Relational Learning in Preverbal Infants

Evidence from Developmental Science

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This paper attempts to integrate infant cognitive development research with behavioral analytic work on stimulus and functional equivalence as a critical next step in our understanding of these processes.

Categorization of environmental stimuli based on non-perceptual relations is a fundamental aspect of cognitive/behavioral systems (Estes, 1994; Quinn & Eimas, 1996). Such categorization entails discriminating stimulus features embedded in a compound stimulus and the ability to operate on discriminably different stimuli in a similar way. Furthermore, categorization and the ability to make non-feature-based associations between stimuli are recognized as skills associated with vocabulary and language acquisition (Gentner, 1977; Gershkoff-Stowe, Thal, Smith, & Namy, 1997; Poulin-Dubois, Graham, & Sippola, 1995; Roberts & Horowitz, 1986; Sidman, 1994; Woodward & Hoyne, 1999).

In the cognitive developmental literature, debate has arisen concerning the relative importance of *perceptually driven* versus *theory driven* processes for concept acquisition in human children (Gelman & Medin, 1993; Jones & Smith 1993a; 1993b; Keil, 1987; Mandler, 1993; Mandler & McDonough, 1993; Neisser, 1987; Newcombe, Dummey, & Lie, 1995; see also Eimas, 1994, and Gentner & Rattermann, 1991, for discussions of continuity in categorization development). This debate grew out of findings on the development of children's ability to form categories that suggested a heavy reliance on relations between stimuli (e.g., they are identical, one is larger than the other, they always occur together) rather than on the absolute properties of the stimuli (e.g., they are both blue, they both are round) as the basis of the category (Barsalou, 1987, 1993; Bower, 1989; Carey, 1985; Gelman & Markman, 1987; Gelman & O'Reilly, 1988; Greco, Hayne, & Rovee-Collier, 1990). It also follows from a long-standing interest in cognitive psychology on the distinction between relational learning and learning based on perceptual discrimination and generalization of stimulus features in category formation (e.g., Barsalou, 1999; Barsalou, Huttenlocher, & Lamberts, 1998; Gentner, 1988; Medin & Schaffer, 1978; Premack, 1983; Reese, 1968).

By the end of their first year, infants are on the verge of an explosion in categorizing behaviors, and the processes by which this occurs are under investigation (Bertin & Bhatt, 2001; Quinn & Bhatt, 2001; Rose, Futterweit, & Jankowski, 1999). This paper will suggest that the current cognitive and developmental research in this area has significant implications for behavior-analytic discussions of the phenomenon of stimulus equivalence (Sidman, 2000) and relational stimulus classes in general (Hayes, 1991), particularly discussions concerning the role of verbal behavior in forming *arbitrary* stimulus classes.

The phenomenon known as *Stimulus Equivalence* involves the formation of arbitrary stimulus classes based upon contingencies that frequently result in additional generalized conditional discriminations without the use of reinforcement or explicit instruction (see Harrison & Green, 1990; Pilgrim, Chambers, & Galizio, 1995; Saunders, Williams, & Spradlin, 1995; Smeets, 1994; Zentall, 1998). If these conditional discriminations involve reflexivity, symmetry, and transitivity, then stimulus equivalence is said to be exhibited (Dixon & Spradlin, 1976; Eikeseth & Smith, 1992; Hall & Chase, 1991; Lazar, Davis-Lang, and Sanchez, 1984; Sidman, 1986; Sidman, Rauzin, Lazar, Cunningham, Tailby, & Carrigan, 1982). The usual assessment of stimulus equivalence involves reinforcing responding to choice B in the presence of sample A, and choice C in the presence of sample B, using a matching-to-sample procedure with one sample and three choices. Correct matching of choices to the sample is based solely on the contingencies operating in the procedure – none of the stimuli share any absolute features that could be used to make the match. Thus, the subject produces initially blind choices that are differentially selected or reinforced (or made to be functional) (Neuringer, 1993). After consistently correct responding has been attained on the conditional discriminations trained between A and B and B and C (achieved through careful manipulation of the frequency, latency, and sequence of consequences, as well as of the order, position, and type of stimuli within and across trials), testing *without reinforcement* then occurs for the following emergent conditional discriminations: (a) A to A, B to B, C to C (identity or reflexivity); (b) B to A, C to B (symmetry); and (c) A to C (transitivity), C to A (combined symmetry and transitivity). These emergent conditional discriminations mark the formation of a class of stimuli that are related through a "goes with" relation: A "goes with" B and C.

