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Teaching Stimulus-Stimulus Relations to Minimally Verbal Individuals: Reflections on Technology and Future Directions

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Abstract

This paper discusses recent methodological approaches and investigations that are aimed at developing reliable behavioral technology for teaching stimulus-stimulus relations to individuals who are minimally verbal and show protracted difficulty in acquiring such relations. The paper has both empirical and theoretical content. The empirical component presents recent data concerning the possibility of generating rapid relational learning in individuals who do not initially show it. The theoretical component (1) considers decades of methodological investigations with this population and (2) suggests a testable hypothesis concerning some individuals exhibit unusual difficulties in learning. Given this background, we suggest a way forward to better understand and perhaps resolve these learning challenges.

More than fifty years ago, Murray Sidman and his research group at the Massachusetts General Hospital (MGH) began a long-term effort to develop behavioral technology that could be used to provide effective teaching for individuals who did not benefit from the verbal instructional methods common to regular and special education. Focusing on nonverbal instructional methods, he and his colleagues demonstrated that such individuals could learn if the teaching programs were designed to meet their needs (Sidman & Stoddard, 1966), a remarkable finding at that time. In 1970, the MGH group helped launch the Shriver Center, and the program they began continues to this day. At the 2014 Sarasota meeting, we honored Murray by briefly summarizing recent findings from our continuing search to solve research problems that he identified long ago. In this paper, we have fleshed out that summary in hopes of effectively communicating what we have learned in pursuit of possible solutions to those challenges.

Background

When behavioral development is typical, toddler-aged children rapidly learn stimulus-stimulus relations involving spoken words and their corresponding environmental events. Studies of so-called *fast mapping* have shown that children may learn up to nine new words per day (Carey & Bartlett, 1978). When children are little older, they may show similarly rapid learning of stimulus-stimulus relations involving visual stimuli, for example, between symbols (e.g., printed words) and corresponding pictures or objects. Such rapid learning of arbitrary stimulus-stimulus relations is all the more remarkable when one considers that much of this learning seems to occur in the absence of explicit reinforcement contingencies programmed by others..

By contrast, some children do not show the rapid relational learning exhibited by typical children. They display severely limited verbal behavior and acquire other symbolic relations very slowly – if they learn them at all. Such individuals are often termed *minimally verbal*[1] and diagnosed with intellectual disabilities – typically autism spectrum or some other neurodevelopmental disorder. When Sidman and his colleagues established the behavioral science research program at the Shriver Center in 1970, they did so in part to address the relational learning needs of these individuals and others with minimal verbal behaviors (e.g., those with acquired neurological disorders). In prior work at the Massachusetts General Hospital (e.g., Sidman & Stoddard, 1966), the research group had shown that many minimally verbal individuals could learn simple visual discriminations rapidly via carefully programmed instruction. The next logical step was an effort to extend that methodology to teach symbolic relations, typically operationalized as arbitrary auditory-visual and/or visual-visual relations that define stimulus equivalence (Sidman & Tailby, 1982; cf. Sidman, 1977, 1994).[2]

Implicit in the Sidman program was the idea (and hope) that developing equivalence relations in minimally verbal children would provide behavioral prerequisites for increasing functional verbal behavior – that children characterized initially in this manner would become more conventionally verbal. Indeed, subsequent applied research has shown that systematic behavioral intervention can substantially improve verbal repertoires of children with neurodevelopmental disorders (Bondy & Frost, 1994; Sundberg, 2007). However, research has shown that teaching prerequisite stimulus-stimulus relations to some minimally verbal individuals can be an extraordinarily difficult challenge, particularly so when there is no baseline of stimulus-stimulus relations to build upon. In our experience, many behavior analysts underestimate this challenge, particularly those who work only with nonhumans under laboratory conditions. Long ago, Skinner (1950) demonstrated that pigeons could acquire the first instances of matching to sample using only differential reinforcement techniques, a finding that has been replicated thousands of times in animal behavior laboratories. So…what is the challenge with minimally verbal humans?

The challenges are many: humans cannot not be taught under conditions of social isolation, deprivation to enhance reinforcer potency, protracted training, and other procedures that are used with nonhumans. Moreover, many matching-to-sample studies with nonhumans specify mere conditional discrimination as the objective – not *true matching* that is symbolic in any real sense (cf. Sidman & Tailby, 1982; McIlvane, 2013). Given that neither the conditions of

[1]The term *minimally verbal* seems to have largely replaced the term *nonverbal* when describing this population, perhaps because few individuals exhibit a total absence of verbal behavior. The newer term is intended to convey that the individual's functional verbal repertoire is extremely limited when contrasted with repertoires of typical individuals of a similar age.

[2]Sidman and Cresson (1973) published an early study of stimulus equivalence class formation that demonstrated the very slow learning that concerns us here. That study did show equivalence class formation in minimally verbal individuals, truly remarkable findings at that time. However, those findings were obtained only after very lengthy, painstaking discrimination training. One participant required nearly a year of training before he was ready for basic equivalence tests.

training nor the typical objectives are comparable, it does not seem appropriate to compare most training outcomes obtained with nonhumans to those shown by minimally verbal humans.

