

*EQUIVALENCE CLASSIFICATION BY CALIFORNIA
SEA LIONS USING CLASS-SPECIFIC REINFORCERS*

COLLEEN REICHMUTH KASTAK, RONALD J. SCHUSTERMAN,
AND DAVID KASTAK

LONG MARINE LABORATORY,
UNIVERSITY OF CALIFORNIA SANTA CRUZ

The ability to group dissimilar stimuli into categories on the basis of common stimulus relations (stimulus equivalence) or common functional relations (functional equivalence) has been convincingly demonstrated in verbally competent subjects. However, there are investigations with verbally limited humans and with nonhuman animals that suggest that the formation and use of classification schemes based on equivalence does not depend on linguistic skills. The present investigation documented the ability of two California sea lions to classify stimuli into functional classes using a simple discrimination reversal procedure. Following the formation of functional classes in this context, the second experiment showed transfer of the relations that emerged between class members to a matching-to-sample procedure. The third experiment demonstrated that the functional classes could be expanded through traditionally defined equivalence relations. In these three experiments, appropriate within-class responding produced class-specific food reinforcers. Experiment 3 addressed the role of these reinforcers in equivalence classification and showed that the class-specific reinforcers were sufficient to relate new stimuli to the functional classes. These findings show that sea lions can form equivalence classes in simple and conditional discrimination procedures, and that class-specific reinforcers can become equivalence class members.

Key words: stimulus equivalence, functional classes, reversal procedure, simple discrimination, conditional discrimination, differential outcome, California sea lions



Equivalence classification, or simply equivalence, occurs when perceptually dissimilar stimuli come to exert similar control over behavior through emergent relations. Indeed, equivalence is demonstrated by a subject's successful performance on tests of emergent relations following specific training. Since the concept of equivalence was first applied to studies of symbolic behavior in humans, equivalence relations have been further experimentally or operationally defined. For different stimuli to be considered equivalent, the relations that emerge between them must meet the mathematically derived criteria of

reflexivity, symmetry, and transitivity (Sidman & Tailby, 1982). Thus, the term *stimulus equivalence* describes groups of stimuli that become interrelated in specific and verifiable ways. Reflexive relations are those in which a stimulus is conditionally related to itself (i.e., generalized identity matching: A is related to A, or ArA, BrB, CrC). Symmetrical relations are those that exhibit emergent bidirectionality (i.e., if ArB, then BrA; if BrC, then CrB). Transitive relations are those that include an emergent forward relation (i.e., if ArB and BrC, then ArC). A typical test for equivalence might assess the emergent relation that combines symmetry and transitivity (i.e., if ArB and BrC, then CrA). Thus, the model of stimulus equivalence describes how untrained relations (generalized identity, symmetry, and transitivity) arise from trained stimulus relations (in this case, ArB, BrC).

Due to the explicit nature of these defining properties, equivalence can be effectively demonstrated only by training subjects in the context of a conditional discrimination or matching-to-sample (MTS) procedure. This has been done convincingly in a variety of studies with human subjects. Many studies show that mentally competent adults, chil-

Research was supported by ONR Grant N00014-95-1-0936 to R. J. Schusterman and a DoD AASERT Fellowship to C. Reichmuth Kastak. Additional support was provided by the Earl and Ethel Myers Oceanographic Trust, the Friends of Long Marine Laboratory, and the UCSC Ocean Sciences Board. Parts of this manuscript were presented at the meeting of the Animal Behavior Society in Flagstaff, Arizona, July 1996, and at the 13th Biennial Marine Mammal Conference in Wailea, Hawaii, November 1999.

We thank the dedicated staff of the Pinniped Research in Cognition and Sensory Systems laboratory at UCSC, especially Grace Ho and Shannon Spillman.

Address correspondence and reprint requests to Colleen Reichmuth Kastak, UCSC Long Marine Laboratory, 100 Shaffer Road, Santa Cruz, California 95060 (E-mail: coll@cats.ucsc.edu).

dren as young as 2 years of age, and even many mentally disabled people readily link physically dissimilar stimuli into equivalence classes using these training procedures. Although verbally able subjects have successfully demonstrated equivalence, human subjects who lack basic language skills have historically not passed such tests. These observations, coupled with several failed attempts to demonstrate equivalence in nonhuman animals, have prompted some to conclude that the ability to form equivalence classes is unique to linguistically competent humans (for reviews of relevant studies and for differing viewpoints on this issue, see Fields & Nevin, 1993; Hayes, 1989; Horne & Lowe, 1996, 1997; and Sidman, 1994).

However, recent investigations with nonverbal subjects do not support this anthropocentric and "language-centric" view of stimulus equivalence. Carr, Wilkinson, Blackman, and McIlvane (2000) demonstrated equivalence in several developmentally disabled adults with virtually no functional spoken language. Further, although evidence for emergent reflexivity, symmetry, and transitivity in nonhuman animals has been difficult to obtain experimentally, several recent reports document the requisite relations emerging through MTS procedures in one or more nonhuman species (see brief review in Zentall, 1998; see also Kastak & Schusterman, 1994; Manabe, Kawashima, & Staddon, 1995). The strongest evidence for stimulus equivalence by a nonhuman animal has been reported by Schusterman and Kastak (1993), who trained a California sea lion with a subset of MTS problems that included combinations of emergent relations (e.g., symmetry, transitivity). Following this training, the sea lion showed significant performance on a larger set of completely novel transfer problems. The authors concluded that the lack of strong transfer in many early attempts to demonstrate reflexivity, symmetry, and transitivity (see, e.g., D'Amato, Salmon, Loukas, & Tomie, 1985; Sidman *et al.*, 1982) could be overcome when testing procedures were modified to provide nonverbal subjects with a large number of training exemplars or when the potentially disruptive effect of novel stimulus position was mitigated prior to or during testing. They further suggested that establishing successful generalized identity

matching performance likely facilitated subsequent performance on tests of combined symmetry and transitivity.

Not all of the emergent relations measured in humans or animals fall neatly into the paradigm of stimulus equivalence. For example, Keller and Schoenfeld (1950) described studies of semantic generalization conducted by Riess (1940) in which functional relations between words similar in function but not in form emerged in a classical conditioning context. When a galvanic skin response was conditioned to a word such as *urn*, much stronger generalization occurred to the synonym *vase* than to the homonym *earn*. Generalization between words similar in function rather than structure implies an emergent equivalence between the words. Correspondingly, many studies have demonstrated emergent relations in nonhuman animals outside the constraints of the operational definition of stimulus equivalence. The experimental procedures used in these studies include classical conditioning, MTS procedures, sequential learning procedures, hierarchical stimulus categorization tasks, and simple discrimination reversal procedures. The procedural and theoretical differences introduced in these and other tasks have led to an array of overlapping terms used to describe emergent relations, including symbolic representation; acquired equivalence of cues; mediated generalization; functional equivalence, categorization, or classification; abstract concept formation; and non-similarity-based classification. Because the relations between stimuli or events examined in these studies emerged outside the context of conditional discrimination procedures or traditional testing paradigms, it is impossible to determine in most cases whether these instances are examples of stimulus equivalence as currently defined. However, a review of these studies does leave one with the distinct impression that these are related phenomena (see reviews and commentary in Balsam, 1988; Dube, McIlvane, Callahan, & Stoddard, 1993; Schusterman & Kastak, 1998; Sidman, 1994; Tomonaga, 1999; Vaughan, 1988; Wasserman & DeVolder, 1993; Zentall, 1998).

Some investigators have used broad criteria to define the emergent properties of stimulus classes. For example, Wasserman and his colleagues (Wasserman & DeVolder, 1993; Was-

serman, DeVolder, & Coppage, 1992) describe the formation of non-similarity-based classes by the emergence of untrained relations arising between dissimilar stimuli. Others have defined the classification process by the procedure used to measure it. The latter seems to be the case with the definition of stimulus equivalence as formulated by Sidman and Tailby (1982). This classification scheme is also based on relations that emerge between stimulus class members, but includes the specific mathematically derived properties of the emergent relations as criteria. The demonstration of these criteria is restricted to a narrow experimental context (an MTS procedure) and, thus, this definition of stimulus equivalence excludes emergent abilities that arise in other procedures. Vaughan (1988) first addressed this issue by proposing that behaviorally and mathematically valid equivalence relations could arise in an alternative procedure without demonstrating the presence of identity, symmetry, and transitivity per se. Vaughan theoretically and empirically sought to eliminate the distinction between stimulus classes linked by stimulus equivalence and those grouped into partitions, or *functional classes*.

Functional stimulus classes are sets of discriminative stimuli that control the same behavior. The members of a functional class share a high correlation with a particular response, such that responding to all class members is altered when responding to any one class member is altered (Skinner, 1935). There are limited data available on the formation of functional classes in nonhuman animals. Schusterman and Gisinier (1997) suggested that the grammatical sequences of signs or lexigrams used in animal language research may lead to the formation of functional classes. In many of these studies, referential signs of a given type (e.g., "objects," "actions," or "modifiers") can be interchanged with one another without disrupting the resulting performance of the animal. For example, any sign representing an object, whether a ball, cone, or cube, or even a novel object, generates an object-oriented response when placed in the correct position in an instructional sequence. However, if the signs for an object and an action are transposed between their standard positions in a sequence, the performance of the animal de-

teriorates. Schusterman and Gisinier cited this apparent substitutability of stimuli sharing sequence positions as evidence of functional class formation, with members of each stimulus class controlling similar response topographies that did not extend to stimuli occupying other sequential positions. Further support for the idea that functional classes can arise from sequential procedures in nonhuman animals comes from studies with rhesus monkeys showing a transfer of function between stimuli sharing the same ordinal positions in different stimulus sequences (Chen, Swartz, & Terrace, 1997).

The best evidence for functional class formation by nonhumans comes from Vaughan (1988). He trained pigeons on a discrimination reversal procedure in which the subjects were presented with a sequence of 40 different slides of trees that were divided into two arbitrary sets of 20 slides each. The pigeons were conditioned to peck at any of one set of slides, designated as positive, and to withhold pecking when presented with any of the other set of slides, designated as negative. Following learning of the positive set, the reinforcement contingencies were reversed, and members of the formerly negative set were reinforced as positive. After repeatedly shifting the reinforcement contingencies between the two sets of stimuli, the pigeons began changing their responses to all members of a set after experiencing the reversed contingency with just a few. Thus, the reversed contingency for slides presented at the beginning of a session predicted reversed contingencies for slides presented in the remainder of the session.

Within the context of this simple discrimination reversal procedure, Vaughan (1988) showed that pigeons classified a large set of stimuli into two functionally equivalent subsets based only on shared reinforcement histories of the stimuli. He argued that the relations that eventually emerged between stimuli, as demonstrated by a transfer of function between each of the stimuli in a set, implied stimulus equivalence as well as functional equivalence. Vaughan's viewpoint established a basis for investigating the specific conditions that give rise to equivalence. Studies with human subjects show unequivocally that traditionally defined equivalence classes established in an MTS procedure immediately

transfer to functional classes demonstrated in a simple discrimination procedure (Lazar, 1977; Wulfert & Hayes, 1988). This transfer from MTS to simple discriminations was also found following the only study to successfully demonstrate equivalence in a nonhuman animal, a California sea lion (Schusterman & Kastak, 1998). However, if equivalence relations and functional classes reveal the same cognitive-behavioral processes through different procedures, then functional classes should also transfer to equivalence classes in an MTS context.

Although Vaughan (1988) did not extend his functional classification experiment to an MTS context, Sidman, Wynne, Maguire, and Barnes (1989) followed Vaughan's study with a multistep classification experiment to test whether the functional classes formed by human subjects were also equivalence classes. To accomplish this, these investigators (a) generated functional classes in a simple discrimination reversal procedure using an approach similar to Vaughan's, (b) presented the functional class members in the context of an MTS procedure to determine if class-consistent conditional discriminations emerged, and (c) tested whether the functional classes, following additional training with new stimuli in the MTS procedure, would yield emergent equivalence relations. Two of 3 subjects passed these tests, indicating that for these subjects, members of the functional classes were also related by equivalence (Sidman, 1994). These findings support Vaughan's claim that equivalence relations can, in fact, emerge through simple discrimination reversal training. A consideration of these procedural transfer studies, which show equivalence classes formed in MTS procedures transferring to functional classes in simple discriminations and vice versa, has proven problematic for the traditional view of equivalence relations (Sidman, 1994).