The findings of the behavior-analytic literature on this "goes with" relation have been extended to other kinds of relations among stimuli (Hayes, 1991). For example, Hayes (1991) suggested that equivalence is one kind of relational responding and other kinds include relations of opposition, distinction, and comparison. Although there are a number of differences in the theoretical assumptions between Hayes' work and Sidman's (Sidman, 2000), these differences are germane only to the issue of the role of verbal behavior in the current discussion. Both stimulus equivalence and other forms of relational responding are said to be the product of genetic endowment and specific experience with contingencies that differentially select responding in the presence of stimuli within a class from stimuli outside of the class (Shahan & Chase, in press). Because the seminal behavior-analytic research on this topic was conducted under the rubric *stimulus equivalence,* we will use this term throughout the rest of the paper to refer to this literature and its findings.

Currently, equivalence class formation has only been observed in individuals with some degree of language ability (e.g., D'Amato, Salmon, Loukas, & Tomie, 1985; Devany, Hayes, & Nelson, 1986; Dube, McIlvane, Callahan, & Stoddard, 1993; Hayes, 1989; Lipkins, Kop, & Matthijs, 1988; Peláez, Gewirtz, Sanchez & Mahabir, 2000). This makes a certain amount of sense because equivalence relations are similar to those involved in language (Hall & Chase, 1991; Sidman, 1986), particularly semantic and word order relations, and provide a potential model of linguistic symbol systems. That is, making arbitrary "goes with" associations between stimuli that share no physical features (e.g., when a small, furry animal that barks is around, somebody emits the word *dog*), expanding classes of stimuli (e.g., relating the words *dog, pooch,* and *canine*) and arranging stimuli in novel ways (e.g., using the word *canine* in the correct word order or a sentence after learning that it is synonymous with *dog*) are precisely the tasks of a language learner. Critically, whether language mediates equivalence class formation or whether the ability to form equivalence classes underlies language acquisition is unclear (see discussion in Sidman, 2000). An understanding of the current status of cognitive research on these abilities in human infants is thus of direct relevance to the equivalence research. While most of the infant research has been conducted using the visual preferential looking paradigm (testing with novel stimuli), which involves associative, respondent learning, and the equivalence paradigm involves operant conditioning, the infant research findings suggest that the components of stimulus equivalence may be present prior to the onset of verbal behavior (see Rehfeldt & Hayes, 1998, for a discussion of the respondent-operant distinction and stimulus equivalence).

The human infant work involves demonstrations of relationally-based categorization abilities, including both transpositional relational learning (identity and other reversible relations like left-right, up-down) and arbitrary relational learning ("goes with" associations). In addition, research on human infant sensory integration skills has been conducted in this area, as the capacity for amodal relational learning (detection of an absolute feature that is shared between 2 sense modalities) may be especially important for the learning of relational as opposed to unimodal absolute feature information about objects and events in categorization.

Sensory integration allows for the detection of shared *amodal* absolute features of stimuli, ones that are not unique to a given sense modality (Bahrick, 1988; 1992; 1994; 2000; 2001; Lewkowicz, 1996; Slater, 1999; see also Lickliter and Bahrick, 2000, for a recent review of this literature). A large portion of human cortex is devoted to integration of information between sensory modalities, particularly sound and vision. Tempo, or rhythm, is one such amodal feature and, using the habituation paradigm, one-month-old human infants show differential responding in the presence of synchrony or asynchrony between seeing and hearing the impact of an object on a hard surface (Bahrick, 1994; 2000).

We first review the infant literature on the transpositional relation of identity. The ability to attend to and respond on the basis of identity relations between stimuli has been suggested (in both the developmental and behavior-analytic literatures) as a critical stepping stone in the ability to form arbitrary classes of stimuli based on their relation to some contingency (Gentner & Ratterman, 1991; Premack, 1983; Sidman, 1994). Detection of identity relations of stimuli might focus an organism's attention away from the details or absolute properties of stimuli.

Young infants can attend and respond to similarity relations. Tyrrell and his colleagues (Tyrrell, Stauffer, & Snowman, 1991; Tyrrell, Zingaro, & Minard, 1993), utilizing a synchronous reinforcement paradigm (Coldren & Columbo, 1994), found that seven-month-old infants differentially responded to the intrapair relationships of identity and difference within a given problem set. Infants received training trials during which visual fixation to the target stimuli, either a pair of identical toys or a pair of different toys, was reinforced with access to an audio recording of a children's story. On test trials with *novel* pairs of toys, infants showed significantly increased looking at the pair that instantiated the previously reinforced relation (identity or difference), suggesting class formation based on identity. In addition, infants changed their responding to the opposite relation when the contingencies were reversed. Infants have also been shown to learn complex discriminations between familiar and novel stimuli using the habituation paradigm (Orlian & Rose, 1997; Rose et al., 1999), which suggests an understanding of same/different relations, and similarity relations have also been studied in older infants (Daehler, Lonardo, & Bukatko, 1979).