Many applied behavior analysts are challenged daily to teach symbolic stimulus-stimulus relations to minimally verbal humans as part of augmentative/alternative communication (AAC) intervention. For example, they often use the Picture Exchange Communication System (PECS; Frost & Bondy, 2002) in efforts to establish the first instances of functional symbolic communication. At the beginning of training, individuals learn to exchange a picture symbol for a preferred reinforcer. Subsequently, they are taught to relate different pictures and with their corresponding reinforcers – requiring discrimination of stimulus-stimulus (i.e., picture-reinforcer) relations. Whereas training goes quite rapidly in the initial stage for most individuals, outcomes in the subsequent stages are highly variable (Bondy & Frost, 1994). Some individuals require only a few days of discrimination training whereas others require training over several months to learn – if they learn at all. A major objective of the Shriver research program has been to understand learning challenges of the latter type and to develop instructional technology to ameliorate them.

In focusing on this topic, we certainly do not want to imply that teaching new verbal behavior to children need always begin with structured teaching of prerequisite equivalence relations using methods such as ours. Children with neurodevelopmental disorders comprise a behaviorally heterogeneous group, and individuals within that group may respond more or less well to different teaching approaches including those used in less structured so-called “naturalistic” teaching. Our particular interest has been in the subset of children who make little or no progress despite seemingly well-structured applied behavior analyses. For such children, we believe that highly structured teaching aimed at developing or augmenting critical prerequisite processes can offer a way to reduce behavioral variability, jump-start learning, and prepare children for success when they taught in a more conventional manner.

From the outset of its program, Sidman’s group went against the tide of then-prevalent large-N group designs and statistical control of behavioral variability in educational and clinical research. They followed principles from *Tactics of Scientific Research* (Sidman, 1960), particularly those relating to managing behavioral variability procedurally in individuals rather than relying on statistical control with groups. The single-case approach was virtually demanded by realities of the populations that they wanted to help. For example, the minimally verbal population is extremely heterogeneous etiologically and behaviorally. Unless effect sizes (Cohen, 1988) are very large, the numbers needed for group designs are also quite large. Moreover, implementing such designs for work such as theirs would have required an enormous investment of personnel and other resources. That consideration alone virtually demanded use of single-case and/or small-N research designs in which participants served as their own controls. Such designs were appropriate also because special education and behavior therapy for minimally verbal individuals was then and continues to be delivered in individual or small-group settings.

McIlvane and Kledaras (2012) described Sidman and Stoddard’s (1966) nonverbal program for assessing visual perception. In among the earliest instances of translational behavior analysis (McIlvane, 2009), they adapted stimulus control shaping procedures[3] reported in animal behavior studies by Terrace (1963a,b) and others to teach minimally verbal individuals to discriminate a circle from a relatively flat ellipse via stimulus fading procedures. Thereafter, the program used stimulus shaping to round the ellipses progressively over trials such that they came increasing to resemble the circle. The measure of visual perception – determined individually for each participant – was smallest circle-ellipse difference that could be discriminated.

Moving towards general applications

When single-case/small-N methods are used, an obvious issue is how to develop instructional technology that is applicable with larger groups. In its early days, Sidman's group approached that problem through (1) testing their programs with an increasing number of participants and (2) making ongoing refinements of their instructional programs where single case/small-N outcomes proved unsatisfactory. Their aim was to optimize the degree to which the programs taught the behavioral prerequisites for success at each step. They reasoned that such optimization would increase the scope of program effectiveness across individuals who entered the program with different levels of preparation for success. Nevertheless, a program with virtually universal effectiveness was viewed at best a very long-term development and perhaps an unrealizable objective. Indeed, Ray and Sidman (1970) wrote:

> "*All stimuli are complex in that they have more than one element, or aspect, to which a subject might attend [and thus] …we may never have a generalizable formula for forcing subjects to discriminate a specific stimulus aspect. We may have to settle, instead, for a combination of techniques, each of which is known to encourage stimulus control*" (p. 199).

Toward the aim of achieving the suggested combination of techniques, our research group has focused on computer technologies that have facilitated development of even greater optimization of programs intended for minimally verbal individuals, employing multiple instructional paths and branching options aimed managing individual variability in response to teaching. For example, McIlvane and colleagues (2011) summarized a long-term program of research aimed at developing reliable methods for teaching minimally verbal individuals to make generalized sameness-difference judgments (i.e., generalized identity matching [IDMTS]) with abstract visual stimuli – modeling procedures for teaching such individuals to discriminate different symbols as required by PECS and other AAC programs with similar objectives. Like the Sidman and Stoddard (1966) program, the IDMTS program evolved from an accumulation of single-case and small-N studies. Unlike it, the latter incorporated numerous program options to manage individual variability. Options included various stimulus control shaping procedures: fading in the S− by gradually increasing size or intensity (McIlvane et al., 1995, 1996), delayed prompting (Touchette & Howard, 1984), repetition of reinforced single-stimulus selections (Dube, Iennaco, & McIlvane, 1993),

[3]S*timulus control shaping* (McIlvane & Dube, 1992) is typically used to refer to methods that use graduated, progressive stimulus changes over trials to prompt correct selections (i.e., stimulus shaping, stimulus fading, progressive delayed prompting, etc.).

gradual introduction of changing S+/S− functions (Dube et al., 1993), and certain other programming methods developed for this application (Serna, Dube, & McIlvane, 1997).

The Present Challenge and Program Objective

In parallel with development of its sameness-difference program, Shriver researchers have sought also to develop programs for teaching stimulus-stimulus relations in which the stimuli are not physically identical. Two types are needed: (1) programs for establishing so-called *feature* (McIlvane at al., 1993) or *perceptual* (Fields, 2009) equivalence classes and (2) *arbitrary equivalence* classes (Sidman, 1994). The former type involves relations between/among stimuli that share defining physical features (i.e., stimuli that resemble each other in some way). The latter classes do not share defining features (e.g., pictures and corresponding printed words).