In the last decade, Sidman (1994, 2000) has proposed an expanded approach to describing and predicting emergent behavior in the context of equivalence classes. Accordingly, potential equivalence class members include responses and reinforcers, in addition to stimuli. This expanded viewpoint allows the demonstration of equivalence in procedures other than MTS, including simple discrimination reversal procedures. Although

the traditional definition has constrained our notions of equivalence, this broader concept of equivalence provides a flexible and more useful model of classification. It is likely that Sidman's revised concept of equivalence encompasses a great deal of theoretical and empirical work on behavioral learning and conditioning that, like Vaughan's demonstration of functional classification, has historically been excluded from the equivalence literature.

Vaughan's (1988) results, showing that pigeons formed functional classes from a large group of stimuli, have not been reliably replicated with pigeons or any other nonhuman species (but see Delius, Jitsumori, & Siemann, 2000; Dube, Callahan, & McIlvane, 1993; Tomonaga, 1999); however, von Ferson and Delius (2000) recently reported that 2 bottlenose dolphins trained on an auditory discrimination reversal task successfully transferred responses established for one pair of stimuli to a second pair of stimuli. Our objective in the present experiment was to determine if 2 California sea lions were capable of differentiating functional classes from a large set of stimuli. Then, following the model established by Sidman *et al.* (1989), we sought to demonstrate the transfer of the functional classes to an MTS procedure and to evaluate whether class membership would be extended through traditionally defined equivalence relations. The studies described herein support an expanded view of equivalence by showing a nonhuman species to be capable of (a) forming functional classes in a simple discrimination reversal context, (b) transferring the relations between class members to an MTS procedure, (c) expanding the classes through stimulus-mediated equivalence relations, and (d) expanding the classes through reinforcer-mediated equivalence relations.

GENERAL METHOD

Subjects

The subjects were 2 female California sea lions (*Zalophus californianus*) named Rio and Rocky. Rio was 8 years old at the start of the study and had previously participated in several similar experiments, including generalized identity MTS (Kastak & Schusterman,

1994) and a demonstration of stimulus equivalence using an MTS procedure (Schusterman & Kastak, 1993), which later transferred to a simple discrimination procedure (Schusterman & Kastak, 1998). Rocky was 17 years old at the start of the study and also had extensive experience with MTS, including generalized identity matching (Kastak & Schusterman, 1994). Rocky had been trained and tested on stimulus equivalence class formation using an MTS procedure, but failed to demonstrate emergent stimulus equivalence relations. She had also received additional experience with conditional discrimination learning in the form of an artificial gestural language that she had been trained with for over 10 years (for a review, see Schusterman & Gisiner, 1997). Rocky had no experience with simple discrimination learning prior to this study.

Both animals were housed outdoors in free-flow seawater tanks and adjacent haul out areas at Long Marine Laboratory at the University of California Santa Cruz. Each animal was fed between 4 and 5 kg of freshly thawed cut herring and capelin each day, one half of which was typically consumed during experimental sessions. Each animal participated in experimental sessions twice each day for 5 days per week, generally between 9:00 a.m. and 1:00 p.m. The animals were trained using standard operant conditioning procedures and fish reinforcement.

Apparatus

A two-choice visual MTS apparatus, shown in Figure 1, was used. The apparatus was a three-dimensional display constructed of three horizontally arranged plywood boards, each housing a window-fronted stimulus box. The boxes were 30 cm by 30 cm square and 10 cm deep, and were covered by movable opaque doors. The center (sample) box was positioned 90 cm in front of a T-bar station at which the subject's head rested, and the two side (comparison) boxes were angled such that each was 110 cm away from the subject's head.

The stimuli used in the experiment were planometric plywood squares (30 cm by 30 cm) consisting of black patterns painted on white backgrounds. A set of 20 stimuli were designed and divided into two subsets of 10 that were coded as "letters" and "numbers,"

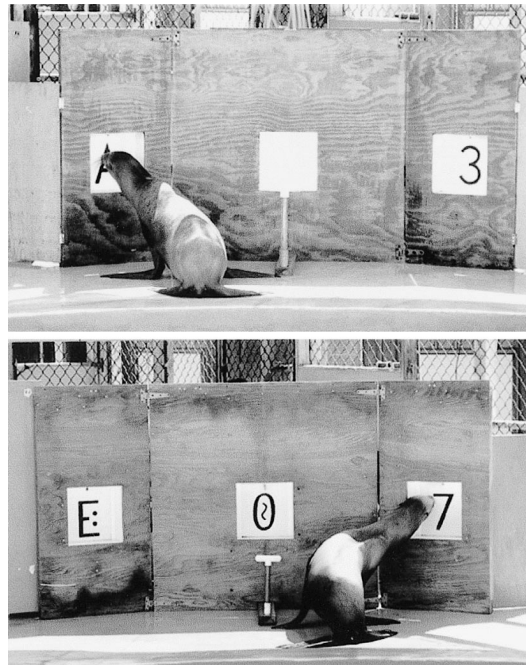
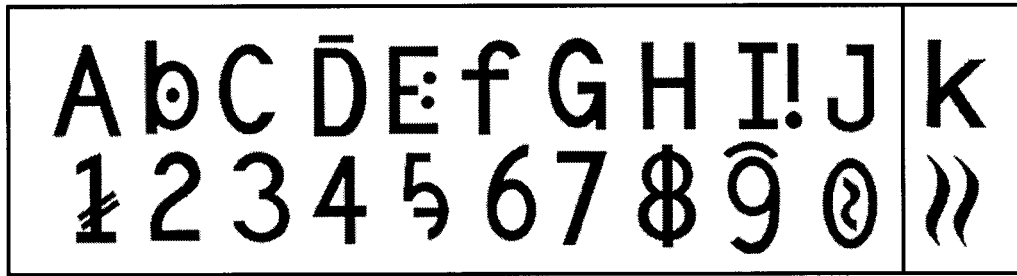


Fig. 1. The top photograph shows sea lion Rio performing a simple discrimination trial. The trial began when the sea lion positioned her head at the stationing bar located in front of the center stimulus box. Following this stationing response, the sliding doors covering the side boxes were opened to reveal Comparison Stimuli A and 3. The sea lion observed the stimuli from her position at the stationing bar until she was signaled by an acoustic cue to make a response. She responded by moving from the stationing bar to touch Stimulus A with her nose. Her correct response was marked by an acoustic tone which signaled that a fish reward would be provided. The bottom photograph shows an example of a conditional discrimination trial. The trial was similar to a simple discrimination, except that following the stationing response and prior to the presentation of the two Comparison Stimuli E and 7, Sample Stimulus 10 was revealed in the center box. Rio's correct selection of Stimulus 7 as the match to the sample was rewarded.

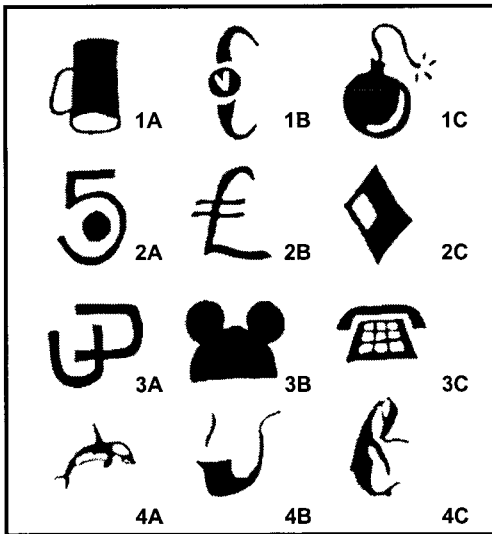
as depicted in Figure 2. Each pattern was configured to be roughly equal in area and brightness and to be discriminable from each of the other stimuli.

During experimental sessions, two assistants were seated behind the apparatus, where they were out of view of the subject. On each trial, the assistants were instructed via headphones to place the required stimuli into the appropriate boxes. Stimuli were always placed into comparison boxes simultaneously, so that the subject could not be cued to the correct choice by the timing of its placement. Instructions were provided to the

EXPERIMENTAL STIMULI



RIO MTS TRAINING SETS



ROCKY MTS TRAINING SETS

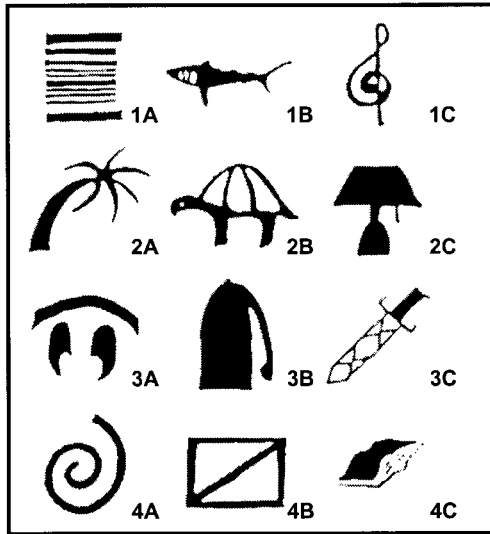


Fig. 2. Stimulus configurations used in Experiments 1, 2, and 3. Stimuli were coded as A through J (top row) and 1 through 10 (bottom row). Stimuli K and 11 (far right) were introduced in Experiment 3. The MTS training sets used in Experiments 2 and 3 are shown separately for Rio and Rocky in the lower panels.

assistants by a remote experimenter who observed the session in real time on video. At the start of each session, the subject entered the enclosure and was signaled by an assistant to station in front of the apparatus. Sessions consisted of either simple discrimination trials or conditional discrimination trials, as described in detail in the following sections. In either case, a trial began when the experimenter signaled an assistant to open one or more of the stimulus doors to reveal the hidden stimuli. After an observation interval of 2 to 4 s, the subject was released from the station by an acoustic cue to select one of the two comparison stimuli. A response was defined by the touch of a comparison stimulus by the subject with her nose (see Figure 1).

Correct responses were marked by a 0.5-s acoustic tone that served as a conditioned reinforcer. The tone was followed by a piece of fish tossed to the animal from behind the apparatus. Incorrect responses were not reinforced, and were marked by the vocal signal "no." The stimulus doors were closed simultaneously at the end of each trial. All acoustic cues were triggered by the experimenter and broadcast from a speaker mounted near the apparatus.

Analysis

Performance on experimental (novel) and baseline (familiar) trials was measured as the number of correct responses out of the total number of trials completed. The subjects'

rate of acquisition of novel relations was measured by calculating the numbers of errors they made on the experimental trials *prior to* reaching the designated performance criterion. Performance in experimental conditions was evaluated relative to performance predicted by chance (50% correct responding) with two-tailed binomial tests. Performance between subjects or conditions was evaluated with two-tailed Fisher's exact tests. Changes in performance within each condition were evaluated by linear regression analysis, with a positive slope indicating improvement with time or trial number and a slope not different from zero indicating stable performance. The statistical significance of these tests was evaluated at alpha levels of .05 or .01.

EXPERIMENT 1

To evaluate the sea lions' capability to form functional classes, we used a simple discrimination reversal procedure in which all of the members of a potential class shared in common only a similar pattern of reinforcement. Like Vaughan (1988), we repeatedly shifted the reinforcement contingency from one potential class to the other to determine whether encountering the reversed contingency with a few class members would result in the subjects altering their responses to the remaining members of each class.

Procedure

The approach used in this experiment was based on the successive reversal procedures used by both Vaughan (1988) with pigeons and Dube, Callahan, and McIlvane (1993) with rats, but employed a design involving simultaneous two-choice simple discriminations rather than sequential discriminations, similar to the procedure used by Sidman et al. (1989) with humans. This procedure involves presenting the subject with two different visual stimuli and then signaling the subject to select one of the stimuli. An example of such a simple discrimination trial is shown in the top panel of Figure 1. This approach was chosen because both subjects had extensive prior experience with two-choice visual discriminations presented in an MTS procedure.

