Some of these studies had considerable success (Rilling, 1977). Variability in results of such studies attracted comparatively little experimental attention, however.

One possible source of variability was identified in a study by Touchette (1969). Using probe designs, he demonstrated that the controlling properties of line tilts varied within and between subjects and included features such as the distance between the end of the line and the side or corner of the display key. This work emphasized two important points: (a) Dimensional stimulus control by orientation (the experimenter-intended outcome of many line-tilt discrimination training procedures) should not be uncritically assumed. (b) Additional discrimination training could be necessary to ensure that the stimulus differences that were deemed relevant by the experimenter were the actual differences of relevance for the subject.

Similar conclusions were reached in two studies that examined generalization gradients in monkeys (Stoddard & Sidman, 1971b) and 2-year-old children (Stoddard & McIlvane, 1989) with a stimulus set that included a circle and several ellipses equal in width to the circle but varying in height. Using a stimulus-control shaping procedure that will be described in a later section of this article, the investigators established highly accurate performance with the circle and a relatively flat ellipse (ratio of minor to major axis = .53). Then, generalization tests presented discrimination trials with intermediate ellipse ratios ranging from .74 to .91. For a substantial number of subjects, initial gradients were relatively flat, but became peaked after additional training with ellipse values closer to those that were tested. Stoddard and McIlvane concluded that the need for additional training "shows that new learning had to occur; the original stimulus control had to be replaced by new control. Viewed this way, the training and test dimension is shown to be discontinuous" (pp. 332–333; see Bickel & Etzel, 1985, and Sidman, 1969, for further discussions of the continuous vs. discontinuous interpretations of generalization gradients).

Stoddard and Sidman (1971a) used a different method to demonstrate that the circle-ellipse stimulus dimension may actually include several distinct SCTs. A well-learned performance with a circle and ellipses with axis ratios ranging from .53 to .91 was first disrupted by presenting an impossible discrimination (circle vs. circle). Different procedures for recovering the circle-ellipse discriminations were then tested. The results showed that the procedure sufficient to reinstate previously accurate discriminations varied according to the degree of circle-ellipse difference in those discriminations. For example, for one subject the procedure that reestablished a circle versus .77 ellipse discrimination was insufficient to reestablish circle versus .83 ellipse, but another procedure was sufficient. The discontinuity in the conditions sufficient to reinstate stimulus control along the circle-ellipse stimulus dimension was interpreted as showing that SCT was not continuous along that dimension.

Temporal separation of multiple SCTs. More recent studies using a so-called "delayed S+" procedure illustrate another approach to demonstrating the presence of multiple SCTs within a discrimination baseline (e.g., McIlvane, Kledaras, Callahan, & Dube, 2002; McIlvane, Kledaras, Dube, & Stoddard, 1989). In these studies, individuals with severe intellectual disabilities were given a simultaneous visual-discrimination task with two stimuli that were identical except for one feature (the positive stimulus flashed, alternated with a gray field, or appeared on a colored background). Simple differential reinforcement contingencies were in effect: Selecting the

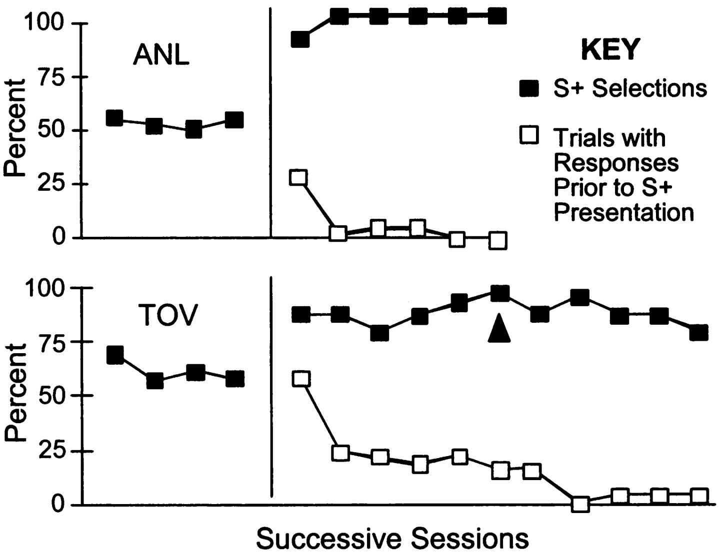

Figure 1. Performances of 2 subjects with severe mental retardation on a simple simultaneous discrimination procedure. Filled points show percentage of selections of S+ stimulus when both S+ and S− were displayed. Open points show percentage of trials with responses to displays with two S− stimuli during imposition of a delayed S+ procedure.

positive stimulus (S+) was followed by a reinforcer, and selecting the negative one (S−) was not. Individuals were selected for study because they had low, variable, or asymptotic intermediate accuracy scores during the initial sessions. From the SCT perspective, such results present a challenge to isolate the relevant SCT and to demonstrate that low or intermediate accuracy scores reflect the presence of or competition from other SCTs.