Concerning feature/perceptual classes, our focus is on procedures for teaching 3D:2D (e.g., object:picture) equivalence relations, that is, to establish both 3D and 2D stimuli as members of the same class. Extensive research by developmental scientists has shown that object-picture equivalence is shown in typically developing children between 18–36 months (e.g., Daehler, Perlmutter, & Myers, 1976; Hartley & Allen, 2014). There has been much interest also in this topic by animal cognition researchers (e.g., Watanabe, 1993; Fagot, Martin-Malivel, & Dépy, 1999).

By contrast, there is little behavior analytic work on behavioral technology for teaching picture:object relations that can inform efforts of teachers of minimally verbal individuals. One exception was reported by Dixon (1981). Working with minimally verbal adolescents with severe intellectual disabilities, she was able to facilitate photo:object matching by removing potentially distracting stimuli from the former. If photo:object matching of a banana was the target, for example, the teacher cut away all but the yellow form from the photo (i.e., leaving the figure but removing the ground). After that history, her participants showed at least limited accurate matching on a conventional photo:object task that they had formerly failed.

In a systematic replication of Dixon’s (1981) procedures, we found that even those careful efforts may prove insufficient for some minimally verbal individuals. For example, Lionello-DeNolf and McIlvane (in preparation) conducted a case study in which instruction had established generalized IDMTS with: (1) familiar objects; (2) unfamiliar objects; (3) objects constructed out of LEGO blocks so as to approximately equalize their overall area and weight; (4) high-quality color photos of the familiar objects, and (5) photo cut-outs similar to those used by Dixon (1981). Despite very high accuracy on these IDMTS tasks, the participant exhibited chance-level score when required to match the familiar objects with the photos. In contrast to Dixon’s typical outcomes, our participant also failed initially to match objects with cutouts. Moreover, even cutout-photo matching was established only after extensive stimulus control analyses, stimulus control shaping and other programmed teaching based on those analyses, and a number of failed programming efforts. With further systematic teaching of this sort, we ultimately established accurate but fragile photo-object matching (i.e., criterion level responding that was maintained only unreliably).

Findings such as these may seem unbelievable to those who do not have experience in stimulus analyses and stimulus control shaping with minimally verbal participants. Particularly vexing is the frequent observation of failures at the final step(s) of stimulus control shaping despite careful, seemingly effective shaping programs that maintain virtually errorless performance until that point (e.g., McIlvane & Cataldo, 1996). With minimally verbal individuals, we have observed instances in which final performance breakdowns occurred when the difference between the final and penultimate program steps differed by only a few pixels – even one – out of hundreds that comprised form stimuli to be discriminated. This phenomenon is also demonstrable with nonhuman primates doing similar tasks (Brino et al., 2011, 2012).

A fundamental lesson from Sidman and Stoddard's (1966) studies was that program failures occurred when the programming steps were too big; the recommended solution was to break such steps up into smaller ones to establish behavioral prerequisites for successful shaping. Often but not always, this recommendation serves us well in our work. Too frequently, however, we have seen shaping programs break down at a final step when high accuracy was maintained on a penultimate step differing by only a few pixels. In such cases, programming even smaller steps does not seem to be the solution. Indeed, when of stimulus control shaping program fails to establish a target feature/perceptual class involving two stimuli that differ merely by a few pixels out of hundreds, one is led to ask whether the program is actually shaping *increasingly overselective attending* to common features that are preserved during shaping.

As our data pointed to this possibility, our group began to investigate procedures that might help forestall development of overselective attending during shaping. One early effort systematically deleted a quasi-randomly selected 25% of pixels during the shaping program (missing quadrant procedure, cf. Serna [2004]). The deletion procedure was intended to minimize the likelihood that the participant would attend to any particular stimulus feature (i.e., set of pixels) over trials, perhaps avoiding the overselectivity problem. While this procedure seemed to have benefits, it did not resolve the general problem of program failures at late stages of the program.

More recently, we sought to extend this approach, using computer graphics to conduct what we call "dynamic stimulus control shaping" – within-trial animated stimulus changes instead of those typically implemented across trials in stimulus control shaping procedures. Like the missing quadrant procedure, dynamic shaping was intended to minimize persistence of control by specific features; it also arranged circumstances under which specific features were not always available – because they morphed away either temporarily or permanently depending upon the program step. Moreover, the dynamic shaping maximized both spatial and temporal contiguity between previously controlling stimulus features and those that were intended to gain control via shaping.

Armed with some very promising preliminary results on dynamic shaping (Gomes et al., 2011), we launched an extensive research program to explore the benefits of this innovative approach to stimulus control shaping. We experimented with several dynamic shaping methods in the course of the program. While these studies are still underway, our present conclusion is that dynamic shaping *does not* provide the general solution to final-performance program failures that we had hoped for. At best, it appears minimally superior to the across-trial shaping (static) contrast procedure. Thus, we cannot yet offer "*a generalizable formula for forcing subjects to discriminate a specific stimulus aspect*" (or stimulus-stimulus relation) that Ray and Sidman (1970) suggested might always escape us. While the situation might indeed be hopeless as they suggest, we are determined to make it otherwise.