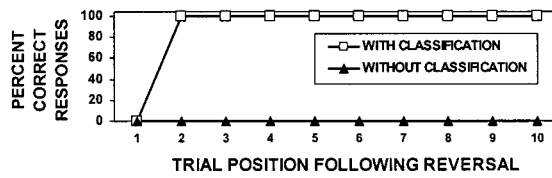
Each session consisted of 40 trials that in-

cluded four consecutive blocks of 10 individual trials. Each trial included the presentation of one stimulus from each stimulus set (one number and one letter). Each block of 10 trials contained a single presentation of each of the stimuli from the two classes (i.e., A through J and 1 through 10). Each stimulus appeared once in each block for a total of four times per session, balanced for left and right presentation. On a given session, stimuli belonging to either the letter set or the number set were designated as positive, and all responses to members of the positive set (S+) were reinforced as correct choices. The members of the remaining set were designated as negative (S-) and served as alternate stimuli on each trial. The probability of left or right placement of the S+ on each trial was .5, the probability of the S+ appearing on the same side or alternate side as the previous trial was .5, and each session contained a unique sequence of trials.

The general procedure consisted of a series of sessions in which responses to members of the class designated as positive were reinforced until the subject's performance met a preset criterion of 90% correct responses on either one or two consecutive sessions (see below). Following acquisition of the positive set, the reinforcement contingencies were reversed so that previously positive stimuli were made negative and previously negative stimuli were made positive. Responses to members of the previously negative set were then reinforced until the animal's performance once again reached criterion, at which point the contingencies were reversed again. This series of reversals between the letter set and the number set continued throughout the experiment.

Theoretical performance following a reversal of reinforcement contingencies is summarized in the top panel of Figure 3. Prior to the first trial of a reversal, a model subject is consistently rewarded for selecting stimuli belonging to the positive class. When the positive class unexpectedly becomes negative, the subject's performance should fall to 0% on the first trial following the reversal. From this point, two scenarios describe the potential performance. If each stimulus pairing is treated as an independent problem, performance levels should remain at 0% on Trials 2 through 10, because the most recent feed-

THEORETICAL PERFORMANCE



ACTUAL PERFORMANCE

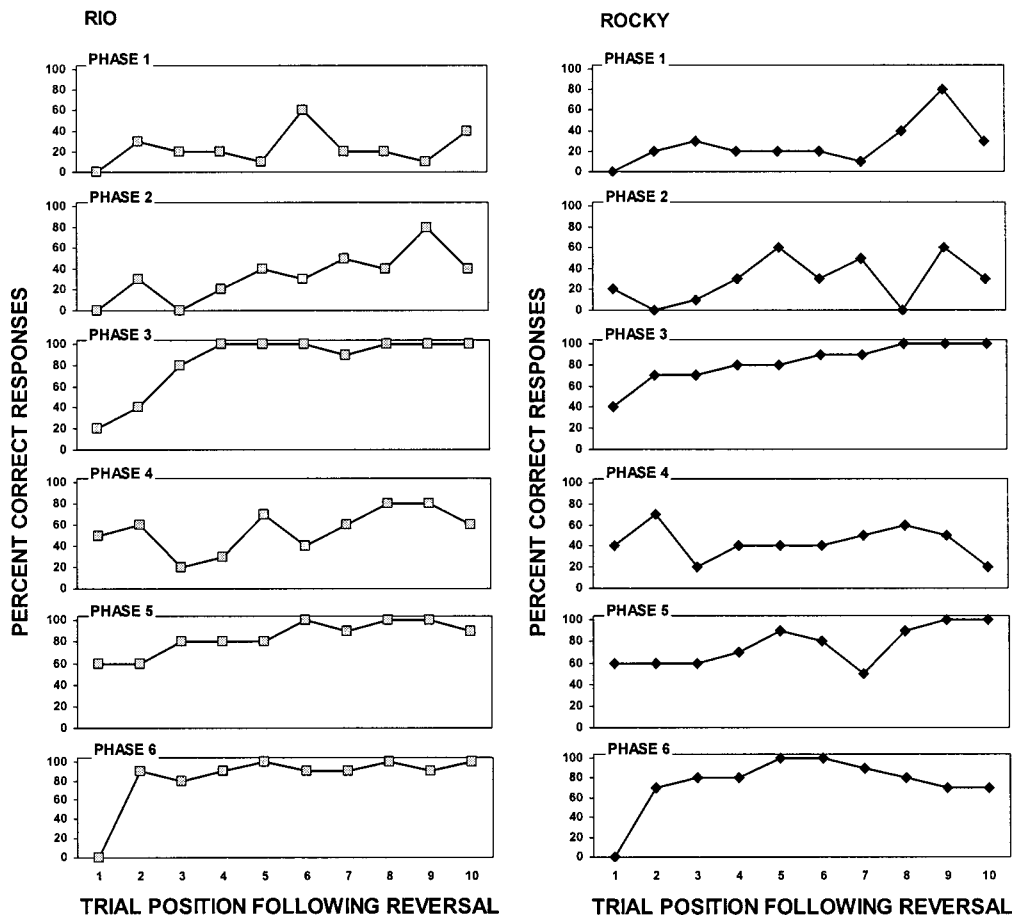


Fig. 3. The top panel shows theoretical performance following a reversal with and without stimulus classification. The lower panels show the actual performance of each subject on Phases 1 through 6 of Experiment 1. Data for the last 10 reversals of each phase are shown to represent stabilized performance levels under each condition. The trials in Positions 1 through 10 following a reversal include a single presentation of each S+ and S-.

back the subject has about each stimulus is now incorrect. However, if functional relations have emerged between members of each stimulus set through reversal training, then feedback about one member of the set

should provide information about other members of the set. In this case, performance following the first trial of a reversal should rapidly rise to near-perfect levels.

Experiment 1 tested these predictions by

Table 1

Each testing phase in Experiment 1 comprised a different experimental condition under which reversals were completed. The number of trial types was either 10 (stimuli presented in matched pairs) or 100 (stimuli presented in shuffled pairs). The reinforcer type was either uncorrelated (randomized with respect to the two different stimulus sets) or correlated (specific to each stimulus set). Reversals of reinforcement contingencies occurred either at the start of session or unpredictably within a session.

| Condition | Trial types | Reinforcer type | Reversal position | Reversals completed | |
|--|--------------------|-----------------|-------------------|---------------------|-------|
| | | | | Rio | Rocky |
| Initial training | 10 matched pairs | Uncorrelated | | | |
| Phase 1: | | | | | |
| Discriminations in matched pairs | 10 matched pairs | Uncorrelated | Start of session | 20 | 15 |
| Phase 2: | | | | | |
| Discriminations in shuffled pairs | 100 shuffled pairs | Uncorrelated | Start of session | 22 | 20 |
| Phase 3: | | | | | |
| Assignment of class-specific reinforcers | 100 shuffled pairs | Correlated | Start of session | 22 | 41 |
| Phase 4: | | | | | |
| Removal of class-specific reinforcers | 100 shuffled pairs | Uncorrelated | Start of session | 53 | 24 |
| Phase 5: | | | | | |
| Reintroduction of class-specific reinforcers | 100 shuffled pairs | Correlated | Start of session | 10 | 10 |
| Phase 6: | | | | | |
| Begin within-session reversals | 100 shuffled pairs | Correlated | Within session | 40 | 40 |

dividing reversals into one training and six testing phases. The training phase was required to introduce each subject to the procedure and stimuli and to establish reliable responses to all the members of one stimulus set. Each of the six testing phases comprised a different experimental condition under which reversal sessions were performed. The experimental conditions were established for each phase during the course of the experiment in a continuing effort to elicit performance consistent with functional class formation. The number of reversals completed by each subject in each testing phase was not standardized. Rather, we continued to reverse and retrain the positive sets in each phase until performance on the first block of trials following reversals reached an asymptotic level. When performance on at least 10 consecutive reversals showed no further improvement, the subject progressed to the subsequent testing phase. In all phases, regression analysis confirmed stable performance on the last 10 reversals in each phase of the experiment. Rio completed a minimum of 10 and a maximum of 53 reversals in each test phase; Rocky completed a minimum of 10 and a

maximum of 41 reversals. Testing under each condition is summarized in Table 1 and was carried out as follows:

Initial training. All 20 stimuli were introduced to each subject in the first session of the experiment. In this phase, letters and numbers were presented on each trial in matched pairs (i.e., A and 1, B and 2, . . . , J and 10). This design generated a total of 10 trial types that appeared four times each per session, once in each block of trials. Responses to stimuli belonging to the positive set (designated as letters for Rio and numbers for Rocky) produced a 440-Hz tone that served as a conditioned reinforcer followed by a piece of randomly selected capelin or herring. Training proceeded until the subjects' performance met a criterion of two consecutive sessions containing at least 90% correct responses.

Reversal Phase 1: Stimuli presented in matched pairs. Following initial training, the reinforcement contingencies were reversed: Responses to stimuli belonging to the previously positive set no longer produced food, and responses to members of the previously negative set were now reinforced. Once performance

reached the criterion of 90% correct responses on two consecutive sessions, the reinforcement contingencies were again reversed and retrained to criterion. All correct responses produced the 440-Hz tone followed by either capelin or herring. Throughout Phase 1, the stimuli continued to be presented in matched pairs following the same design used in the initial training phase.

Reversal Phase 2: Stimuli presented in shuffled pairs. Following Phase 1, during which no substantial improvement in reversal performance occurred, several additional phases were incorporated into the experimental design (see Table 1). In Phase 2, the stimulus pairings were shuffled so that any S+ could be presented with any S- on an individual trial (e.g., F and 2, 7 and B, J and 8). This change in procedure increased the number of different trial combinations from a total of 10 in Phase 1 to a total of 100 different trial combinations in Phase 2. The presentation of stimuli within each session remained balanced as outlined in the general procedure, with each S+ and S- appearing once in each block for a total of four times per session. As in Phase 1, all correct responses produced a 440-Hz tone followed by either capelin or herring.

Reversal Phase 3: Assignment of class-specific fish reinforcers. Following Phase 2, reversals continued as before with one exception: Each of the two different fish reinforcers that were previously uncorrelated with different stimulus sets were now assigned to one of the two stimulus sets. In this condition, correct responses to stimuli from a given set produced a specific acoustic conditioned reinforcer (either a higher pitched tone or a lower pitched tone) followed by a specific fish reward (either capelin or herring). For Rio, when members of the letter set served as S+, correct responses produced a 587-Hz tone followed by capelin; when members of the number set served as S+, correct responses produced a 293-Hz tone followed by herring. For Rocky, the opposite outcomes were correlated with each stimulus set.

Reversals continued throughout Phase 3, with the original criterion of two consecutive sessions with performance at or above 90% correct until each subject's performance reached 90% on the first session following a reversal. At this point (the 9th reversal of the

phase for Rio; the 15th reversal for Rocky), the defined criterion was reduced to one session with performance at or above 90%.

Reversal Phase 4: Removal of class-specific fish reinforcers. In this phase, the specific reinforcers that had been assigned to each class were desegregated. As in Phase 2, correct responses to members of either class produced the original 440-Hz tone and a mixed (either capelin or herring) fish reward.

Reversal Phase 5: Reintroduction of class-specific fish reinforcers. Upon completion of Phase 4, the class-specific reinforcers used in Phase 3 were reinstated.

Reversal Phase 6: Within-session reversals. In the final phase of Experiment 1, the position of the contingency reversal in the session was manipulated. Prior to this phase, reversals of the positive and negative stimulus sets always occurred at the start of a session. During Phase 6, a reversal could occur one or more times within a session, with the only restriction being at least 90% correct on the previous 10 to 14 consecutive trials.