Studies involving matching-to-sample with discrete responses have produced some evidence of generalized identity with nonhuman primates using operant procedures (Bhatt & Wright, 1992; D'Amato & Colombo, 1985; Neiworth & Wright, 1994; Oden, Thompson, & Premack, 1988), a sea lion

(Schusterman & Kastak, 1993), older infants and children (Brown, Brown, & Poulson, 1995; 1997; Lipkens, Hayes, & Hayes, 1993), and even pigeons under special conditions (Wright, Cook, Rivera, Sands, & Delius, 1988; Zentall, Edwards, Moore, & Hogan, 1981; although see Iversen, 1997, for a criticism of these studies that suggests that identity matching performance in these cases may be best described as specific discriminations involving the spatial location of visual stimuli rather than identity; also see Thomas and Noble, 1988, for a discussion of the lack evidence for the concept of generalized oddity in nonprimate animals).

Other types of transpositional relational learning have also been examined in very young infants (Quinn, 1994). For example, in a study by Behl-Chadha and Eimas (1995), 3- to 4-month old infants showed dishabituation to a novel left-right spatial relation between a novel pair of animals. Familiarization training included multiple presentations of a horse and a zebra that varied in size, orientation, and location, but stayed the same with respect to the left-right dimension. Testing involved a novel pair of animals in reversed left-right relation and a novel pair of animals in the original left-right relation. The infants dishabituated to the novel left-right spatial relation. In other words, infants formed classes that included specific information about the left-right spatial dimension and indicated their formation of these classes by demonstrating a novelty response.

Turning to the learning of arbitrary relations, by six months of age, Hernandez-Reif and Bahrick (2001) showed that human infants are able to learn an arbitrary relation between the shape of an object and its color/pattern (the detection of a correlation, or repeated association, between two stimuli that share no absolute features). In this study, infants were repeatedly and simultaneously presented with two identical colored/patterned objects, one viewed above a barrier as the infant was allowed to touch and feel the other object below the barrier. During the test phase, infants were presented with the object below the barrier for tactile exploration and shown two poster boards above the barrier, one whose color pattern was identical to that of the object and one that did not match (control conditions included counter-balancing multiple objects and color patterns). Infants looked significantly more at the poster board that matched the color pattern of the object. Older infants demonstrate this ability to detect correlated features more quickly and with more complex object and events (e.g., Bhatt & Rovee-Collier, 1994; Bhatt, Wilk, & Rovee-Collier, 1996; Eimas & Quinn, 1994; Eimas, Quinn, & Cowan, 1994; Hernandez-Reif & Bahrick, 1996; Kaye & Bower,1994; Kuhl & Meltzoff, 1984; Lewkowicz & Turkewitz, 1980; Quinn, 1987; Quinn, Eimas, & Rosenkrantz, 1993; Walker-Andrews, 1986; Wilk, Bhatt, & Rovee-Collier, 1996; Younger, 1990; 1992; Younger & Cohen, 1983, 1986; Younger & Gotlieb, 1988).

The interest in infant ability to detect correlated features has been stimulated by the fact that correlated features are characteristic of basic-level categories (e.g., beaks usually "go with" feathers) (Malt & Smith, 1984; Medin, 1983; Rosch, 1978). Infants demonstrate their detection of the category exemplified by the correlated features when they show a preference for a novel stimulus with a pattern of correlations that violates the familiar correlation over a *novel* stimulus that maintains the pattern of correlated features (Quinn & Eimas, 1996).

> The abstraction of an invariant relation (i.e., the correlation) from a set of discriminable stimuli and the subsequent generalization to a novel stimulus is reminiscent of the definition of a category - an equivalence in response to a set of discriminable stimuli (Younger & Cohen, 1983, p. 865).

In addition, several researchers have demonstrated anticipatory and reactive responses (in the form of eye saccades) to (a) repeated pairings of a brief stimulus at a cued location or an arbitrary abstract visual pattern and the subsequent presentation of another stimulus at the cued location, and (b) presentation of a sequence of alternating pictures that reliably predicts information about spatio-temporal patterns (Canfield & Haith, 1991; Gilmore & Johnson, 1995; Haith, Hazen, & Goodman, 1988; Wentworth & Hood, 1996).