Re-booting the Search

We were frustrated by our modest successes with dynamic shaping procedures. Based on much prior research and task analysis of behavioral prerequisites, we had been confident that we were on a promising path that would lead to greater successes. As students of Sidman, our first inclination was to optimize the dynamic shaping methods by systematic variation in various task parameters (e.g., stimulus variables, number and size of program steps, animation rate, etc.) as Sidman and Stoddard had done in the original development of the circle-ellipse program. We ultimately rejected that approach for practical reasons. There would be a great many possible combinations to evaluate, and today's meager research budgets will not support explorations of this type. Because we are students of Sidman, we followed another of his lessons: carefully review what you know and then do the best behavior analysis that you can from that point on.

What We Think We Know

Although well-designed stimulus control shaping procedures typically are successful with minimally verbal individuals when teaching simple discriminations (e.g., the circle vs. ellipse discrimination), those procedures tend to fare less well when the goal is to teach stimulus-stimulus relations. In the latter applications, overselective reliance on preserved stimulus features (as encountered in our dynamic shaping studies) or extra-stimulus prompts (e.g., stimuli added to indicate correct selections as in delayed-prompting procedures) has been a common outcome, as noted. Concerning feature/perceptual classes, one solution pursued in the past has been to use within-stimulus/criterion-related prompts (Schreibman, 1975; Schillmoeller et al., 1979) in which common physical features are preserved during stimulus control shaping. However, such methods by themselves cannot teach arbitrary stimulus-stimulus relations because such relations do not involve shared defining physical features by definition.

However, there are other methods – also unreliable with our target population – that can establish stimulus-stimulus relations without relying on graduated stimulus change/extra-stimulus prompt procedures. Concerning feature/perceptual classes, the generalized IDMTS program described earlier (Serna et al., 1997; Dube & Serna, 1998) used a mixture of stimulus control shaping methods and other methods that used progressive structuring of simple discrimination tasks. We will use the term *progressive structuring procedures* here merely for convenience in differentiating them from stimulus control shaping procedures. The former refers to nothing more than typical programmed instruction that lacks progressive stimulus change features. As in Sidman and Sidman's (1965) classic

Neuroanatomy program, for example, each teaching step is intended to prepare the student for success on the next. His/her attention was drawn to critical details of target stimuli by other superimposed stimuli (e.g., highlighting, text prompts, etc.), but there was no progressive shaping *per se*. The subsequent trial(s) merely tested whether the preceding one(s) provided behavioral prerequisites for correct responding.

Teaching the first instances of arbitrary matching via progressive structuring procedures: Summary of methodological studies to date

One such procedure uses a yoked simple-discrimination reversal method (A1/B1 vs. A2/B2 with the S+/S− stimulus functions of Set A and Set B held constant over reversals e.g. Saunders & Spradlin, 1989; McIlvane et al., 1990). In this method, the S+ and S− stimulus function of yoked stimuli are reversed repeatedly until reversal of one S+/S− combination (e.g., A1/B1) by direct reinforcement and extinction leads to spontaneous reversal of S+/S− functions of the other combination (A2/B2), thus demonstrating a functional stimulus class. Thereafter, further progressive structuring methods are used to transform the simple discrimination reversal procedure into arbitrary matching to sample.

A second method adapts procedures based on the pop-out phenomenon (Serna & Carlin, 2001; Morro, Mackay, & Carlin, 2014). It displays sample and comparison to be related with an initially large number of identical negative comparison stimuli – thus drawing attending to the positive comparison stimulus. Over trials, the number of negative comparisons is reduced progressively until there is only one, at which point the task is transformed into arbitrary matching to sample.

Yet a third method begins with a well-learned IDMTS baseline (A1:A1+,A2−; A2:A2+,A1−). Thereafter, one employs a variant of the learning by exclusion (LBE) method (McIlvane & Stoddard, 1981): One merely substitutes as yet undefined (by the prevailing contingencies of reinforcement) stimuli for the positive stimuli on each trial type (e.g., A1:B1+,A2−; A2:B2+,A1−). Given this arrangement, research participants typically *exclude* S− stimuli defined in relation to each sample (i.e., selecting B1 in relation to A1 and B2 in relation to A2; cf. McIlvane, Munson, & Stoddard, 1988). Although such performances are procedurally arbitrary matching to sample at this point, one does not know whether participants have actually learned to relate A1 with B1 and A2 with B2 – they may be merely continuing to exclude A2 and A1, respectively. To assess whether A1:B1 and A2:B2 selections constitute true arbitrary matching, *learning outcome tests* are needed, for example, A1:B1+,B2− and A2:B2+,B1−.[4]

By contrast to stimulus control shaping procedures, none of the procedures just described employ graduated stimulus changes or added extra-dimensional prompts that may lead participant to ignore target stimuli and rely on prompts. Might our efforts be better directed in optimizing the effectiveness of methods such as these? Because they do not require extensive stimulus preparation (i.e., definition and production of stimulus control shaping

[4]As Sidman (1987) reminds us, positive results on two-comparison tests do not necessarily imply that the participant has learned both sample:comparison relations. For example, such performance could result from learning merely the A1:B1 relation and selecting the B2 comparison in relation to the A2 sample via exclusion of B1.

program steps), they would seem to align with the *parsimony principle* put forth by Etzel and LeBlanc (1979): use stimulus control shaping methods only when procedurally and logistically simpler methods have failed to achieve the desired learning outcomes. Indeed, these methods tend to be simpler procedurally than most stimulus control shaping methods, they may be easier to explain to practitioners who might use them in AAC applications, and they may ultimately prove more effective.