Results and Discussion

Both subjects began the training phase with chance levels of performance. Rio reached criterion following three sessions (120 trials with 36 errors); Rocky reached criterion following six sessions (240 trials with 75 errors). Following this training phase, the subjects began the reversal phases of the experiment.

Functional classes are demonstrated when experience with a few members of one stimulus set alters responding to the remaining members of that set. Therefore, performance on the first exposure of each S+ following a reversal must be isolated from performance on subsequent trials to prevent the effects of learning from influencing assessment of functional class formation. Because the first 10 trials of each reversal included a single presentation of each S+ and S-, any improvement that occurred between the trials in Positions 1 through 10 can be attributed to the formation of relations between class members. Consequently, only the first 10 trials following each reversal (Block 1) were considered for analysis in the reversal phases of the experiment.

The performance trends of both subjects on the first block of trials following a reversal

Table 2

Linear regressions were completed to evaluate each subject's performance across a series of reversals. Performance was measured as the number of correct responses made on the 10 unique trials following a reversal, and that metric was evaluated across reversals. In this way, changes in performance were measured across all reversals in each testing phase, and on the last 10 reversals within each testing phase. Stable performance evaluated at $p > .05$ is denoted by *ns*, significant improvement evaluated at $p < .05$ is denoted by *, and significant improvement evaluated at $p < .01$ is denoted by **. Note that in all phases, performance across the last 10 reversals was stable.

| Subject | Phase | Performance across all reversals | | | Performance across last 10 reversals | | |
|---------|-------|----------------------------------|-------|--------------|--------------------------------------|-------|--------------|
| | | Sample size | R^2 | Significance | Sample size | R^2 | Significance |
| Rio | 1 | 20 | .175 | <i>ns</i> | 10 | .001 | <i>ns</i> |
| | 2 | 22 | .000 | <i>ns</i> | 10 | .042 | <i>ns</i> |
| | 3 | 22 | .654 | ** | 10 | .141 | <i>ns</i> |
| | 4 | 42 | .006 | <i>ns</i> | 10 | .288 | <i>ns</i> |
| | 5 | 10 | .036 | <i>ns</i> | 10 | .036 | <i>ns</i> |
| | 6 | 40 | .119 | * | 10 | .063 | <i>ns</i> |
| Rocky | 1 | 15 | .091 | <i>ns</i> | 10 | .000 | <i>ns</i> |
| | 2 | 20 | .023 | <i>ns</i> | 10 | .031 | <i>ns</i> |
| | 3 | 44 | .358 | ** | 10 | .054 | <i>ns</i> |
| | 4 | 24 | .008 | <i>ns</i> | 10 | .263 | <i>ns</i> |
| | 5 | 10 | .027 | <i>ns</i> | 10 | .040 | <i>ns</i> |
| | 6 | 40 | .261 | ** | 10 | .182 | <i>ns</i> |

were similar for all six phases of the experiment. Results from regression analysis of performance following reversals in each phase are shown in Table 2. For this analysis, trials in the first block following a reversal were grouped for each reversal. Performance was measured as the total number of correct responses in each block of 10 trials. When performances across all the reversals in a phase were considered, both Rio and Rocky showed

stable performance (slope of regression line not different than zero) in Phases 2, 4, and 5. Both subjects exhibited substantial improvement (slope of regression line positive) across the reversals in Phases 3 and 6.

All further comparisons of performance between each subject and between each phase of the experiment were restricted to the last 10 reversals completed in each phase. The purpose of this analysis was twofold. Performance on the last 10 reversals in each phase for both animals was asymptotic, as shown by the regression analysis in Table 2. Thus, this region represents the best performance achieved by each subject under each condition. In addition, this measure provided a standardized way of comparing the performance of both animals, because the number of reversals completed by each subject in each testing phase was not the same.

The pattern of performance on trials within the last 10 reversals of each testing phase is shown in Figure 4, which also documents the strong similarities observed between the subjects. The performance of the 2 subjects compared within each phase was not different for any of the six phases (Fisher's exact tests, $p > .05$). Performance was lowest in Phase 1, in which the stimuli were presented in matched pairs. In Phase 2, in which the

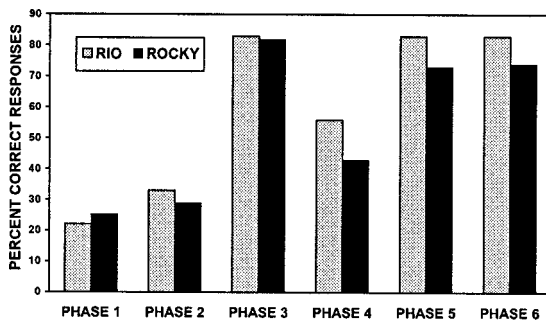


Fig. 4. Performance of each subject in Phases 1 through 6 of Experiment 1. Each bar represents the proportion of correct responses made to the 10 stimuli on their first presentation following a reversal. The idealized performance maximum is 90% correct responses (perfect performance following one error after a reversal; see Figure 3, top panel). Data for the last 10 reversals of each phase are shown to represent stabilized performance levels under each condition.

stimuli were shuffled, both animals showed a slight but nonsignificant improvement in performance (Rio improved from 21 of 95 correct responses to 33 of 100, Rocky improved from 24 of 95 to 29 of 100; Fisher's exact tests, $p > .05$). They also showed a reduction in the average number of errors required to reach criterion following a reversal between Phases 1 and 2 (Rio improved from an average of 126 errors per reversal on Phase 1 to 55 errors on Phase 2, Rocky improved from 137 to 117 errors). However, the most dramatic change in performance occurred for both subjects in Phase 3, when different reinforcers were assigned to each stimulus set. Performance for both subjects under this condition showed dramatic improvement relative to Phase 2 (Rio improved from 33 of 100 to 83 of 100, Rocky improved from 29 of 100 to 82 of 100; Fisher's exact tests $p < .01$), and performance was also much better than would be expected by chance (Rio scored 83 of 100, Rocky scored 82 of 100; binomial tests, $p < .01$). By the end of this phase, both subjects were responding appropriately after only a few trials following a reversal. Because both subjects generally met criterion within the minimum number of sessions required, almost every session was a criterion session; thus, Rio made an average of 0 errors prior to criterion, and Rocky averaged 0.5 errors to criterion in Phase 3.

In Phase 4, class-specific reinforcers were removed from the testing procedure. This phase replicated the testing conditions of Phase 2. Under this condition, the performance of both subjects declined significantly from Phase 3 levels (Rio's performance dropped from 83 of 100 to 56 of 100 and Rocky's dropped from 82 of 100 to 43 of 100; Fisher's exact tests, $p < .01$), but remained elevated relative to performance in Phase 2 (Rio scored 56 of 100 on Phase 4 and 33 of 100 on Phase 2; Rocky scored 43 of 100 and 29 of 100; Fisher's exact tests, $p \leq .05$). In Phase 5, when the reinforcers were reassigned to the two classes, performance recovered to Phase 3 levels (Rio scored 83 of 100 on Phase 5 and 83 of 100 on Phase 3; Rocky scored 73 of 100 and 82 of 100; Fisher's exact tests, $p > .05$).

The final measure used to assess functional class formation was an analysis of performance following a reversal by trial position.

This analysis can be compared to the theoretical reversal performance predicted with and without stimulus classification as described in the top panel of Figure 3. The actual data plotted by trial position for each animal for each phase of the experiment are depicted in the lower panels of Figure 3. In all phases, performance was better on trials that occurred in the latter half of the test block, suggesting some degree of functional classification by the sea lions. Phases 3 and 5, in which test conditions were the same (shuffled stimulus pairings and class-specific reinforcers), showed close to perfect performance. The only anomaly was performance on the very first trial following a reversal. As depicted in the top panel of Figure 3, expected performance following a reversal of reinforcement contingencies is zero. However, the performance of both subjects on Trial 1 improved from zero to near chance levels during Phases 1 through 5. Because reversals occurred frequently, and only at the start of a session during these phases, it is likely that the subjects eventually began responding at random on the first trial of a session. To determine if this was the case, Phase 6 moved the reversal contingency from the start of the session to an unpredictable position within the session. In this condition, performance was predictably zero on the first trial following a reversal, and test performance on subsequent trials mirrored that expected from successful functional class formation (compare the top and bottom panels of Figure 3).

These results document the formation of functional classes in two California sea lions and provide strong support for Vaughan's (1988) finding with pigeons. The finding that sea lions, as well as pigeons, can form classes of functionally equivalent stimuli indicates that this classification process may be a fundamental learning ability. Further support for this view comes from less definitive studies conducted with other nonhuman subjects. Dube, Callahan, and McIlvane (1993) reported that rats showed some savings on sequential auditory discrimination reversals using different reinforcers for correct responses to different classes. However, improvement did not occur within the first exposure of each stimulus following a reversal of reinforcement contingencies, and only 2 of 5 subjects showed savings at all. Tomonaga (1999) re-

cently reported some evidence of functional class formation in a chimpanzee with a two-item sequential responding procedure, without using different reinforcers. Because this study included only two two-member classes and failed to show an immediate transfer of function following a reversal, the findings are of limited value regarding this issue. In contrast, the strong reversal transfer performance demonstrated by 2 dolphins (von Fersen & Delius, 2000), also using a small set of stimuli, does provide support for the idea that functional classification is a general process.

The measures used to assess functional class formation in the present study are powerful because they rely on Trial 1 performance, or the performance of the subjects on their first encounter with each stimulus following a reversal. Despite a sample size of only 10 stimuli per set, both subjects eventually showed that reversed reinforcement contingencies for a few members of a set would result in reversed responses to the remaining members of that set on their first exposure. Although the members of each set had never been directly associated and were not physically similar, they became related to one another through a shared history of reinforcement and formed distinct functional classes.

The first variable manipulated in this study was the number of exemplars (stimulus configurations) provided to each subject. We predicted that increasing the number of exemplars from 10 in Phase 1 to 100 in Phase 2 would facilitate classification, based on other studies using the same subjects (Kastak & Schusterman, 1994; Schusterman & Kastak, 1993). We observed, however, only a slight improvement in reversal performance following shuffling of the stimulus pairings. Rather than facilitating performance immediately following the reversal, increasing the number of exemplars appears to have aided reversal acquisition, as shown by the reduction in the average number of errors made prior to criterion. This trend likely involved improvement in the memorization of specific responses and in the identification of individual stimuli rather than in the strengthening of relations between stimuli. Thus, increasing the number of exemplars was not directly associated with stimulus classification.

The major variable assessed in this study

was the assignment of different primary and conditioned reinforcers to each stimulus set. Following the assignment of class-specific reinforcers to each stimulus set, both subjects rapidly improved to near-perfect performance levels within the first block of trials following a reversal. This effect culminated in the reversal of responses to all members of a stimulus set following only one or two information trials with individual stimuli.

The rationale for correlating reinforcers with potential stimulus classes was based on several studies linking differential outcomes or rewards to increased performance on various discrimination tasks (see Goeters, Blakeley, & Poling, 1992, for a review). In addition, the assignment of differential reinforcers had been used to facilitate class formation in both simple and conditional discrimination procedures, ostensibly by providing an additional source of information about each set (see, e.g., Schenk, 1994). Most recently, Meehan (1999) used class-consistent differential reinforcement with pigeons to demonstrate emergent stimulus relations, including transitive and reflexive relations.

The assignment of class-specific reinforcers apparently catalyzed functional class formation for the sea lions. Why Vaughan's (1988) pigeons were able to demonstrate functional class formation without assigned reinforcers is not clear. Variability in performance between our study and Vaughan's may be related to differences in procedure (Vaughan used a sequential discrimination; we employed a simultaneous procedure), response criteria (Vaughan used a pecking rate index; we used a discrete correct or incorrect response), or analysis (Vaughan used a likelihood ratio of choosing a positive stimulus over a negative stimulus; we measured the number of correct responses of the first exposure of each stimulus following a reversal).