The delayed S+ procedure was designed to ask whether the low accuracy resulted from competing SCTs involving positional stimuli and stimulus onset; such control could be captured and maintained by the contingencies because selections were frequently followed adventitiously by reinforcers. As an analytical technique or intervention, the contingencies were altered so that every trial began by presenting two S− stimuli only. The appropriate response was to wait a few seconds until one stimulus became S+ (e.g., began to flash). Any failures to wait merely extended the delay.

The upper portion of Figure 1 presents data for Subject ANL, which represent the findings obtained with a substantial majority of subjects. Initiation of the delayed S+ procedure (indicated by the vertical dividing line after the fourth data point) had two characteristic results: First, subjects frequently respond at the beginning of the trials when the two S− stimuli are presented (Figure 1, open squares), a demonstration of competing control by stimulus onset (sometimes referred to as "impulsive" responding) or position (see McIlvane et al., 2002, for extensive illustrative data). Because such responding is never followed by reinforcers, its frequency typically declines over successive trials and sessions as it is extinguished.

The second finding has been an immediate improvement in accuracy scores when the subject waits appropriately in the presence of the two S− stimuli and an opportunity to make the S+ versus S− discrimination is ultimately presented (Figure 1, filled squares). Often the improvement is to perfect or near-perfect accuracy in the very first delayed S+ session. Such outcomes show at minimum very rapid acquisition of control by the experimenter-specified relevant stimulus differences. They also suggest that those stimulus differences exerted some prior control of behavior, perhaps masked by more frequent irrelevant SCTs (see Mackintosh, 1977, for a similar perspective on competition between different controlling stimuli).

Our laboratory has reported analogous findings with conditional discriminations (McIlvane et al., 1989; McIlvane, Kledaras, Stoddard, & Dube, 1990). In these studies, low or intermediate matching-to-sample accuracy scores improved immediately with the imposition of a delayed sample procedure: Trials began with presentation of the comparison stimuli only, and the sample stimulus was presented only after a brief delay in which there was no responding to the comparison array. A more detailed discussion of the delayed sample procedure appears in Dube and McIlvane (1996).

Current Challenges for SCT Coherence Theory Research

Coherence theory takes a molecular approach that is clearly in the spirit of the longstanding interest of behavior analysts in understanding behavioral variability and moment-by-moment influences on behavior (Sidman, 1969; Skinner, 1953). As such, the theory must give a plausible, reasonably detailed account of how SCT frequency changes with exposure to constant or changing reinforcement contingencies. The theory must also acknowledge the great difficulty of accomplishing the empirical work necessary to confirm or disconfirm its tenets. Unlike response topographies, SCTs cannot be observed directly (Sidman, 1979). Rather, SCTs must be inferred from the results of systematic variations in procedure or by application of potentially helpful quantitative methods such as signal-detection theory (e.g., Commons, Nevin, & Davison, 1991). What follows will consider both types of analytical approaches.

Limitations of delayed S+ analyses. As noted earlier, the delayed S+ procedure is potentially helpful in revealing and selectively extinguishing competing SCTs exemplified by stimulus onset or position. Other competing SCTs, however, may not submit so readily to delayed S+ analysis. This suggestion is supported by data of the type shown for Subject TOV in the lower portion of Figure 1. Prior to the imposition of the delayed S+ procedure, the data were very similar to those shown above for Subject ANL. Following the procedure change (again indicated by the vertical dividing line), open squares show initially high levels of responding prior to the delayed S+ onset; also shown is progressive reduction in the level of such responding in the subsequent sessions. Regarding other effects of the delayed S+ procedure, S+ selections occurred substantially more frequently than they had in the first four (i.e., predelayed S+) sessions. By comparison with ANL's data, however, TOV's accuracy scores were lower and more variable. Moreover, this variable accuracy pattern continued even when the delayed S+ procedure had virtually eliminated responses during the delay.

Stable intermediate accuracy scores of the type just discussed pose an analytical and theoretical challenge. Clearly, TOV was sometimes attending to the flashing versus nonflashing stimulus characteristic that differentiated S+ from S−. Note that both ANL and TOV achieved a 100% accuracy score in their sixth delayed S+ session (indicated by the arrowhead). Had this been a learning experiment of the type often done, both individuals would have met a stringent accuracy criterion, and data collection might have ended at that point. Because data collection continued, however, we have the problem of accounting for the accuracy declines in TOV's seventh and subsequent sessions. From our present theoretical perspective, these data indicate maintenance of competing SCTs intermixed with those specified as relevant in the experimenter's specification of the reinforcement contingency. In other words, full SCT coherence was not achieved.

Interpretation and Analysis of Imperfect SCT Coherence

In Dube and McIlvane (1996), we endeavored to account for persistent intermediate accuracy by noting that competing SCTs might be analyzed within a concurrent reinforcement-schedule framework. The experimenter-specified (coherent) SCT would always lead to reinforcement provided that a schedule of continuous reinforcement (CRF) was programmed for a given discrimination task. By contrast, competing (noncoherent) SCTs would lead to reinforcement on a variable-ratio (VR) schedule (e.g., a VR 2 on a two-choice task). Noting frequently obtained accuracy levels in the 75% to 85% range, we speculated that intermediate accuracy might result if subjects allocated behavior in proportion to the reinforcers available on the concurrent schedules embedded within discrimination tasks, that is, exhibiting SCT allocation in proportions consistent with Herrnstein's (1970) matching law rather than maximizing reinforcement by exhibiting consistently coherent SCTs. More recently, we have been reconsidering our analysis as we sought to address a broader range of performances in which subjects exhibit persistently low or intermediate accuracy scores in discrimination learning situations. Before presenting our more recent thinking, some further background information will be necessary.