Optimizing a *progressive structuring* procedure: One example

To illustrate a stimulus control structuring approach to teaching stimulus-stimulus relations to minimally verbal individuals, we will summarize a recent study that concerned development and expansion feature/perceptual classes, specifically the teaching of 3D:2D relations between food items and pictures of the type that might be selected for a PECS AAC program. The study sought to optimize the LBE method, specifically incorporating an intelligent algorithmic *steering logic* for implementing this procedure.

The main purpose of the steering logic was to systematize implementation of the various components of the LBE. For widespread application, the procedure has one drawback. To use it in an optimal manner, one must make a number of initial and ongoing informed decisions about the progressive structuring of trial types. These decisions include but are not limited to: (1) the number of exclusion trials and control trials programmed; (2) the number and nature of baseline matching-to-sample trials that provide procedural context for LBE teaching; (3) the number and nature of trials that test learning outcomes; (4) the rate of introducing new relations via LBE; (5) the proportion of baseline trials that review relations established in earlier teaching, including the proportion of recently acquired relations; and (6) the method for handling any persistent errors on learning outcome trials of individual relations. Table 1 summarizes these considerations, giving further details of their rationale and foundations.

In our current 3D:2D LBE steering logic, we make the assumption that there is no established baseline of 3D:2D relations at the beginning. Thus, the initial progressive structuring relies in part on differential reinforcement to teach the first instances of 3D:2D relations. Figure 1 presents data from an illustrative case. During the initial teaching, minimally verbal Participant TF learned a two-sample, two-comparison 3D:2D matching task. Thereafter, LBE teaching procedures established three-sample, three-comparison MTS, introducing a new object:picture relation on control and exclusion trials (18 each in a 72-trial session, all correct). Overall, the first LBE session accuracy score (light gray bars) was also very high. Next, the new relation was added to the baseline (dark gray bars) and reviewed in three subsequent baseline sessions (black bars) in which all sample:comparison relations were presented in equal proportions. This same approach was replicated twice more, adding two new object:picture relations to the baseline. Across all LBE sessions, accuracy on control and exclusion trials exceeded 96%.

To further validate our LBE steering logic, we replicated this study with 12 additional minimally verbal children. Notably, three children did not master the initial 3D:2D baseline (as TF had) within the time available to us. The remaining nine children performed similarly to TF. Summary data for this study are presented in Table 2 (upper portion). This lower portion of Table 2 also reproduces data from a recent re-analysis (McIlvane & Kledaras, 2012; see their Tables 1 and 2) of the most on-point LBE study available in the current literature (Carr & Felce, 2008); it showed that LBE was substantially more effective than the standard-of-care error correction procedure recommended in the PECS program (Frost & Bondy, 2002). We did that re-analysis to illustrate another lesson that we learned from Sidman (1981) – accuracy scores by themselves can be misleading. When we analyzed the Carr and Felce (2008) data in terms of stimulus control measures, the LBE data were shown to be even stronger than the accuracy scores suggested. Our replication data suggest that using the LBE steering logic might lead to learning outcomes that were better still.

In presenting these data, we do not want to imply that LBE is a fully mature method for teaching stimulus-stimulus relations to minimally verbal individuals. In many single-case and small-N studies, it has produced excellent learning outcomes in most but not all participants. Perhaps 20% of participants do not seem to learn stimulus-stimulus relations reliably with LBE, and we do not yet understand why this is so. Below we will offer a hypothesis that may help us move towards ultimate resolution of this challenge.

Establishing the first instances of arbitrary visual-visual exclusion

To use the LBE method, participants must show reliable exclusion performances. In numerous studies of auditory-visual and visual-visual matching to sample, we have found that most minimally verbal individuals do exhibit reliable exclusion after high-accuracy matching-to-sample baselines have been acquired. Occasionally, we encounter someone who does not, most often with visual-visual relations. Recently, we had an opportunity to conduct extended study of one such individual during our dynamic stimulus control shaping research. The task was visual-visual arbitrary matching of picture comparisons with letters representing the initial consonant of their corresponding printed word in English (e.g., D = Desk, G = Gate, etc. cf. Carr et al., 2000).

The participant had already learned to match a small number of pictures to their corresponding spoken words and had generalized IDMTS with pictures and letters of the alphabet. The teaching goals were two-fold: (1) Using an LBE procedure, teach a series of new auditory-visual relations and (2) using the IDMTS baseline, attempt to teach arbitrary visual-visual relations via LBE. If LBE outcome data were poor in either case, then we were prepared to use stimulus control shaping programs to teach the relations.

The upper portion of Figure 2 shows results of the auditory-visual LBE training. The most critical data were performance on exclusion trials (highly accurate) and on *outcome exclusion* trials (only slightly less so). The latter evaluate acquisition of each auditory-visual relation by testing whether the participant would exclude the visual comparison stimulus defined by LBE when an as yet undefined auditory sample was presented (successive introduction method; cf. Wilkinson & Albert, 2001). *Control trials* corresponding to exclusion and outcome exclusion trials verified that previously defined auditory-visual relations would be maintained when undefined comparison stimuli were available; performance on these were also highly accurate. In summary, the participant learned six new auditory-visual relations fairly rapidly and with a low error rate.