The effect of assigning differential outcomes was not entirely predictable based on previous work. One of our subjects, Rio, had previously formed stimulus equivalence classes in an MTS procedure in the absence of specific outcomes for responses to members of specific classes (Schusterman & Kastak, 1993). Subsequently, Rio was tested with a simple discrimination procedure similar to the one used in the current study to determine if equivalence classes formed in an MTS

procedure would transfer to functional classes in a simple discrimination procedure. Rio showed immediate transfer, indicating that functional classes could emerge from equivalence relations without the assignment of class-specific reinforcers (Schusterman & Kastak, 1998). Whether different reinforcers would have facilitated the formation of equivalence classes in the Schusterman and Kastak studies, as reported by Schenk (1994) for children, is unknown. However, the results from this experiment suggest that differential outcomes may play a more important role when stimuli are related through a common behavioral response, as in a simple discrimination reversal procedure, rather than through a common stimulus, as in an MTS procedure.

The powerful effect of assigning reinforcers to stimulus classes led to the question of whether our subjects could retain functional class memberships in their absence. It was possible that the reinforcer following each correct response served as a direct discriminative cue for performance on the following trial. Essentially, a specific reinforcer following a correct response to one S+ could occasion responding to the S+ presented on the following trial, without the two stimuli becoming interrelated. Two pieces of evidence suggest that this was not the case. Following the reversal of reinforcement contingencies, the responses of both subjects eventually shifted to members of the positive class after responding to only one or two members of the negative class, in the absence of any cues provided by class-specific fish or conditioned reinforcers. In addition, when reinforcer assignments were randomized in Phase 4, performance declined but remained significantly elevated with respect to the preassignment levels measured in Phase 2.

Despite this evidence, we could not rule out the possibility that the emergent performance we observed was a result of conditional control by the class-specific reinforcers. Removal of the class-specific reinforcers in Phase 4 was problematic. Ideally, the two reinforcers assigned to each class should have been replaced with a third, neutral reinforcer. Unfortunately, this was not possible because the subjects were maintained on a diet of two fish types and could not be coaxed to accept a third within the time constraints of

the experiment. The results for both subjects when food reinforcers were varied in Phase 4, however, suggest that the role of the assigned reinforcers in Phase 3 was to strengthen the relations between individual stimuli by relating members of a common class to a common reinforcer. When the reinforcers were uncorrelated in Phase 4, the relations that had formed between stimuli were sufficient to sustain elevated levels of performance relative to the prior uncorrelated reinforcer condition. The decline in performance in the uncorrelated condition (Phase 4) relative to the previous correlated condition (Phase 3) can be attributed to the confusing effects of mixing reinforcers that had previously been assigned to each class. When the reinforcer assignments were reestablished in Phase 5, performance immediately recovered to Phase 3 levels.

EXPERIMENT 2

From an experimental standpoint, measuring the transferability of a stimulus class from one procedure to another can reveal the strength of the relations that exist between class members. Based on the results of Experiment 1, we believed that functional relations had formed between the members of each stimulus class. We next tested the sea lions to determine if the functional classes established in a simple discrimination reversal procedure would yield conditional discriminations in an MTS procedure; given a sample stimulus from one class and comparison stimuli from each of two classes, would the subjects immediately relate the two stimuli belonging to the same functional class? To succeed in this experiment, the sea lions would have to transfer functional class membership to an MTS procedure, one that eliminated the potential for discriminative control by class-specific reinforcers.

Procedure

An MTS procedure was used for all experimental sessions according to the general design already described. The same apparatus was used; however, in this experiment, the center (or sample) stimulus box was used in addition to the two comparison boxes. On each trial, the assistants were directed via headphones to simultaneously place the ap-

appropriate stimuli into each comparison box and then place the sample stimulus into the center box. To begin a trial, the door covering the sample box was opened to expose the sample stimulus. The subject was given a 3- to 4-s observing interval, and then, on the experimenter's cue, the two comparison stimuli were exposed. After another 3- to 4-s pause during which all three stimuli were visible to the subject, the subject was prompted by the acoustic release to select one of the comparison stimuli as the match to the sample. An example of such a conditional discrimination trial is shown in the lower panel of Figure 1.

The experiment was divided into a series of baseline training and transfer tests as follows:

Maintenance of MTS baseline relations. Prior to testing the transfer of functional classes to conditional discriminations, a baseline of familiar conditional discriminations was established for each subject. These stimuli, coded as *MTS training sets*, were plywood squares (30 cm by 30 cm) with a variety of black shapes painted onto white backgrounds. These stimuli, shown in the lower panels of Figure 2, were a subset of stimuli used by each animal in a previous experiment (see Schusterman & Kastak, 1993). Rio and Rocky were each assigned 12 training stimuli divided into four three-member sets labeled MTS Training Sets 1, 2, 3, and 4. The three stimuli in each set were labeled A, B, and C members as shown in Figure 2; A1, B1, and C1 were all members of Set 1, B1, B2, and C2 were all members of Set 2, and so on. The stimuli within each training set could be combined to generate six different conditional discriminations based on the stimulus combinations ArB, BrC, ArC, BrA, CrB, and CrA, where the letter code represents the sample r S+ configuration. The S- presented on each trial was the corresponding member of one of the other sets. An important characteristic of these trained relations was that all of the stimuli in a set appeared as samples, positive comparisons, and negative comparisons on different trials, a feature that would later be incorporated into the transfer tests.

When the subjects originally learned these baseline conditional discriminations, reinforcement was not class specific. However, several months prior to the start of the Ex-

periment 2 transfer tests, each training set was assigned one of the two class-specific reinforcers used in Experiment 1. For Rio, correct responses to A1, B1, C1 or A3, B3, C3 produced the 587-Hz tone followed by capelin, and correct responses to A2, B2, C2 or A4, B4, C4 produced the 293-Hz tone followed by herring. For Rocky, the opposite outcomes were correlated with each MTS training set. Both subjects were trained on conditional discriminations with these stimuli using class-specific reinforcers until a performance criterion of 90% correct was maintained.

Maintenance of reversal performance. Performance on simple discrimination reversals with the letter class and the number class was maintained throughout Experiment 2. These sessions were continued in accordance with the design used in Phase 6 of Experiment 1. A minimum of one simple discrimination reversal session and one MTS baseline session were completed at criterion prior to each of the transfer tests described below. The purposes of these sessions were threefold: (a) to ensure that the subjects were properly trained to perform the MTS procedure, (b) to establish baseline performance levels to which test performance could be compared, and (c) to ensure that the integrity of the functional classes established in Experiment 1 was maintained.

Conditional discrimination transfer tests. Experiment 2 was designed to measure the transfer of the functional classes established in a simple discrimination procedure to an MTS procedure. Each of six transfer tests comprised novel pairings of functional class members in the MTS procedure. There were 4 novel trials presented in Tests 1, 2, and 3, 48 novel trials in Test 4, 24 novel trials in Test 5, and 96 novel trials in Test 6, for a total of 180 novel conditional discrimination trials.

The transfer tests were designed so that a subset of novel pairings would be tested, trained to criterion, and then incorporated in the baseline of familiar conditional discriminations before the subsequent test was conducted. This design provided an opportunity for the subjects to become accustomed to the testing procedure and to diminish novelty effects that might disrupt test performance. In addition, this design provided a series of procedural exemplars that could facilitate per-

formance on later transfer tests involving novel combinations of stimuli. The transfer-test procedures are detailed below; an exhaustive list of the trial configurations used in each test appears in Appendix A.

The test trials within each test session were presented randomly within a baseline of familiar conditional discrimination trials. Correct responses on test trials were defined as selection of a letter conditionally upon the presentation of another letter as the sample stimulus, and selection of a number conditionally upon the presentation of another number as the sample stimulus. All correct responses produced the same class-specific reinforcers that had been paired with the letter and number stimulus sets in Experiment 1.

Transfer Test 1. Two members from each functional class were randomly selected to be tested in Transfer Test 1: E and I and 4 and 8. These stimuli generated a total of four unique conditional discrimination test trials (i.e., ErI, IrE, 4r8, and 8r4). The S- on these trials was one of the stimuli being tested from the alternate set. Each of the four test trials appeared three times in each session against 28 familiar baseline MTS trials. Following two sessions, the number of test trials appearing in each session was increased from 12 to 24 and the number of baseline trials was decreased from 28 to 16. These sessions were continued until each subject reached a performance criterion of 90% on the test trials within one session; the test trials were then incorporated into each subject's baseline of conditional discriminations.

Transfer Test 2. Transfer Test 2 replicated Test 1 with two new stimuli drawn from each functional class: B and H and 2 and 10. Following testing and training to criterion, the four test trials were incorporated into each subject's baseline of conditional discriminations.

Transfer Test 3. Transfer Test 3 replicated tests 1 and 2 with two new stimuli drawn from each functional class: A and J and 7 and 9. Following testing and training to criterion, the four test trials were incorporated into each subject's baseline of conditional discriminations.

Transfer Test 4. Transfer Test 4 utilized all combinations of the stimuli tested in Transfer Tests 1, 2, and 3, yielding a total of 48 untested conditional discriminations. Testing

took place over two sessions that each contained 24 test trials and 16 baseline trials. Following these two sessions, which included the first presentation of each novel stimulus combination, two additional sessions were conducted in which test trials appeared for the second time with a different S- and in a different configuration. After these four sessions were completed, the 48 test trials were incorporated into each subject's baseline of conditional discriminations.

Transfer Test 5. The remaining four stimuli from each functional class (C, D, F, G; 1, 3, 5, 6) were used in Transfer Test 5. This procedure generated 24 novel conditional discriminations. The test trials were presented in one test session with 16 baseline trials. A second session was conducted in which test trials appeared for the second time with a different S- and in a different configuration. Following this session, the test trials were incorporated into each subject's baseline of conditional discriminations.

Transfer Test 6. The final transfer test included all new combinations of the eight stimuli used in Transfer Test 5 with the 12 stimuli used in Tests 1 through 4. This procedure generated 96 novel class-consistent stimulus pairings. This test was fashioned after Transfer Tests 4 and 5, with testing occurring over four sessions with 24 test trials and 16 baseline trials each. Following these four sessions, four additional sessions were conducted in which test trials appeared for the second time.

Results and Discussion

The results of these transfer tests are summarized in Table 3. The primary measure of transfer performance was the subjects' performance on the first exposure of each novel conditional discrimination. The use of this Trial 1 measure precluded the possibility that positive results could arise from trial-and-error learning of individual conditional relations. Performance on the second exposure of each test trial and performance on the baseline trials that were presented during testing are also reported. Finally, a measure of any trial-and-error learning that did occur is shown by the number of errors made on new trials prior to reaching the 90% performance criterion.

Transfer Tests 1, 2, and 3 contained four

Table 3

Performance on conditional discrimination transfer tests summarized as number of correct trials out of total number of trials. Categories in which performance is not significant relative to chance at an alpha level of $p > .05$ (calculated from a two-tailed binomial) are denoted by *ns*; categories in which performance is significant relative to chance at an alpha level of $p < .05$ are denoted by *; categories in which performance is significant relative to chance at an alpha level of $p < .01$ are denoted by **. Number of errors to criterion includes the total number of errors made on test trials prior to the first session of better than 90% performance. If the subject achieved criterional performance on test trials within the first session, the number of errors to criterion was zero.

| Subject | Transfer test | Baseline performance | Test performance | | Errors to criterion |
|---------|---------------|----------------------|------------------|-----------------|---------------------|
| | | | First exposure | Second exposure | |
| Rio | 1 | 27/28** | 2/4 | 2/4 | 90 |
| | 2 | 27/28** | 3/4 | 3/4 | 20 |
| | 3 | 24/28** | 3/4 | 2/4 | 8 |
| | 4 | 28/32** | 40/48** | 47/48** | 0 |
| | 5 | 15/16** | 16/24 <i>ns</i> | 21/24** | 8 |
| | 6 | 59/64** | 89/96** | 96/96** | 0 |
| | Total | 180/196** | 154/180** | 171/180** | 126 |
| Rocky | 1 | 24/28** | 2/4 | 4/4 | 66 |
| | 2 | 25/28** | 0/4 | 3/4 | 27 |
| | 3 | 27/28** | 3/4 | 3/4 | 27 |
| | 4 | 32/32** | 48/48** | 48/48** | 0 |
| | 5 | 16/16** | 18/24* | 21/24** | 9 |
| | 6 | 61/64** | 92/96** | 90/96** | 0 |
| | Total | 185/196** | 163/180** | 169/180** | 129 |

novel test trials each. The sample size for each test was too small to evaluate Trial 1 transfer of functional classes to conditional discriminations. When Trial 1 performance was pooled over the first three tests, neither subject demonstrated significant transfer (Rio scored 66% and Rocky scored 41%; binomial tests, $p > .05$). Both subjects, however, showed a reduction in the number of trials required to reach criterion on each successive test.