The problem of stable inaccuracy: An illustration. Persistently low or intermediate accuracy in discrimination learning situations is a frequently encountered outcome in studies of persons with intellectual disabilities, the population that primarily interests our research group. One example of such outcomes was reported in a 1979 article by House, Hanley, and Magid. Nineteen subjects were studied on an oddity learning task. A large number of stimuli were used such that every trial presented one unique odd stimulus (S+) and two identical nonodd incorrect stimuli (S−). This large-set approach might be expected to provide an optimal basis for abstracting the oddity relation (Holland, Solomon, Doran, & Frezza, 1976).

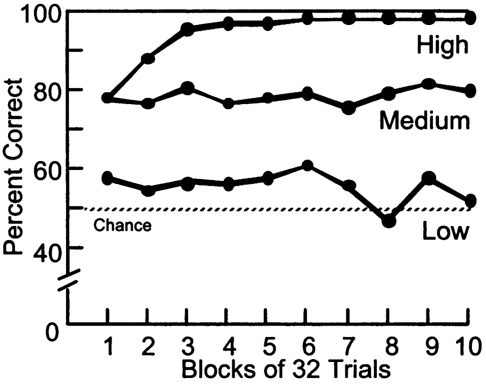

Figure 2. Data from House, Hanley, and Magid (1979).

Summary data from their study, shown in Figure 2, revealed three patterns of behavior. The high-accuracy group (top, $n = 6$) showed very rapid learning of oddity via differential reinforcement. A low-accuracy group showed no improvement after 320 trials (bottom, $n = 7$). The medium group ($n = 6$) showed no improvements from the first block through the end of training. This stable intermediate accuracy was a challenge to the highly influential (at the time) attention theory of Zeaman and House (1979). Scores were well above chance, suggesting to the authors that participants were attending to the relevant stimulus dimension. How could it be that there was no improvement despite appropriate attending *and* continuing differential reinforcement? These data were sufficiently challenging that the authors proposed that some individuals with intellectual disabilities may have deficits in the capacity to be reinforced. To emphasize this curious conclusion, they entitled their article "A Limitation on the Law of Effect." Were these findings unusual, they could be dis-

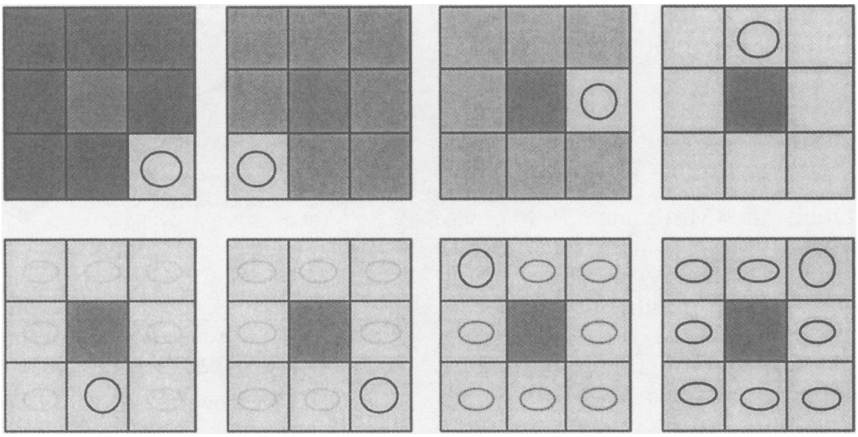

Figure 3. Representative frames from Sidman and Stoddard's (1966) circle-ellipse discrimination program.

missed, perhaps the result of flawed procedures. Unfortunately, the problem of stable low or intermediate accuracy is well known to both researchers and special educators alike.

Bypassing stable inaccuracy via stimulus control shaping procedures. Early in the history of research on discrimination learning in persons with intellectual disabilities, it was discovered that stimulus-control shaping procedures could often prevent problems of this nature (see McIlvane & Dube, 1992, for a discussion of this class of SCT shaping procedures). The seminal work in this area was done by Sidman and Stoddard (1966, 1967). Selected steps from their classic program for teaching the circle-ellipse discrimination are shown in Figure 3. To establish an initial baseline of stimulus control, they required their subjects merely to attend to a gross stimulus difference, a brightly lit key containing a circle versus seven dark, empty keys. Then, over a series of trials, the dark keys were gradually illuminated until they were as bright as the key with the circle (Figure 3, top). In a subsequent phase, flat ellipses were introduced on the formerly empty keys (Figure 3, bottom). At first, the ellipses were a very light shade of gray, much like the key background. Then, ellipse intensity was gradually increased until it was the same as the circle, completely black. In this way, subjects were taught to attend to stimulus differences that differentiate a circle from an ellipse. The program proved highly successful even with persons who had severe mental retardation.