In contrast, the lower portion of Figure 2 shows that the participant showed no evidence of exclusion on the first six relations tested, either avoiding the undefined comparison stimulus entirely or selecting the defined and undefined comparison stimuli indiscriminately across trials. In each case, stimulus control shaping programs succeeded in establishing the targeted visual-visual relations. Accurate exclusion emerged, however, with the next three relations. To our knowledge, these are the first data that suggest that exclusion performances may emerge after multiple-exemplar training with previous relations of the same type. Regrettably, we could not continue our studies with this participant, and we do not know whether learning by exclusion would also have occurred had we been able to test for it.

In search of a reliable method for teaching stimulus-stimulus relations

We would like to report that stimulus control shaping, LBE, and the other progressive structuring methods mentioned earlier together comprise a fully mature behavioral technology for teaching stimulus-stimulus relations to minimally verbal individuals, but that is not yet the case. As compared to our starting point, we can now teach stimulus-stimulus relations to more individuals more rapidly and more reliably than ever before. Gratified as we are with these achievements, there remains too much variability in response to these procedures for us to claim we have a mature technology for teaching stimulus-stimulus relations to minimally verbal individuals. That said, we think that we may have a way forward either for achieving our goal or for understanding why the mature behavioral technology that we seek may always elude us.

A Way Forward?

To summarize our earlier points: (1) one cannot use within-stimulus and/or criterion-related prompts to teach such relations; some form of extra-stimulus prompting is needed for teaching truly arbitrary stimulus-stimulus relations by definition. (2) Stimulus control shaping programs fail when participants continue to attend to preserved stimulus features – even miniscule ones – during shaping and seemingly fail to attend to the seemingly more obvious stimulus features introduced in shaping – even when they prove capable of discriminating those stimuli on IDMTS trials. (3) Based on much data, we have concluded that stimulus control shaping may explicitly teach overselective attending to some individuals.

Those familiar with the literature on stimulus overselectivity may wonder whether we have missed some important developments that bear on this problem. Long ago, for example, Schreibman, Charlop, and Koegel (1982) published an important paper in which they (1) used differential reinforcement techniques to teach children with autism to attend to more than one simultaneously displayed stimulus during discrimination training (e.g. XY+, XA−, YB−) and (2) reported that such training led to success in subsequent use of extra-stimulus prompting procedures. Subsequently, procedures for teaching multiple-cue attending have been incorporated in pivotal response training for children with autism (Kogel, Koegel, & McNerney, 2001).

Regrettably, this seemingly simple approach – teach attending to multiple stimulus cues via simple differential reinforcement techniques – proves extremely difficult with minimally verbal individuals. Indeed, the stimulus control programming methods discussed so far have been developed explicitly because mere differential reinforcement technique are often ineffective with such individuals (Sidman & Stoddard, 1967; Richmond & Bell, 1986). Moreover, until recently, we have had only limited success in research aimed at using programming methods to overcome overselective attending. For example, although overselective attending can be reduced by explicitly requiring differential observing responses to each stimulus separately, it often returns when such responses are no longer explicitly required (e.g., Dube & McIlvane, 1999). What is needed now is intensive research to develop broadly effective programming methods to teach such individuals to attend to multiple stimuli simultaneously as Schreibman and colleagues (1982) suggested.

A recent study by Farber, Dube, and Dickson (accepted) may be pointing the way towards the needed behavioral technology. Their study was similar to the approach taken by Schreibman and colleagues. They studied five children with autism who had exhibited low to intermediate accuracy scores on a computer-presented IDMTS task that required attending to multiple stimuli (e.g., chair-tree+, chair-sun−, airplane-tree−). Thereafter, the children were given a tabletop sorting-to-matching task that adapted behavioral technology developed by Serna et al., (1997) to teach IDMTS. As training progressed, multiple-stimulus matching was introduced gradually, supported as needed by temporary imposition of differential observing response requirements. The multiple-element attending training succeeded with all children. In addition, when they were returned to the computer multiple-element IDMTS task, accuracy scores improved to 95%–99%.

Summarizing Our Current Hypothesis

To convey key aspects of our current thinking, we will start with two additional quotations, one scientific and one whimsical:

> "Terrace (1963b) *found that superimposing horizontal and vertical bars on the red and green stimuli of an established discrimination facilitated transfer to a discrimination of horizontal and vertical. The transfer was effected without errors. … As the red and green stimuli became less intense, a point may have been reached where behavior came under the control of both aspects of the composite stimuli*"
>
> (Ray, 1967, p. 31).

> "*The test of a first-rate intelligence is the ability to hold two opposing ideas in mind at the same time and still retain the ability to function*"
>
> (Fitzgerald, 1936).

Ray (1967) suggested that stimulus control transfer occurred at the point at which the bird *attended simultaneously* to the diminishing color and to the tilt of the line. Had the bird attended selectively only to the color, it would have failed to show transfer. Our Fitzgerald quote is intended merely to suggest the challenge entailed in transfer: one must attend simultaneously not only to elements of the positive and/or negative stimuli that controlled responding originally but also to new stimuli being superimposed on them. In a sense, one is required to keep at least two stimulus elements "in mind" simultaneously.