Performance on the 48 novel trials presented in Transfer Test 4 was strong for both subjects. Rio scored 83.3% on the first exposure of the test trials, and Rocky scored 100% (binomial tests, $p < .01$). The performance of both subjects on test trials was not different from their performance on familiar baseline trials (Fisher's exact tests, $p > .05$). An advantage to the design of Transfer Test 4 was that each of the stimuli tested had previously appeared as both a sample and a comparison in other trial combinations. Thus, any novelty effects generated by the unexpected appearance of a letter or number in the sample position were mitigated, and performance on novel stimulus pairings could still be assessed.

Performance on the 24 novel trials in

Transfer Test 5, which included stimuli never before presented in the MTS procedure but which did not control for the effect of novel stimulus position, was not quite as strong as on Test 4. Rio scored 66% on test trials (binomial test, $p > .05$), and Rocky scored 75% (binomial test, $p < .05$). Performance on test trials was slightly but not significantly worse than performance on corresponding baseline trials for both subjects (Fisher's exact tests, $p > .05$). However, on the second exposure of each test trial, Rio's performance rose from 66% to 91%, and Rocky's performance rose from 75% to 87% (binomial tests, $p < .01$).

Transfer Test 6 included 96 novel trial combinations, which, like Transfer Test 4, did control for the effect of novel stimulus position. Consistent with performance on Transfer Test 4, performance on Transfer Test 6 was significantly better than expected by chance. On this test, Rio scored 92% on the first exposure of the test trials, and Rocky scored 95% (binomial tests, $p < .01$). Their performance on novel test trials was not different from performance on familiar baseline trials (Fisher's exact tests, $p > .05$).

Overall, performance on Transfer Tests 1 through 6 combined shows highly significant

transfer of functional classes to conditional discriminations. Rio was correct on 154 of 180 novel stimulus pairings (85.6% correct; binomial test, $p < .01$), and Rocky was correct on 163 of 180 novel pairings (90.5% correct; binomial test, $p < .01$). There was no difference in performance on transfer trials in which letters served as the discriminative stimulus relative to trials in which numbers served as the discriminative stimulus (Fisher's exact tests, $p > .05$), and overall performance on test trials was not different from performance on familiar baseline trials (Fisher's exact tests, $p > .05$).

The weakest transfer for each subject was observed during tests that involved presenting functional class members in the MTS procedure for the first time. It is likely that the unexpected change in context or stimulus position for the functional class members caused some disruption in performance on transfer trials in some or all of these tests. The results of Test 5 provide evidence to support this hypothesis. In this test, each subject was presented with 24 novel transfer trials composed of stimuli that had not yet been presented in the MTS paradigm; Rio's performance on this test was marginally worse than predicted by chance, and Rocky's performance was marginally better. However, on the second session of Test 5, when the same test trials were presented (this time appearing with a different S- and in a different positive position), performance of both subjects rose to near-perfect levels. It is unlikely that either subject learned the 24 new relations presented in the first session after a single exposure to each. Therefore, improved performance on the second session can be attributed to a reduction or elimination of the novelty effect that had disrupted transfer in the first session.

The two tests that involved novel combinations of stimuli that had already been presented in the MTS paradigm provided the opportunity to assess transfer in the absence of a possible disruptive novelty effect. Transfer Tests 4 and 6 were composed of stimuli that had been used in previous transfer tests reshuffled into novel combinations. The performance of both subjects on these test trials was not different than performance on completely familiar trials; Rio was correct on 90% of the transfer trials, and Rocky was correct

on 97% of novel transfer trials on their first exposure.

The disruptive effects of novel stimulus positions are consistent with data reported for the same subjects on tests of identity matching (Kastak & Schusterman, 1994). The anticipated disruption of test performance was a key factor in designing the block format of the transfer tests incorporated into this experiment. The procedure allowed any disruption in performance caused by novel stimulus position to be isolated and measured by presenting novel combinations of individual stimuli that either had or had not been previously exposed to the subjects in the MTS procedure. In addition, the experimental design incorporated a sequential component that provided the subjects with experience relating some members of functional classes to one another in the MTS procedure; this feature may have facilitated transfer on subsequent tests.

The design of the experiment was also advantageous because it allowed us to resolve the question of whether the functional classes formed in Experiment 1 were under the discriminative control of the reinforcer. Had the reinforcer controlled responding in the simple discrimination reversal procedure, correct responding would not necessarily require emergent stimulus relations to arise between class members. In the MTS procedure, however, either a letter or a number could appear as the S+ on any trial, and consequently, the sequence of reinforcers alternated irregularly throughout the session. In this context, the reinforcer given on the preceding trial served no predictive function for correct responding on the following trial. With reinforcers no longer serving as potential discriminative cues, both subjects still matched functional class members with a great deal of accuracy. These results support the interpretation that the relations between members of the functional classes were not based solely on stimulus-reinforcer relations, but at least in part on stimulus-stimulus relations that emerged between functional class members. Thus, we believe that the stimulus-reinforcer relations established in Experiment 1 served primarily to strengthen or facilitate the relations between stimuli, rather than to replace them.

EXPERIMENT 3

In the first two experiments, the subjects formed functional classes in a simple discrimination procedure and then transferred the relations between class members to conditional discriminations. However, as Sidman et al. (1989) noted, demonstrating the emergence of conditional discriminations within functional classes does not suffice to demonstrate equivalence relations among class members. In this final series of experiments, we tested the sea lions to determine if functional class members that shared common stimulus and reinforcer relations would generate verifiable equivalence relations. Further, we attempted to determine whether stimuli with only reinforcer relations in common would also become related through emergent equivalence relations.

Procedure

This experiment followed the same general testing procedures used in the previous experiments and consisted of two primary components. The first component tested whether emergent equivalence relations could form from functional classes. For this task, the sea lions were trained to relate novel stimuli to existing class members in MTS, and were then tested to determine whether equivalence relations would emerge between the new stimuli and the remaining class members. The second component was designed to examine the role of the different reinforcers in class formation. For this task, the sea lions were tested to determine if a common reinforcer would establish emergent relations between functional class members and previously unrelated stimuli.

The MTS apparatus and general testing procedure used in Experiments 1 and 2 were also used in Experiment 3. The stimuli consisted of the MTS training sets used for each subject in Experiment 2 and the two 10-member functional classes established in Experiment 1. In addition, one new member was added to each existing functional class in the current experiment: K was added to the letter class and 11 was added to the number class. All of these stimuli are shown in Figure 2.

Expansion of functional classes through stimulus-mediated equivalence relations. Stimuli K and 11 were related to J and 10 as follows. First,

the conditional discriminations JrK and 10r11 were trained with the familiar stimulus (either J or 10) serving as the sample, and the new stimuli (K and 11) serving as comparisons. Each training trial appeared 12 times each per session with 16 familiar baseline trials. All correct responses produced the same class-specific reinforcers used previously. These training sessions were continued to a performance criterion of 90% correct on training trials. Following attainment of this criterion, the same testing procedure was used to train the symmetrical relations KrJ and 11r10. Once relations KrJ, 10r11, JrK, and 11r10 were established, the training trials were combined into sessions that included six trials with each of the four newly trained discriminations. The subjects were required to perform one of these sessions at criterion prior to proceeding to the transfer test. The transfer test is described below; all of the trial configurations used in training and transfer testing are shown in Appendix B.

Transfer testing took place over two consecutive sessions that consisted of 18 test trials and 12 baseline trials each. Transfer trials consisted of presenting the new stimuli (K and 11) with the remaining nine members of each functional class (A through I and 1 through 9) in novel conditional discriminations. On these trials, either K or 11 could appear as the sample stimulus, paired with an S+ and S- from each of the two functional classes as comparisons; in addition, K and 11 could appear together as the S+ and S- on a trial, with one of the functional class members appearing as the sample. Correct responses were defined by class-consistent responses (i.e., matching K with any letter and matching 11 with any number). This test design generated 36 completely novel conditional discrimination transfer trials.

Expansion of functional classes through reinforcer-mediated equivalence relations. The final tests were designed to determine whether common associations with specific reinforcers would establish emergent relations between previously unrelated stimuli and the functional classes. To accomplish this, test trials with MTS Training Sets 1 and 2 were presented in the context of the simple discrimination reversal procedure for the first time. Test trials consisted of pairing one stimulus from each of the two training sets in simple discrimina-

tion test trials. Each of the two choice stimuli presented on a trial had previously been paired with a different reinforcer (stimuli in Set 1 had been correlated with capelin; stimuli in Set 2 had been correlated with herring). The test trials were embedded in six functional class reversal sessions that alternated between letters and numbers positive. When letters served as S+, selection of the test stimuli that had also been paired with capelin and the 587-Hz tone was reinforced; conversely, when numbers served as S+, selection of the test stimuli that had also been paired with herring and the 293-Hz tone was reinforced. Thus, the functional class currently designated as positive determined the S+ for each test trial. In this way, the same test trial could appear in two different reversal sessions with opposite reinforcement contingencies. There were nine novel pairings of arbitrary stimuli tested (e.g., 1A vs. 2A, 1B vs. 2C, 1C vs. 2A). Each pairing appeared twice during testing with opposite reinforcement contingencies to generate a total of 18 novel simple discrimination test trials. Three test trials, which included a single exposure of each stimulus in a set, were presented in each of the six reversal sessions. All correct responses produced the same class-specific reinforcers that had been used throughout the study.

Immediately following the simple discrimination transfer test, a second transfer test was conducted. This test utilized the MTS procedure and tested for the emergence of novel conditional discriminations between the MTS training stimuli and the functional class members that shared common reinforcers. Prior to testing, the training stimuli had never been directly paired with any functional class members. During testing, the training stimuli and the functional class members were combined into novel conditional discriminations. On each trial, the S- presented was a stimulus assigned to one reinforcer, and the sample and S+ presented were assigned to the alternate reinforcer. On test trials, a training stimulus could serve as the sample with two stimuli from opposing functional classes as comparisons, or conversely, a functional class member could appear as the sample with two stimuli from opposing training sets as comparisons. Correct responses were defined as selection of the comparison stimulus that had

been assigned to the same reinforcer as the sample. All correct responses produced the same class-specific reinforcers that had been used throughout the study. The test procedure generated a total of 132 novel conditional discrimination transfer trials. Testing occurred over six sessions that contained 22 test trials and 12 baseline trials each. A complete list of the trial configurations tested can be found in Appendix C.

Results and Discussion

After trained relations were established between the new stimuli K and 11 and the functional class members J and 10, untrained relations emerged between the new stimuli and the remaining members of each functional class. This transfer was nearly perfect. On the first presentation of the 36 novel conditional discriminations, Rio was correct on 100% of trials, and Rocky was correct on 91% of trials (binomial tests, $p < .01$). Performance on transfer trials was not different from performance on familiar baseline trials for either subject (Rio scored 36 of 36 on test and 24 of 24 on baseline trials; Rocky scored 33 of 36 and 24 of 24; Fisher's exact tests, $p > .05$). These data indicate that the functional classes formed by the sea lions also met the requisite criteria for stimulus equivalence classes as described by Sidman and Tailby (1982).