Subsequent work on extensions of stimulus control shaping techniques (e.g., McIlvane, 1992) has also been very successful. In the course of that work, however, periodic anomalous findings have arisen with sufficient frequency that explanation and experimental analysis are required. One illustrative finding, drawn from many possible in our laboratory, is shown in Figure 4. The subject was an individual with severe mental retardation and the task was to transfer stimulus control from a size-disparity prompt to a difference in form (see McIlvane, Dube, Kledaras, Iennaco, & Stoddard, 1990, for an example of successful use of this procedure with this population). The plot shows results for one session. Point A shows accuracy for prompted training trials at the beginning of the session. Points B and C show scores for unprompted trials that followed gradual withdrawal of prompts. The trials at Point B appear to show discrimination acquisition. Subsequent scores on the trials at Point C, however, fell to chance levels, despite continu-

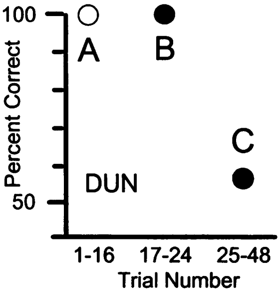

Figure 4. Simple discrimination performance of an individual with severe mental retardation during one session with a fading procedure. Point A shows accuracy for prompted training trials at the beginning of the session. Points B and C show scores for unprompted trials that followed the gradual withdrawal of prompts. Trial numbers are shown below the plots.

ous reinforcement of correct responses during the trials at Point B with generalized reinforcers of verified effectiveness.

Fortunately, performances like these are not characteristic outcomes of prompt procedures; successful stimulus control transfers are maintained in many cases. Data like those shown in Figure 4, however, occur frequently enough to constitute both a scientific and practical problem. Such data recall ongoing themes in research with populations with intellectual disabilities, for example, the work on teaching strategic behavior to individuals with disabilities (e.g., Bray, Fletcher, & Turner, 1997). Unfortunately, the strategic behavior is often not maintained after the training or fails to generalize to other similar situations. No one to our knowledge has offered a compelling process-level account of why teaching adaptive behavior that brings the individual into contact with more effective environmental interactions is not maintained or does not occur outside the context of teaching.

As we have reflected on these longstanding challenges, we have concluded that their ultimate solution will likely entail a marriage between the findings of SCT analysis and those of the extensive research on behavioral allocation in choice situations (e.g., Davison & McCarthy, 1988). Bringing these areas together may potentially resolve difficulties that neither could resolve alone and set the stage for a more effective capacity to understand and perhaps ameliorate slow, inconsistent, and ineffectual discrimination learning. A recent article by Davison and Nevin (1999) has been highly influential in helping to structure our thinking in the area, and we shall spend some time considering its relation to SCT coherence theory.

Contingency Discriminability Analysis

Davison and Nevin's (1999) analysis has roots in signal-detection theory, and its fundamentals are supported by extensive behavioral data from experiments with both humans and laboratory animals. Their exceedingly detailed quantitative analysis is of a complexity that precludes a thorough presentation here. One way to explain its essential features simply is as follows: The authors suggest that degree of behavioral differentiation is a functional relation among three dimensions of discriminability that correspond to the fundamental relations among elements of three-term contingency analysis: antecedent stimuli, behavior, and consequences. Degree of differentiation may be related to the discriminability values along and across each of these dimensions.

To illustrate the critical relations, we have plotted values within a three-dimensional contingency space in Figure 5. Dimensions range from the origin to infinity. Values at or near the origin indicate maximum "confusability" within that dimension, and those approaching infinity indicate the opposite. These dimensions are related to but not isomorphic with corresponding physical dimensions: Dimensions are necessarily psychological, because "confusability" does not necessarily relate directly to psychophysical threshold values. Decades of research on discrimination learning have demonstrated that events initially "confused"

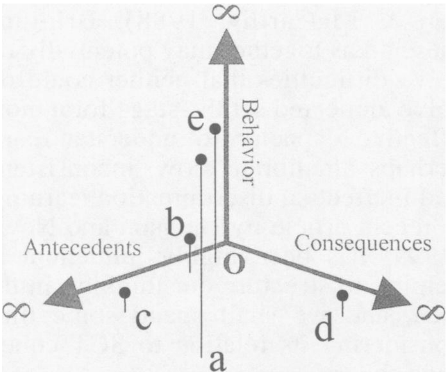

Figure 5. Three-dimensional contingency space. Dimensions represent the three terms of the operant contingency. Values approaching the origin (O) indicate low discriminability, and those approaching infinity (∞) indicate high discriminability.

(i.e., undifferentiated) may become discriminable through experience.

In what follows, we will apply the contingency discriminability analysis to discrimination learning situations. Thus, we follow Davison and Nevin's (1999) invitation to address behavior in transition. Those familiar with their paper will recall that it was articulated in relation to steady-state behavior. The authors pointed out, however, that there was no conceptual barrier to an extension to transitional states. To illustrate our adaptation of contingency discrimination analysis, the value at Point a in Figure 5 indicates a situation in which antecedent stimuli, behavior, and consequences are all highly discriminable. In this instance, one would predict very rapid acquisition of discrimination.