Finally, evidence exists for a developmental progression in these particular relational learning abilities, such that the learning of transpositional and arbitrary relations are facilitated by the presence of amodal information (see Hernandez-Reif & Bahrick, 2001 and Bahrick & Pickens, 1994, for discussions). The perceptual features of an amodal relationship (e.g., tempo) between two stimuli are more abstract, although not necessarily perceived any less directly nor requiring any postnatal experience or learning in a species with the requisite sensory and cognitive apparatus than unimodal identity matching. Recall that one-month-olds can discriminate between synchronous and asynchronous temporal information across vision and hearing (Bahrick, 1994; 2000). Critically, by seven months of age, infants learned arbitrary auditory-visual feature combinations (a vowel sound "goes with" an object) when the object was moved in synchrony with the speech sound, but not in the absence of such amodal information (Gogate & Bahrick, 1998). Repeated experiences across the early infancy period with arbitrary relations that also contain amodal relations may contribute to the capacity for integrating a generalized identity concept (and other transpositional relations) with the functional information available in equivalence classes. The importance of the ubiquity of redundant visual, auditory, tactile and temporal information present in human infant-caregiver vocal, facial, and gesture communications, and the role of imitation, for language acquisition is also being investigated using this paradigm, as a model for the types of experiences in human infancy that might facilitate fluency and flexibility in these capacities (Gogate, Bahrick, & Watson, 2000; Gogate, Walker-Andrews, & Bahrick, 2001; Lickliter & Bahrick, 2001).

These infant relational learning capacities are all being found to occur in an age range *prior* to the onset of the production of words (although critically, potentially concurrently with the onset of first word comprehension). Furthermore, the merger of absolute-feature based classes, classes based on transpositional relations, and arbitrary "goes with" class formation, in any and all combinations, provides models of the emergence and use of complex categories and concepts that form the basis of much of human cognitive behaviors related to language (Fields, Adams, Brown, & Verhave, 1993; Fields, Reeve, Adams, Brown, & Verhave, 1997; Lane, Clow, Innis, & Critchfield, 1998).

In addition to the theoretical significance of an integration of current knowledge derived from this ongoing research in behavior analysis and infant cognitive developmental science, the application of behavior-analytic methods may help address specific concerns regarding current infant research. First, Bahrick and Pickens (1995) have noted problems in the infant categorization work having to do with changes in preferential looking to novel versus familiar stimuli as a function of time between training and testing. This would suggest the need to use long term, intensive (i.e., longitudinal, small-N) research designs similar to those used in operant psychology (thus far, all of the infant research is cross-sectional). In addition, variability in performance across subjects is a difficulty for infant group design studies. Operant methods typically minimize these problems through the careful monitoring of baseline performance, and the use of subjects' own performance as the control (Reeve, Reeve, & Poulson, 1993).

Conclusion

The next obvious extension of this research is to use operant techniques, rather than the habituation/visual preference paradigm. The most basic type of contingency-based learning of arbitrary relations can be seen in the behavior-analytic research on the formation of functional stimulus classes. A functional class is a class of stimuli that are related because a certain response is reinforced in the presence of those stimuli. For example, in the classic study with pigeons, Vaughn (1988, 1989) arbitrarily selected two groups of stimuli from 40 different slides of trees and established differential responding to these two sets with differential reinforcement training. In other words, during training, responding to one of these classes was followed by food and responding to the other was not. Subjects learned to respond to the stimuli followed by food. Then the contingencies were reversed (the class that had previously been reinforced was no longer reinforced and vice versa) and the subjects learned the new set of contingencies. After multiple reversals, the subjects learned to reverse their responding to all members of each class after experience with just a few trials. Similar results have been obtained in adult humans (Sidman, Wynne, Maguire, & Barnes, 1989). Although classes formed on the basis of similar function have been investigated in young infants (Greco et al., 1990), and performance has been reversed by reversing contingencies in the examination of identity/difference relations as discussed above (Tyrrell et al., 1991, 1993), the reversal discrimination paradigm using classes formed through functional equivalence procedures has not been explored in human infants. If successful, the full operant paradigm for the building of equivalence classes could then be attempted.

Summary

In summary, categorization of environmental stimuli is a fundamental aspect of all cognitive/behavioral systems (Estes, 1994; Quinn & Eimas, 1996). It entails the ability to discriminate stimulus features embedded in a multiple-feature stimulus array and the ability to operate on discriminably different stimuli in a similar way. Furthermore, non-perceptual relational learning categorization abilities are recognized as a critical set of skills associated with vocabulary and language acquisition (Gentner, 1977; Gershkoff-Stowe, Thal, Smith, & Namy, 1997; Poulin-Dubois, Graham, & Sippola, 1995; Roberts & Horowitz, 1986; Sidman, 1994; Woodward & Hoyne, 1999). Integration of infant cognitive development research with behavioral analyses in this area is a critical next step in our understanding of these processes.

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