Looking back over decades of research, the Shriver group has investigated (very successfully) a variety of programming techniques for directly teaching stimulus-stimulus relations to minimally verbal individuals. We developed a reasonably mature behavioral technology for teaching generalized IDMTS to such individuals (Serna et al., 1997; Dube & Serna, 1998), giving us confidence that a similar technology for teaching arbitrary stimulus-stimulus relations was within reach. Explicitly or implicitly, our researchers hypothesized that teaching multiple exemplars of specific arbitrary stimulus-stimulus relations would lead to growing facility in learning such relations. The rapid relational learning shown in most LBE research has been consistent with that hypothesis. Moreover, we hypothesized that teaching specific arbitrary stimulus-stimulus relations would lead to the emergence of stimulus equivalence and exclusion, either immediately or after multiple-exemplar training. Our case study on the emergence of visual-visual exclusion is one example of findings consistent with that hypothesis.

With the benefit of hindsight, we are beginning to think that our working hypotheses concerning arbitrary stimulus-stimulus relations were correct in many respects but not complete. As Ray (1967) suggested, *simultaneous attending* to prompt and target stimuli may be a key behavioral prerequisite that must be established in order to achieve routine success in stimulus control shaping of arbitrary stimulus-stimulus relations. Notably, Dube has led a long-term program of research (cf. Dube, 2009) that (1) demonstrated that simultaneous attending to compound sample stimuli can be very hard to achieve and sustain in individuals with severe intellectual disabilities but (2) developed a number of useful methods for establishing such simultaneous attending, at least temporarily. The most recent work (Farber et al., accepted) connected directly with the final stage of our generalized IDMTS program – a sorting-to-matching program that appeared to be the key to establish generalized performance in minimally verbal participants. Through their extension of that approach, Farber and colleagues may have pointed us to the work that is needed now – developing a reliable set of programmed methods for teaching and sustaining simultaneous attending.

Stating our hypothesis explicitly, when seemingly well-designed stimulus control shaping programs fail to teach arbitrary stimulus-stimulus relations effectively, the optimizing solution may not be ever-greater refinement of those shaping programs. Rather, the optimizing solution may be instead programmed teaching to establish and sustain simultaneous attending. If such attending can be established reliably, we may find that shaping programs that formerly failed at the final step now succeed. It seems logically possible that such training might have even broader effects – perhaps obviating the need for stimulus control shaping entirely at some point. For example, normally capable participants may acquire arbitrary stimulus-stimulus relations via mere pairing of the stimuli – so-called respondent-type training procedures (Leader, Barnes, & Smeets, 1996). Similar pairing procedures have succeeded in establishing arbitrary stimulus-stimulus relations in adults with autism and in normally capable children (e.g., Maguire, Stromer, Mackay, & Demis, 1994). Might successful programmed training in simultaneous attending prepare minimally verbal children to learn similarly? If so, we would have taken a very long step towards developing the general solution to teaching stimulus-stimulus relations that we have pursued since Sidman's early studies encouraged us to take on this very difficult – but perhaps not impossible – challenge.

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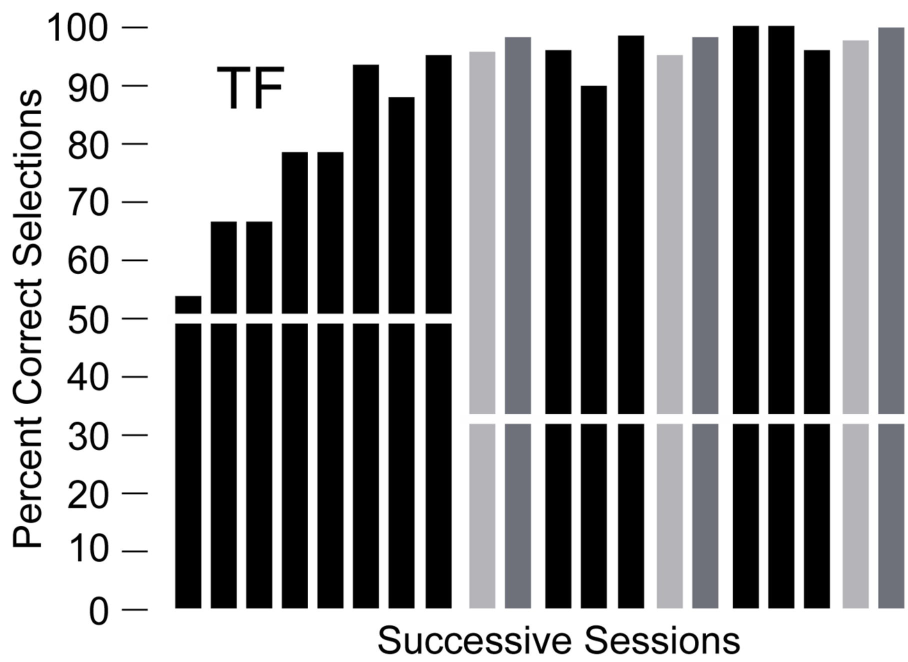

Figure 1.

Illustrative learning by exclusion (LBE) data obtained with minimally verbal participant TF. During the initial training, all matching to sample (MTS) trials displayed two comparisons; indiscriminant selections would have led to accuracy scores around 50% (suggested by the break in the bars at that point). In subsequent training, three comparison stimuli were presented on each trial. On such trials, indiscriminant selections would have led to accuracy scores around 33% as shown.