The situation at Point b in Figure 5 corresponds to tasks often presented in research on discrimination learning, exemplified by House et al. (1979). Discriminative stimuli differed in many dimensions, the correct item was different on every trial, and the participant was to make his or her selection without guidance as to which of the stimulus differences was relevant. From the perspective of the participant, therefore, the antecedent stimuli were initially confusable, the responses were the same on each trial (i.e., touching), and the consequences for various selections were identical. From the contingency discriminability analytical perspective, one could scarcely have designed a task more likely to challenge a subject's learning abilities. Indeed, these methods likely evolved in part because they were challenging. In much learning research, errors were a major dependent variable, and it was necessary to generate many errors to differentiate among groups or conditions.

Discriminative stimulus versus consequence discriminability. It has long been known that increasing the stimulus salience will enhance discrimination (e.g., Mackintosh, 1977). To our reading of the literature, stimulus salience and stimulus discriminability appear to be synonymous (or virtually so). Referring to Figure 5, Point c is intended to indicate a highly salient stimulus difference that would be rapidly discriminated despite the fact that (a) differential responses are not required to the positive and negative stimuli and (b) the schedules of reinforcement associated with other, potentially competing stimulus differences (SCTs in our formulation) are minimally different. Regarding the latter, a typical two-choice discrimination procedure provides reinforcers for behavior under the control of relevant (i.e., experimenter-specified) stimulus differences every time (a CRF or fixed-ratio 1 schedule); the procedure also provides reinforcers for behavior under the control of irrelevant differences, but only every other time on average (a VR 2 schedule).

The schedules available for relevant and irrelevant SCTs have been understood for a long time. Rarely, however, have investigators taken the next step—asking explicitly whether the disparity between a CRF and a VR 2 schedule is sufficient to support discrimination. An important concept in contingency discriminability analysis is that reinforcement-schedule discriminability is a psychological matter and is itself a signal-detection task. It makes no difference if the experimenter specifies the schedules as different: If the schedules are similar or indiscriminable for the subject (i.e., have similar or equivalent effects, at least initially), then acquisition of discrimination will occur very slowly (if schedules are minimally discriminable) or never (if they are indiscriminable).

The importance of the schedule disparity detection task can be more fully appreciated by reconsidering the data of House et al. (1979) that are shown in Figure 2. One could account for the observed differences in the learning abilities of subjects by suggesting that faster learners were more facile in attending to the stimulus differences than slower learners were. Viewed in the context of contingency discrimination analysis, however, it seems equally plausible that facile learners were more sensitive to the differences in the reinforcement schedules. Notably, House et al. had no independent measures of schedule sensitivity. Put another way, without knowing the degree to which the participant was sensitive to the difference between the CRF schedule (for selections controlled by relevant stimulus differences) and the VR 3 schedule (for selections controlled by irrelevant differences), it is not possible to know whether the intersubject differences were due to antecedent or consequential stimulus differences.

Enhancing consequence discriminability via differential-outcome procedures. Also readily incorporated within the contingency discrimination analytical framework is the well-known but poorly understood differential-outcome effect (DOE; Trapold, 1970). The DOE is often studied in conditional discrimination procedures such as matching to sample. In the presence of Sample A1, selecting Comparison B1 is followed by Consequence 1 (e.g., a token), and in the presence of Sample A2, selecting Comparison B2 is followed by a different Consequence 2 (e.g., a penny). Studies with both humans and nonhumans have shown repeatedly that discrimination learning outcomes may be enhanced in comparison with procedures that provide the same reinforcing consequence for all matching-to-sample selections (Estávez, Fuentes, Overmier, & Gonzalez, 2003; Goeters, Blakely, & Poling, 1992). Also demonstrated has been the fact that DOE procedures may render consequential stimuli as members of stimulus equivalence classes with antecedent stimuli (e.g., Dube, McIlvane, Mackay, & Stoddard, 1987; Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989).

Point d in Figure 5 indicates a condition under which the consequences of behavior are exceptionally discriminable, as might be expected in a differential-outcomes procedure. One implication of contingency discriminability analysis is that such conditions will enhance discrimination learning in cases in which stimulus discriminability appears to be low and the response requirement is the same for all comparison stimuli. This is consistent with the results of most DOE studies.

The dimension of behavior. Point e in Figure 5 indicates circumstances in which the antecedent stimuli and consequences associated with two situations are minimally discriminable but very different behavior is required. Contingency discriminability analysis implies that discrimination learning should be enhanced in this situation relative to circumstances in which the behavioral requirements are similar. Literally hundreds of studies with humans and nonhumans have shown enhanced acquisition when procedures required differential responses to the stimuli to be discriminated. For example, in matching-to-sample studies, it has been well established that requiring differential responses to sample stimuli (e.g., different schedules in nonhumans, Cohen, Brady, & Lowry, 1981, and sample naming in humans, Horne & Lowe, 1996) enhances acquisition.

Coherence in Contingency Space Analysis

Although Davison and Nevin's (1999) analytical framework was presented as a work in progress, we think they may have taken a long step toward a comprehensive, integrated, and ultimately quantitative account of behavior. In our ongoing empirical work, we find their ideas (and those they inspire in us) extremely helpful for thinking about problems of behavioral differentiation in general and SCT differentiation in particular. For example, one can consider SCT coherence in terms of a relation between two contingency spaces. One space describes the experimenter's evaluation of the salience of antecedent stimuli and consequence disparities to which he or she exposes the subject; the other describes actual salience of those events for the subject. Departures from SCT coherence may be conceptualized in terms of a third psychological dimension, the relation between the points on the experimenter's and the subject's contingency spaces.