In the test just described, functional classes were expanded when equivalence relations emerged between stimuli that were related through a common stimulus as well as a common reinforcer. The next set of transfer tests was conducted to determine whether a common reinforcer alone was sufficient to establish equivalence classes consisting of functional class members and previously unrelated stimuli. On the first test, MTS training stimuli that had been associated with the same reinforcers as functional classes were presented as novel simple discrimination trials in sessions in which one functional class was designated as positive. Both Rio and Rocky correctly chose the stimulus that shared a common reinforcer with the positive functional class on 16 of the 18 novel transfer trials (binomial test, $p < .01$). On the second test, the training stimuli and functional classes were combined into novel conditional discriminations. Rio and Rocky both correctly matched the training stimuli with the functional class member

sharing a common reinforcer on 129 of the 132 transfer trials (binomial test, $p < .01$). Performance on novel trials was not different from performance on familiar baseline trials (Rio scored 72 of 72 on baseline trials; Rocky scored 68 of 72; Fisher's exact test, $p > .05$). Both of these tests provide strong evidence that stimuli associated with a common reinforcer can become equivalence class members. This effect was strong and immediate, with appropriate classification occurring 99% of the time on novel transfer trials.

These results show that 2 California sea lions formed equivalence classes following experience with class-specific reinforcement. Thus, our findings support and add to previous work by Schusterman and Kastak (1993, 1998) that demonstrated equivalence classification by a California sea lion in the absence of class-specific reinforcement. The completion of these studies with California sea lions provides the strongest available evidence of equivalence in nonhuman subjects. The immediate transfer of controlling stimulus relations between functional classes and more traditional equivalence classes suggests that the two classification schemes may comprise the same cognitive-behavioral process, that is, that functional classes *are* equivalence classes. These findings bolster Vaughan's (1988) view of stimulus classification and are consistent with the results of Sidman et al. (1989) and Sidman (1994) for 2 of the 3 human subjects tested with a similar procedure. These findings also support the interpretations of Schusterman and Kastak (1998), who found transfer of equivalence classes to functional classes, by showing the bidirectionality of this transfer.

The transfer of stimulus function solely through relations with common reinforcers supports Sidman's answer to the question, "Where do equivalence relations come from?" He has proposed that equivalence relations arise directly from the reinforcement contingency (Sidman, 2000). A key consideration in his expanded equivalence model is the inclusion of responses and reinforcers as potential equivalence class members. Responses and reinforcers enter into equivalence relations directly, through the contingencies that connect one or more stimuli to a defined response and then a defined reinforcer. Consequently, when responses and re-

inforcers are the same for all contingencies, the differentiation of stimuli into equivalence classes may be hindered. Conversely, equivalence relations may arise more easily between stimuli when responses or reinforcers are contingency specific. Within this expanded model, stimuli that share common responses or reinforcers can become equivalent in much the same way that stimuli related to one another become equivalent.

This theory is testable, and the current study provides at least two lines of empirical evidence in its support. In all of the experiments that included shared stimulus relations as well as class-specific reinforcers, the role of the reinforcers in our subjects' performance was best explained by the idea that they functioned as members of an equivalence class (Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989; Sidman, 1994, 2000). As class members, reinforcers could serve to strengthen new equivalence relations that arise between stimuli through common stimulus-reinforcer relations. Thus, in Experiment 3, equivalence relations emerged between stimuli that were linked through intermediate stimuli as well as through specific reinforcers. However, if reinforcers can act as fully functioning class members, then it follows that class-specific reinforcers alone should be sufficient to induce equivalence relations to emerge between stimuli. The results of tests pairing functional class members with other stimuli related *only* through shared reinforcers indicate that specific reinforcers did function as class members in our experiments.

GENERAL DISCUSSION

The present experiments show that 2 California sea lions organized perceptually different stimuli into equivalence classes on the basis of common functional relations and reinforcers. The classes that emerged were robust, transferring readily from one procedure to another. The equivalence relations formed within the simple discrimination reversal procedure were maintained and even expanded across procedures to a conditional discrimination task. Most significantly, the expanded classes formed by the 2 sea lions met the formal criteria of stimulus equivalence classes. Thus, this study supports Vaughan's (1988) proposition that functional classes generated

in simple discrimination reversal procedures are the same as equivalence classes generated through MTS procedures. In addition, our results are consistent with Sidman's (1994, 2000) expanded theory of equivalence relations, which includes responses and reinforcers as potential class members and allows the demonstration of equivalence beyond the traditional, mathematically derived framework of stimulus equivalence (Sidman & Tailby, 1982).

Based on the evidence provided by this and other studies, we agree that equivalence classes should be disentangled from the restrictive procedural definitions imposed by a mathematically based characterization. Given an expanded theoretical framework, emergent stimulus relations demonstrated in a variety of experimental contexts may also comprise equivalence relations. This idea is supported by work with human subjects showing that relations that emerge between stimuli sharing ordinal positions in sequence training also meet the traditional criteria of equivalence classes (Sigurdardottir, Green, & Saunders, 1990). Sequence training conducted with nonhuman species in tasks requiring control by ordinal positions or discrimination of sequential sign classes likely depends on similar proximal mechanisms (see Chen *et al.*, 1997; Schusterman & Gisiner, 1997). Given the overlap of many stimulus control concepts with the expanded theory of equivalence relations, it is clear that concepts such as functional classification, ordinal knowledge, mediated generalization, non-similarity-based classification, acquired equivalence of cues, and symbolic representation require reevaluation in light of the expanded model of stimulus equivalence.

The incorporation of class-specific reinforcers into our experimental design appeared to be a key element in the sea lions' successful classification performance. From an ethological standpoint, interactions with a variety of environmental signals, including individuals, objects, and events, result in specific consequences. Reinforcement contingencies that give rise to equivalencies may enable individuals to behave adaptively in the presence of disparate signals, to recognize objects across the senses, and to rapidly acquire natural categories. Such categories are subject to contextual control (Bush, Sidman, & de Rose,

1989) and as flexible constructs, they are likely to be useful in facilitating the conceptual organization of predator-prey relations as well as social relations based on variables such as activity, age, gender, kin, friendships, and rivalries (Schusterman & Kastak, 1998; Schusterman, Reichmuth, & Kastak, 2000).

The fact that humans with and without language skills and at least one nonhuman species have demonstrated equivalence suggests that processes for classifying perceptually different stimuli are relatively fundamental. We believe that given the appropriate testing conditions, equivalence can be demonstrated in a variety of animals. Further investigation with different species and procedures that establish emergent relations among stimuli, responses, and reinforcers will be necessary to determine whether this is the case.



REFERENCES

- Balsam, P. D. (1988). Selection, representation, and equivalence of controlling stimuli. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology: Vol. 2. Learning and cognition* (2nd ed., pp. 111-166). New York: Wiley.
- Bush, K. M., Sidman, M., & de Rose, T. (1989). Contextual control of emergent equivalence relations. *Journal of the Experimental Analysis of Behavior*, *51*, 29-45.
- Carr, D., Wilkinson, K. M., Blackman, D., & McIlvane, W. J. (2000). Equivalence classes in individuals with minimal verbal repertoires. *Journal of the Experimental Analysis of Behavior*, *74*, 101-114.
- Chen, S., Swartz, K. B., & Terrace, H. S. (1997). Knowledge of the ordinal position of list items in rhesus monkeys. *Psychological Science*, *8*, 80-86.
- D'Amato, M. R., Salmon, D. P., Loukas, E., & Tomie, A. (1985). Symmetry and transitivity of conditional relations in monkeys (*Cebus apella*) and pigeons (*Columba livia*). *Journal of the Experimental Analysis of Behavior*, *44*, 35-47.
- Delius, J. D., Jitsumori, M., & Siemann, M. (2000). Stimulus equivalencies through discrimination reversals. In C. Heyes & R. Huber (Eds.), *The evolution of cognition* (pp. 103-122). Cambridge, MA: MIT Press.
- Dube, W. V., Callahan, T. D., & McIlvane, W. J. (1993). Serial reversals of concurrent auditory discriminations in rats. *The Psychological Record*, *43*, 429-440.
- Dube, W. V., McIlvane, W. J., Callahan, T. D., & Stoddard, L. T. (1993). The search for stimulus equivalence in nonverbal organisms. *The Psychological Record*, *43*, 761-778.
- Dube, W. V., McIlvane, W. J., Maguire, R. W., Mackay, H. A., & Stoddard, L. T. (1989). Stimulus class formation and stimulus-reinforcer relations. *Journal of the Experimental Analysis of Behavior*, *51*, 65-76.
- Fields, L., & Nevin, J. A. (1993). Stimulus equivalence [special issue]. *The Psychological Record*, *43*.
- Goeters, S., Blakely, E., & Poling, A. (1992). The differ-

- ential outcomes effect. *The Psychological Record*, 42, 389–411.
- Hayes, S. C. (1989). Nonhumans have not yet shown stimulus equivalence. *Journal of the Experimental Analysis of Behavior*, 51, 385–392.
- Horne, P. J., & Lowe, C. F. (1996). On the origins of naming and other symbolic behavior. *Journal of the Experimental Analysis of Behavior*, 65, 185–241.
- Horne, P. J., & Lowe, C. F. (1997). Toward a theory of verbal behavior. *Journal of the Experimental Analysis of Behavior*, 68, 271–296.
- Kastak, D., & Schusterman, R. J. (1994). Transfer of visual identity matching-to-sample in two California sea lions (*Zalophus californianus*). *Animal Learning & Behavior*, 22, 427–435.
- Keller, F. S., & Schoenfeld, W. N. (1950). *Principles of psychology*. New York: Appleton-Century-Crofts.
- Lazar, R. (1977). Extending sequence-class membership with matching to sample. *Journal of the Experimental Analysis of Behavior*, 27, 381–392.
- Manabe, K., Kawashima, T., & Staddon, J. E. R. (1995). Differential vocalization in budgerigars: Towards an experimental analysis of naming. *Journal of the Experimental Analysis of Behavior*, 63, 111–126.
- Meehan, E. F. (1999). Class-consistent differential reinforcement and stimulus class formation in pigeons. *Journal of the Experimental Analysis of Behavior*, 72, 97–115.
- Riess, B. F. (1940). Semantic conditioning involving the galvanic skin reflex. *Journal of Experimental Psychology*, 36, 143–152.
- Schenk, J. J. (1994). Emergent relations of equivalence generated by outcomes-specific consequences in conditional discriminations. *The Psychological Record*, 44, 537–558.
- Schusterman, R. J., & Gisiner, R. C. (1997). Pinnipeds, porpoises, and parsimony: Animal language research viewed from a bottom-up perspective. In R. W. Mitchell, N. S. Thompson, & H. L. Miles (Eds.), *Anthropomorphism, anecdotes, and animals* (pp. 370–382). Albany: SUNY Press.
- Schusterman, R. J., & Kastak, D. (1993). A California sea lion (*Zalophus californianus*) is capable of forming equivalence relations. *The Psychological Record*, 43, 823–839.
- Schusterman, R. J., & Kastak, D. (1998). Functional equivalence in a California sea lion: Relevance to animal social and communicative interactions. *Animal Behaviour*, 55, 1087–1095.
- Schusterman, R. J., Reichmuth, C. J., & Kastak, D. (2000). How animals classify friends and foes. *Current Directions in Psychological Science*, 9, 1–6.
- Sidman, M. (1994). *Equivalence relations and behavior: A research story*. Boston: Authors Cooperative.
- Sidman, M. (2000). Equivalence relations and the reinforcement contingency. *Journal of the Experimental Analysis of Behavior*, 74, 127–146.
- Sidman, M., Rauzin, R., Lazar, R., Cunningham, S., Tailby, W., & Carrigan, P. (1982). A search for symmetry in the conditional discrimination of rhesus monkeys, baboons and children. *Journal of the Experimental Analysis of Behavior*, 37, 23–34.
- Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior*, 37, 5–22.
- Sidman, M., Wynne, C. K., Maguire, R. W., & Barnes, T. (1989). Functional classes and equivalence relations. *Journal of the Experimental Analysis of Behavior*, 52, 261–274.
- Sigurdardottir, Z. G., Green, G., & Saunders, R. R. (1990). Equivalence classes generated by sequence training. *Journal of the Experimental Analysis of Behavior*, 53, 47–63.
- Skinner, B. F. (1935). The generic nature of the concepts of stimulus and response. *Journal of General Psychology*, 12, 40–65.
- Tomonaga, M. (1999). Establishing functional classes in a chimpanzee (*Pan troglodytes*) with a two-item sequential-responding procedure. *Journal of the Experimental Analysis of Behavior*, 72, 57–79.
- Vaughan, W., Jr. (1988). Formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 14, 36–42.
- von Fersen, L., & Delius, J. D. (2000). Acquired equivalences between auditory stimuli in dolphins (*Tursiops truncatus*). *Animal Cognition*, 3, 79–83.
- Wasserman, E. A., & DeVolder, C. L. (1993). Similarity and nonsimilarity-based conceptualization in children and pigeons. *The Psychological Record*, 43, 779–793.
- Wasserman, E. A., DeVolder, C. L., & Coppage, D. J. (1992). Non-similarity-based conceptualization in pigeons via secondary or mediated generalization. *Psychological Science*, 3, 374–379.
- Wulfert, E., & Hayes, S. C. (1988). Transfer of a conditional ordering response through conditional equivalence classes. *Journal of the Experimental Analysis of Behavior*, 50, 125–144.
- Zentall, T. R. (1998). Symbolic representation in animals: Emergent stimulus relations in conditional discrimination learning. *Animal Learning & Behavior*, 26, 363–377.