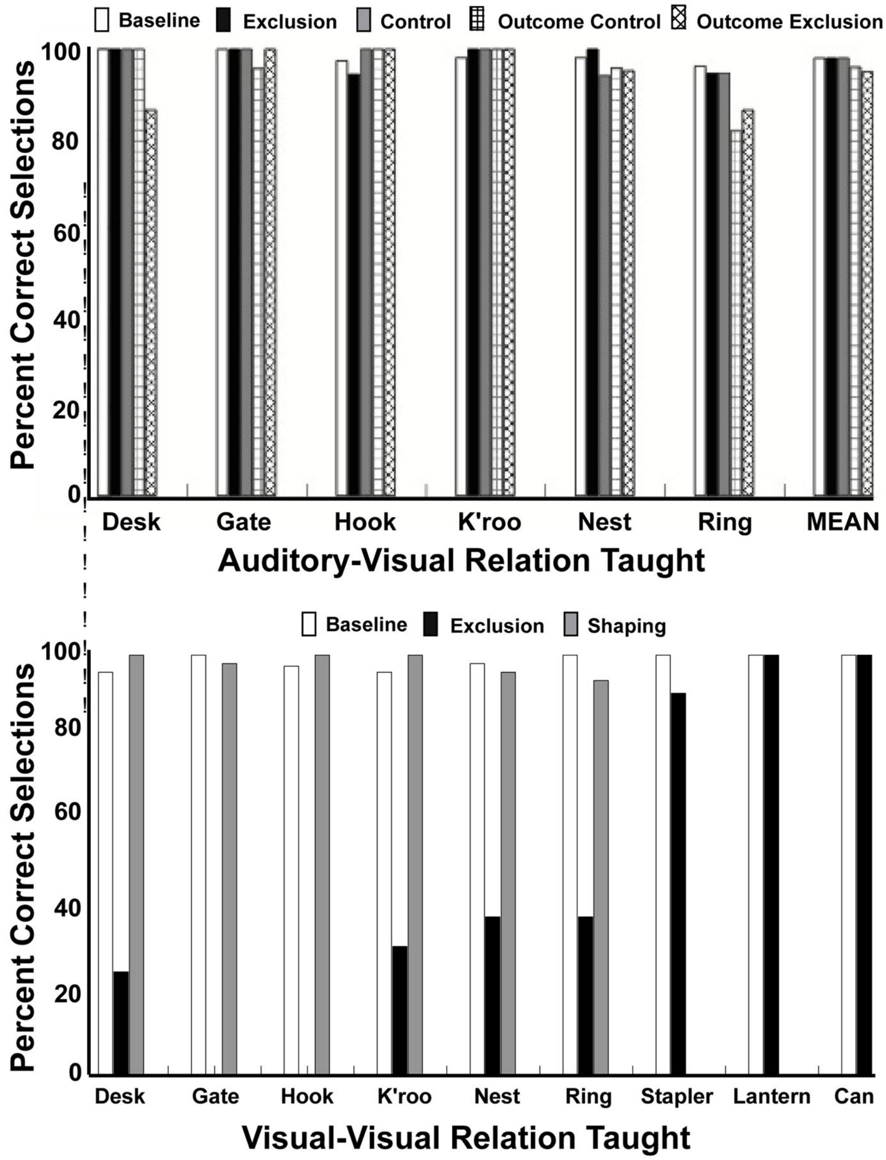

Figure 2.

Upper portion: Accuracy scores on LBE training with six successive new auditory-visual matching relations and mean performance for the six relations overall. Lower portion: Accuracy scores on visual-visual matching. Stimulus control shaping was employed to teach the first six relations. The last three relations included only exclusion trials. Shaping proved unnecessary to establish the relations of interest.

Table 1

Overview of major components of steering logics for teaching stimulus-stimulus relations to minimally verbal individuals using LBE teaching methodology

Component	Purpose(s)	Exemplary References
Learning by Exclusion (LBE) currently implemented	Stimulus-stimulus relational mapping procedure	Carr & Felce, 2008; Wilkinson et al., 2009
Interspersal of LBE teaching, control, and outcome trials within baseline of previously defined stimulus-stimulus relations of the same type inc. IDMTS	**1** Maintain reinforcement density during teaching; **2** Minimize possible error pattern development **3** Contextual exemplars of target relations	Neef, Iwata, & Page, 1977; McIlvane & Stoddard, 1981; Lionello-DeNolf, 2009
Progressive LBE outcome testing: (1) initial tests with trial-unique S− stimuli, (2) probe-to-full outcome testing with immediate history and/or interspersal of LBE review trials	**1** Early detection of LBE mapping failure to minimize error history **2** Probe tests include both sample-S+ and sample-S− to guide further testing and/or remediation	Derives from several sources, among them Dube et al., (1993) and techniques used in unpublished follow-up research conducted during the initial development of the LBE teaching method.
Baseline updating using first-in, first-out procedure; periodic probing of prior relations	Baseline expansion requires an algorithm for maintaining a practical number of trial per teaching session	Used in LBE studies that taught many relations, e.g., McIlvane & Stoddard, 1981; McIlvane et al., 1984
Structured deferral of teaching of stimulus-stimulus relations that occasion errors	Avoid development of permanently faulty discriminations due to error history	Terrace, 1963a (p. 24); Stoddard & Sidman (1967); McIlvane et al., 1992

Table 2

Learning by exclusion data obtained using LBE steering logic and contrast data re-analyzed from Carr and Felce (2008)

Data Source	Procedure	Accuracy > Chance Mean	% > Chance Range
Exclusion and outcome from initial trial of LBE steering logic	*Exclusion*	98%	90%-Max%
	Outcome	94%	84%-Max%
Re-analyzed exclusion and learning outcome data	*Exclusion*	85%	40%-Max%
	Outcome	83%	44%-Max%