There are considerable methodological challenges to determine the subject–experimenter contingency space relations. Probe techniques have their limitations in that extensive, repeated probing can have unwanted effects, perhaps changing or even creating the SCTs that they are intended to measure. In many applications, however, it may be more efficient to specify an intended SCT outcome, arrange contingencies to promote that outcome, and measure selectively to verify that the programmed contingencies have had their desired effect. To use an example from this paper, the delayed S+ technique arranges contingencies that explicitly discourage certain SCTs. Used as a teaching approach rather than an analytical technique, this procedure takes a step beyond the "train and hope" approach (Stokes & Baer, 1977) that often finds its way into discrimination learning experiments and classroom applications of discrimination training technology.

We see the probable future development of new SCT analytic techniques only in general outline right now. As noted earlier, we see a pressing need for a successful marriage between SCT concepts and quantitative analysis of behavioral allocation. Our own research program is moving in that direction (e.g., Dube & McIlvane, 2002, in press). It appears increasingly obvious that signal-detection analyses and other quantitative techniques from signal processing will be part of the story. Also a part will be exploiting our increasing ability to determine what aspects of stimuli-to-be-discriminated are making contact with the sensory receptors (e.g., via eye-tracking methodology, Dube et al., 2003, and perhaps even electrophysiology or other biobehavioral technologies, Deutsch, Oross, DiFiore, & McIlvane, 2000). For now, however, there is much we can do with existing behavior-analytic techniques if they are systematically and carefully applied.

Relational Stimulus Control

Thus far, we have tried to limit our discussion of SCT coherence to fairly simple situations of discriminative stimulus control. The original statements of SCT coherence theory, however, were directed at somewhat complex subject matter, specifically the stimulus–stimulus relations involved in stimulus equivalence and related phenomena. It seems appropriate, therefore, to comment here at least briefly on issues concerning SCT coherence analyses of these phenomena.

In the laboratory, stimulus–stimulus relational learning is typically modeled using conditional discrimination procedures. Such procedures are defined by trial-to-trial changes in positive and negative discriminative stimulus functions:

> The significance of a discriminative stimulus is not invariant, but changes in relation to the stimulus context in which it appears. Thus, the correct response cannot be made solely on the basis of a single stimulus, but must be based on the properties of two or more stimuli. (Cumming & Berryman, 1965, p. 285)

The conditional matching-to-sample procedure is a representative task (see

Dube, McIlvane, & Green, 1992, for a discussion of the requirements for conditional discrimination in matching-to-sample procedures): A series of trials presents an array of two or more comparison stimuli, for example, B1 and B2, along with one sample stimulus that alternates irregularly over trials, for example, A1 or A2. Reinforcers follow responses defined by the experimenter as related to Comparison B1 on trials with Sample A1 and those similarly related to Comparison B2 on trials with Sample A2. Thus, the nominal positive and negative discriminative-stimulus functions of B1 and B2 in relation to the defined response are conditional upon the sample stimulus present on each trial.

The requirement for relational stimulus control adds complexity to the concept of SCT coherence. The potential for multiple SCTs in simple discrimination procedures is augmented by the trial-to-trial changes in the experimenter-specified contingencies. For example, distinct SCTs related to stimulus form and location may themselves come under conditional stimulus control by sample stimuli, as exemplified by "Type D" control in Sidman (1980). In terms of the example above, the subject might respond to B1 on trials with Sample A1 and to the left stimulus location on trials with Sample B2, to produce an overall accuracy score of 75%. Additional examples of conditional stimulus control with poor SCT coherence include descriptions of multiple stimulus-position compounds (Sidman, 1992) and the multiple-hypothesis analysis in Cumming and Berryman (1965).

SCT coherence in relational stimulus control is relevant to the issue of compound versus elemental stimulus control in conditional discrimination. The former perspective is that responding is controlled by specific configurations or stimulus compounds (e.g., A1-and-B1) as in, for example, the configuration model of Carter and Werner (1978). Trial-to-trial stimulus changes present different compound discriminative stimuli, and thus the subject's behavior seems adequately described by the three-term contingency. The elemental perspective holds that the controlling stimuli in a conditional discrimination exert differing stimulus functions. As examples, Cumming and Berryman (1965) referred to the sample stimulus as a "selector of discriminations" (p. 285) that exerted an instructional function, and Sidman (1986) described hierarchical conditional and discriminative stimulus functions for sample and comparison stimuli, respectively. In this view, the discriminative stimuli do not change from trial to trial; stimulus changes involve only instructional or conditional stimuli. The specification of SCT from this perspective seems to require something in addition to the three-term contingency, for example, the four-term contingency described by Sidman (1986).