Received September 20, 2000
Final acceptance June 9, 2001

APPENDIX A

The test-trial configurations and baseline trials used in each phase of Experiment 2 are shown. Each row shows two test trials and corresponding alternate choices.

| Transfer test | Test stimuli | Test trials (Sample r S+) | Alternate choices (S-) | Baseline trials |
|---------------|---------------------------------------|--|--|---|
| 1 | E, I 4, 8 | ErI, IrE 4r8, 8r4 | 4, 8 E, I | MTS Training Sets 1, 2, 3, and 4 |
| 2 | B, H 2, 10 | BrH, HrB 2r10, 10r2 | 10, 2 B, H | MTS Training Sets 1 and 2, Transfer Test 1 relations |
| 3 | A, J 7, 9 | ArJ, JrA 7r9, 9r7 | 9, 7 A, J | MTS Training Sets 1 and 2, Transfer Tests 1 and 2 relations |
| 4 | E, I, B, H, A, J 4, 8, 2, 10, 7, 9 | ErH, HrE ErB, BrE ErJ, JrE ErA, ArE JrH, HrI IrB, BrI IrJ, JrI IrA, ArI BrA, ArB BrJ, JrB HrA, ArH HrJ, JrH 4r2, 2r4 4r10, 10r4 4r7, 7r4 4r9, 9r4 8r2, 2r8 8r10, 10r8 8r7, 7r8 8r9, 9r8 2r7, 7r2 2r9, 9r2 10r7, 7r10 10r9, 9r10 | 7, 9 9, 7 10, 2 2, 10 7, 9 9, 7 10, 2 2, 10 4, 8 8, 4 4, 8 8, 4 A, J J, A B, H H, B A, J J, A H, B B, H E, I I, E E, I I, E | MTS Training sets 1 and 2, Transfer Tests 1, 2, and 3 relations |
| 5 | C, D, F, G 1, 3, 5, 6 | CrD, DrC CrF, FrC CrG, GrC DrF, FrD DrG, GrD FrG, GrF 1r3, 3r1 1r5, 5r1 1r6, 6r1 3r5, 5r3 3r6, 6r3 5r6, 6r5 | 3, 6 1, 5 5, 3 6, 3 5, 1 1, 6 G, C F, D C, F D, F G, C D, G | MTS Training Sets 1 and 2, Transfer Tests 1, 2, 3, and 4 relations |
| 6 | A through J 1 through 10 | CrA, ArC CrB, BrC CrE, ErC CrH, HrC CrI, IrC CrJ, JrC DrA, ArD DrB, BrD DrE, ErD DrH, HrD DrI, IrD DrJ, JrD FrA, ArF FrB, BrF | 10, 4 1, 3 4, 6 8, 4 9, 3 10, 7 9, 5 4, 6 7, 10 1, 8 7, 4 8, 3 9, 5 9, 3 | MTS Training Sets 1 and 2, Transfer Tests 1, 2, 3, 4, and 5 relations |

APPENDIX A

(Continued)

| Transfer test | Test stimuli | Test trials (Sample r S+) | Alternate choices (S-) | Baseline trials |
|-------------------|--------------|------------------------------|---------------------------|-----------------|
| | | FrE, ErF | 7, 2 | |
| | | FrH, HrF | 6, 2 | |
| | | FrI, IrF | 10, 3 | |
| | | FrJ, JrF | 9, 1 | |
| | | GrA, ArG | 6, 2 | |
| | | GrB, BrG | 9, 3 | |
| | | GrE, ErG | 7, 6 | |
| | | GrH, HrG | 6, 2 | |
| | | GrI, IrG | 8, 5 | |
| | | GrJ, JrG | 6, 8 | |
| | | 1r2, 2r1 | D, F | |
| | | 1r4, 4r1 | B, A | |
| | | 1r7, 7r1 | I, F | |
| | | 1r8, 8r1 | J, G | |
| | | 1r9, 9r1 | H, J | |
| | | 1r10, 10r1 | D, J | |
| | | 3r2, 2r3 | C, D | |
| | | 3r4, 4r3 | I, F | |
| | | 3r7, 7r3 | C, H | |
| | | 3r8, 8r3 | C, I | |
| | | 3r9, 9r3 | I, E | |
| | | 3r10, 10r3 | E, A | |
| | | 5r2, 2r5 | J, E | |
| | | 5r4, 4r5 | F, C | |
| | | 5r7, 7r5 | G, J | |
| | | 5r8, 8r5 | F, H | |
| | | 5r9, 9r5 | J, C | |
| | | 5r10, 10r5 | J, G | |
| | | 6r2, 2r6 | D, A | |
| | | 6r4, 4r6 | C, B | |
| | | 6r7, 7r6 | G, B | |
| | | 6r8, 8r6 | G, H | |
| | | 6r9, 9r6 | B, C | |
| | | 6r10, 10r6 | F, E | |
| Total test trials | | 180 | | |

APPENDIX B

The MTS test-trial configurations and baseline trials used in the first part of Experiment 3 (expansion of functional classes through stimulus-mediated equivalence relations) are shown. Each row shows two test trials and corresponding alternate choices.

| Training and testing phases | Train/test trials (Sample r S+) | Alternate choices (S-) | Baseline trials |
|-----------------------------|--|---|--|
| Forward training | JrK 10r11 | 11 K | MTS Training Sets 1 and 2 A-J 1-10 |
| Symmetry training | KrJ 11r10 | 10 J | |
| Combined training | JrK, KrJ 10r11, 11r10 | 11, 10 K, J | |
| Transfer testing | ArK, KrA BrK, KrB CrK, KrC DrK, KrD ErK, KrE FrK, KrF GrK, KrG HrK, KrH JrK, KrI 1r11, 11r1 2r11, 11r2 3r11, 11r3 4r11, 11r4 5r11, 11r5 6r11, 11r6 7r11, 11r7 8r11, 11r8 9r11, 11r9 | 11, 9 11, 6 11, 5 11, 2 11, 4 11, 1 11, 8 11, 3 11, 7 K, H K, F K, D K, C K, G K, I K, A K, E K, B | MTS Training Sets 1 and 2 A-J 1-10 K and 11 training trials |
| Total test trials | 36 | | |

APPENDIX C

The MTS test-trial configurations and baseline trials used in the final part of Experiment 3 (expansion of functional classes through reinforcer-mediated equivalence relations) are shown. Each row shows two test trials and corresponding alternate choices.

| Test stimuli | Test trials (Sample r S+) | Alternate choices (S-) | Baseline trials |
|--|------------------------------|------------------------------|--|
| A-K with MTS Training Stimuli 1A, 1B, 1C | 1ArA, Ar1A | 4, 2A | MTS Training Sets 1 and 2 A-K 1-11 |
| | 1ArB, Br1A | 9, 2A | |
| | 1ArC, Cr1A | 5, 2A | |
| 1-11 with MTS Training Stimuli 2A, 2B, 2C | 1ArD, Dr1A | 3, 2A | |
| | 1ArE, Er1A | 1, 2A | |
| | 1ArF, Fr1A | 11, 2A | |
| | 1ArG, Gr1A | 8, 2A | |
| | 1ArH, Hr1A | 6, 2A | |
| | 1ArI, Ir1A | 2, 2A | |
| | 1ArJ, Jr1A | 7, 2A | |
| | 1ArK, Kr1K | 10, 2A | |
| | 1BrA, Ar1B | 2, 2B | |
| | 1BrB, Br1B | 1, 2B | |
| | 1BrC, Cr1B | 11, 2B | |
| | 1BrD, Dr1B | 7, 2B | |
| | 1BrE, Er1B | 8, 2B | |
| | 1BrF, Fr1B | 9, 2B | |
| | 1BrG, Gr1B | 4, 2B | |
| | 1BrH, Hr1B | 10, 2B | |
| | 1BrI, Ir1B | 3, 2B | |
| | 1BrJ, Jr1B | 6, 2B | |
| | 1BrK, Kr1B | 5, 2B | |
| | 1CrA, Ar1C | 1, 2C | |
| | 1CrB, Br1C | 11, 2C | |
| | 1CrC, Cr1C | 8, 2C | |
| | 1CrD, Dr1C | 2, 2C | |
| | 1CrE, Er1C | 7, 2C | |
| | 1CrF, Fr1C | 10, 2C | |
| | 1CrG, Gr1C | 6, 2C | |
| | 1CrH, Hr1C | 4, 2C | |
| | 1CrI, Ir1C | 5, 2C | |
| | 1CrJ, Jr1C | 9, 2C | |
| | 1CrK, Kr1C | 3, 2C | |
| | 2Ar1, 1r2A | B, 1A | |
| | 2Ar2, 2r2A | F, 1A | |
| | 2Ar3, 3r2A | K, 1A | |
| 2Ar4, 4r2A | E, 1A | | |
| 2Ar5, 5r2A | J, 1A | | |
| 2Ar6, 6r2A | A, 1A | | |
| 2Ar7, 7r2A | G, 1A | | |
| 2Ar8, 8r2A | D, 1A | | |
| 2Ar9, 9r2A | I, 1A | | |
| 2Ar10, 10r2A | C, 1A | | |
| 2Ar11, 11r2A | H, 1A | | |
| 2Br1, 1r2B | A, 1B | | |
| 2Br2, 2r2B | J, 1B | | |
| 2Br3, 3r2B | F, 1B | | |
| 2Br4, 4r2B | G, 1B | | |
| 2Br5, 5r2B | C, 1B | | |
| 2Br6, 6r2B | E, 1B | | |
| 2Br7, 7r2B | D, 1B | | |
| 2Br8, 8r2B | I, 1B | | |
| 2Br9, 9r2B | K, 1B | | |
| 2Br10, 10r2B | H, 1B | | |
| 2Br11, 11r2B | B, 1B | | |

APPENDIX C

(Continued)

| Test stimuli | Test trials (Sample r S+) | Alternate choices (S-) | Baseline trials |
|-------------------|------------------------------|------------------------------|-----------------|
| | 2Cr1, 1r2C | B, 2C | |
| | 2Cr2, 2r2C | I, 2C | |
| | 2Cr3, 3r2C | A, 2C | |
| | 2Cr4, 4r2C | K, 2C | |
| | 2Cr5, 5r2C | E, 2C | |
| | 2Cr6, 6r2C | D, 2C | |
| | 2Cr7, 7r2C | G, 2C | |
| | 2Cr8, 8r2C | C, 2C | |
| | 2Cr9, 9r2C | J, 2C | |
| | 2Cr10, 10r2C | F, 2C | |
| | 2Cr11, 11r2C | 1A, 2C | |
| Total test trials | 132 | | |