Although Sidman (2000) later acknowledged the possibility of stimulus equivalence at the level of the three-term contingency, his earlier analysis remains cogent. There remains an issue of whether the three-term contingency is a sufficient specification of SCT in conditional discrimination under all circumstances. Given a trained baseline of A-B matching (Set A sample stimuli and Set B comparison stimuli, as in the example above) and A-C matching, the emergence of untrained B-C and C-B matching is inconsistent with stimulus control by compounds. Stimulus control by, for example, an A1-and-B1 compound as traditionally defined is not justifiable when the two stimuli can be shown to function independently of one another.

Some experimental findings, however, seem difficult to reconcile with either a compound or elemental perspective. A good example is Markham and Dougher (1993; see also Markham, Dougher, & Augustson, 2002; Serna, 1991). College students were trained to perform matching to sample with two-element samples, AB-C. Trials were arranged so that accurate performance required both discrimination of individual sample elements and sample stimulus control by two-element compounds (e.g., A1B1-C1, A1B2-C3, A3B1-C2, etc.). After mastering this baseline, subjects displayed untrained AC-B and BC-A matching, that is, the trained comparison stimuli and elements of the sample compounds were substitutable for one another. Most other subjects trained to perform both AB-C and C-D matching also displayed a variety of emergent performances consistent with stimulus equivalence: AB-D, D-AB, AD-B, and BD-A. Thus, the experimental procedures apparently established multiple SCTs; the subjects' behavior was controlled by experimental stimuli that sometimes exerted stimulus control as multielement compounds and at other times as individual and independent elements. Stromer, McIlvane, and Serna (1993) referred to such stimulus control in terms of "separable compounds," to distinguish it from the traditional definition of the stimulus compound as an inseparable entity. In the context of the present discussion, this issue serves primarily to illustrate that certain experimental procedures may *require* multiple SCTs to achieve SCT coherence.

Regarding the theoretical issue of whether stimulus equivalence is a basic (Sidman, 1994) or a derived or mediated function (Hayes et al., 2001; Horne & Lowe, 1996), SCT coherence theory is not necessarily wedded inextricably to the former, as one familiar with current theoretical debates might suppose. That said, we do favor Sidman's phylogenic contingency theory—that stimulus equivalence is a basic function that arises from reinforcement contingencies. SCT coherence theory evolved in part to address the empirical fact that not all equivalence-test outcomes are positive (see McIlvane et al., 2000, for extended discussion of this issue). In our laboratory, we tend to respond verbally to the rare failure of emergent behavior in ways that may differ from those prevalent in a number of other laboratories. Rather than saying "We had an equivalence-test failure," we believe that we do our best thinking if we say instead "What got in the way of a positive outcome?" From this perspective, the onus is on the experimenter to improve the procedures such that SCT coherence is structurally required by the programmed contingencies. Accomplishing an accurate, truly comprehensive analysis of behavioral prerequisites is an important part of the often-difficult behavioral engineering necessary to program tight contingencies. SCT coherence principles help by serving as an ongoing reminder that these difficulties cannot and should not be ignored if the ultimate goal of moment-by-moment effective management of stimulus control is to be achieved.

SCT Coherence and a Stimulus Class Account of Generalization

This section addresses the clinically relevant problem of programming for generalization of new behavior across context changes in task, setting, and so forth (e.g., Stokes & Baer, 1977). We will present an account of generalization that is an outgrowth of SCT coherence theory, and one that relates the problem of generalization to laboratory research on stimulus classes and stimulus equivalence (Sidman, 1994).

As background, the upper portion of Figure 6 (labeled "teaching challenge") shows a typical analysis of the effects of operant conditioning procedures. At the beginning of teaching ("entry state"), substantial competition may be evident. Stimuli (or stimulus classes; cf. Skinner, 1935) that the teacher wants to control behavior (i.e., the "target stimulus classes" and "target behavior," respectively) may have uncertain status, as indicated by the question marks, and are in competition with "other stimulus classes" and "other behavior." The target stimulus classes may occasion other behavior, and other stimulus classes may occasion the target behavior. Reinforcers other than those programmed may cap-

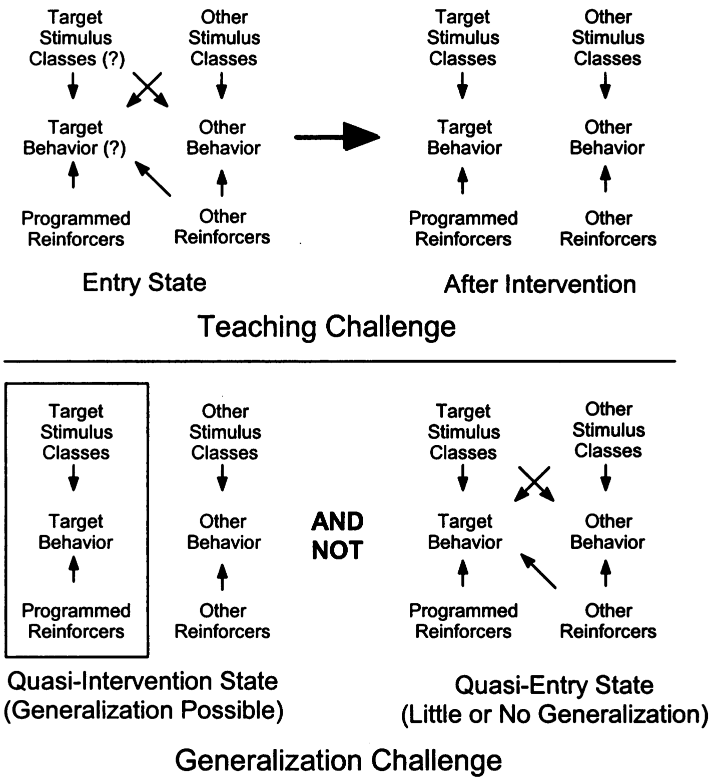

Figure 6. Stimulus class analysis of generalization; see text for details.

ture and maintain undesired forms of behavior or desired behavior under undesired stimulus control. That competitive situation is suggested by the diagonal arrows in the upper left portion of Figure 6. Effective intervention procedures reduce the behavioral competition. Target stimulus classes come to reliably occasion the target behavior, and other environmental events (i.e., other stimulus classes) continue to occasion other behavior. These effects are suggested by the removal of the diagonal arrows in the upper right portion of Figure 6. Put another way, the target behavior occurs only when a member of the target stimulus class is present; under other stimulus conditions, other behavior occurs.

As the bottom portion of Figure 6 suggests, the "generalization challenge" is effectively the reverse of the teaching challenge in certain respects. Generalization can occur if and only if (a) members of the target stimulus class are present in the generalization environment, (b) it is physically possible to emit the target behavior in the generalization environment, and (c) programmed reinforcement schedules are similar in the intervention and generalization environments. These requirements are suggested by the box surrounding the target stimulus class/target behavior/programmed reinforcer behavioral relation. In addition, generalization can occur reliably if and only if other stimuli in the generalization environment do not occasion other behavior with a frequency that competes with the target stimulus class/target behavior relation (suggested by the absence of diagonal arrows in the lower left portion of Figure 6 and termed a "quasi-intervention state"). If such competition does occur (as in the lower right portion of Figure 6), there is effectively a return to conditions similar to those prior to intervention, and generalization will be weak or absent.

Multiple stimulus classes and generalization. Thus far, this analysis of conditions that promote generalization resembles that presented in other behavioral analyses (e.g., Horner, Dunlap, & Koegel, 1988). What has been emphasized more recently, however, is the idea that two types of stimulus classes are involved in generalization (e.g., Mackay, Stromer, & Serna, 1998). The first type—feature or similarity classes—have common physical features, as the name suggests. To promote generalization, one can arrange for physically similar stimuli to be present in both the teaching and generalization environments (e.g., Kirby & Bickel, 1988). The second type of class—the arbitrary or contingency class—does not entail common physical features. Rather, stimuli become class members when they are established as discriminative stimuli in the same reinforcement contingency. When this occurs, one outcome is that the stimuli are members of the same equivalence class; the stimuli are mutually substitutable within a given context. To promote generalization, one can arrange for equivalent stimuli to be present in both the teaching and generalization environments. The notion of arbitrary equivalence is helpful (and may be essential) to account for generalization across physically dissimilar environments. For example, a student who has been taught to sit quietly when his or her teacher says "Quiet" in the classroom, and who has also learned to read the printed QUIET aloud in some other setting, may come to sit quietly in the presence of a printed sign QUIET (e.g., in a hospital hallway), although he or she has not been taught explicitly to do so.

As suggested by SCT coherence theory, the nature of stimulus classes established in the teaching setting directly determines whether or not generalization occurs. Indeed, the theory makes testable predictions. If the requisite feature and arbitrary stimulus classes are demonstrable in both the teaching and generalization environments, then generalization should occur, provided that there are not other competing sources of stimulus control. If the requisite classes are not present, then generalization should not occur. Viewed this way, generalization can be seen as mainly an engineering problem—albeit a critically important engineering problem. Laboratory science has established most or all of the basic scientific principles necessary to assure reliable across-task and across-setting generalization. Those principles have emerged from extensive research on stimulus classes over the past 30 years. Yet to be established is a comprehensive methodology through which those principles can be effectively applied. No one thus far has explicitly modeled all features of our stimulus class analysis of generalization; it is a secondary derivation from extensive primary data. Direct tests of coherence theory's predictions are needed, initially in the laboratory to verify the accuracy and integrity of the basic principles, and then in the field to study the engineering challenges of less well-controlled environments.

Conclusion

Those who are familiar with the history of research on stimulus control will recognize that SCT coherence theory recalls certain classic themes in studies of selective attending and related subject matter (e.g., the problem of stimulus selection). We see its principal value to restate and reorganize that information without the excess baggage of mentalistic constructs that intervene between the stimulating action of the environment and the emitted behavior and between the behavior emitted and its consequences. For example, we think that SCT is preferable to "the stimulus as represented," which often tends to mutate quickly into the quasi-neurological concept of "representation." Thus, SCT coherence notions fit comfortably within contemporary behavior-analytic thinking. If other meaning is inferred, we do not intend or encourage that. We do intend our work to serve as a formal reminder of Skinner's dictum that "the subject is always right" in terms of his or her response to programmed or naturally occurring contingencies. To the extent that the experimenter can maintain this perspective when dealing with stimulus control (often a difficult task in our experience), more fruitful analyses are likely to result.

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