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THE EFFECTS OF DIFFERENTIAL TRAINING PROCEDURES ON LINKED PERCEPTUAL CLASS FORMATION

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When the stimuli in one perceptual class (A`) become related to the stimuli in another perceptual class (B`), the two are functioning as a single *linked perceptual class.* A common linked perceptual class would be the sounds of a person's voice (class A`) and the pictures of that person (class B`). Such classes are ubiquitous in real world settings. We describe the effects of a variety of training procedures on the formation of these classes. The results could account for the development of naturally occurring linked perceptual classes. Two perceptual classes (A` and B`) were formed in Experiment 1. The endpoints of the A` class were called anchor (Aa) and boundary (Ab) stimuli. Likewise, the anchor and boundary stimuli in the B` class were represented as Ba and Bb. In Experiment 2, the A` and B` classes were linked by the establishment of one of four cross-class conditional discriminations: Aa→Ba, Aa→Bb, Ab→Ba, or Ab→Bb. Results were greatest after Aa→Bb training, intermediate after Aa→Ba and Ab→Ba training, and lowest after Ab→Bb training. Class formation was influenced by the interaction of the anchor/boundary values and the sample/comparison functions of the stimuli used in training. Experiment 3 determined whether class formation was influenced by different sets of two cross-class conditional discriminations: Aa→Ba and Ab→Bb, or Aa→Bb and Ab→Ba. Both conditions produced equivalent results. Similarities were attributable to the use of anchor stimuli as samples and boundary stimuli as comparisons in each training condition. Finally, the results after joint Aa→Ba and Ab→Bb training were much greater than those produced by summing the results of Aa→Ba training alone and Ab→Bb training alone. This same synergy was not observed after joint Aa→Bb and Ab→Ba training or either alone.

Key words: linked perceptual classes, conditional discrimination, cross-class probe, stimulus value, stimulus function, immediate and delayed emergence, keyboard responding, college students

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In real-world settings, the stimuli in one perceptual class (A`) can, and usually do, become related to stimuli in at least one other perceptual class (B`). For example, the many sounds of a person's voice (the members of the A` class) become related to the different pictures of the same person (the members of the B` class). The relations between the voices and pictures would be documented when many of the sounds of the voice occasion the selection of many of the pictures in the related class and do not occasion the selection of pictures that are not members of the same pictorial class, and vice versa. Thus, the mutual selection of the stimuli in two perceptual classes demonstrates the emergence of a linked perceptual class, represented as A`-B` (Fields et al., 2005; Fields, Matneja, et al., 2002; Fields & Reeve, 2001).

The linked perceptual class in the prior example was cross-modal because stimuli were drawn from different sensory modalities (i.e., auditory and visual). Linked perceptual classes, however, can consist of stimuli from two classes in the same sensory modality. For example, if the many pictures of an airplane (one visually based class) and the name of the plane written in a variety of English fonts (another visually based class) occasion the mutual selection of each other, they would constitute an intra- or unimodal linked perceptual class (Bahrick & Pickens, 1994; Fields & Reeve, 2001; Fields, Matneja, et al., 2002).

These examples suggest the ubiquity of linked perceptual classes in natural settings, but linked perceptual classes have been considered in only three published studies.

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In a conceptual paper, Fields and Reeve (2001) described how linked perceptual classes were related to perceptual classes, equivalence classes, and generalized equivalence classes. They argued that a linked perceptual class is a type of generalized equivalence class, and also introduced terminology to characterize the stimuli and relations among the stimuli in a linked perceptual class.

Fields and Reeve (2001) referred to the cues that are the endpoints of a perceptual class as the anchor and boundary stimuli. The anchor stimulus is the most salient stimulus in a class and the boundary stimulus is the stimulus most removed along a dimension from the anchor stimulus that still functions as a member of the class; it is the most ambiguous member of the class. For perceptual class A`, the anchor and boundary stimuli are represented symbolically as Aa and Ab, respectively. A third cue in a class is referred to as the midpoint stimulus. For the A` class, the midpoint stimulus is represented symbolically as Am.

After the establishment of at least one conditional discrimination between one stimulus from an A` class and one stimulus from a B` class, the evaluation of class formation involves the presentation of 18 cross-class probes that can be derived from all combinations of the anchor, midpoint, and boundary stimuli from the two classes. Nine probes are presented in an A`–B` format (Aa–Ba, Am–Ba, Ab–Ba, Aa–Bm, Am–Bm, Ab–Bm, Aa–Bb, Am–Bb, and Ab–Bb) and the remaining 9 are presented in a B`–A` format (Ba–Aa, Bm–Aa, Bb–Aa, Ba–Am, Bm–Am, Bb–Am, Ba–Ab, Bm–Ab, and Bb–Ab). These 18 cross-class probes assess the emergence of untrained relations among the members of two perceptual classes. The occurrence of class-consistent selections by the cross-class probes would document the formation of a linked perceptual class.

In the first empirical paper, Fields, Matneja, et al. (2002) demonstrated that the cross-class probes described above tracked the emergence of new relations among the stimuli in two perceptual classes and, thus, the formation of linked perceptual classes. In some cases, probe repetition resulted in the delayed emergence of the linked perceptual classes. The second empirical paper (Fields et al., 2005) noted that the cross-class probes could be presented in many different orders, each of which was called a testing schedule. Fields et al. (2005) studied the effect of four different testing schedules on the formation of linked perceptual classes, each of which was used with a different group of subjects. In all groups, the A` and B` classes were linked by the establishment of Aa–Ba and Ab–Bb conditional discriminations. At the completion of training, class formation was tracked with a different testing schedule. The 2/9 schedule involved the presentation of two serially presented test blocks, each of which contained nine different probes. The 6/3 schedule involved the serial presentation of six test blocks, each of which contained three different probes. The 18/1-RND schedule involved the serial presentation of 18 blocks, where each contained one probe. The type of probe, however, was randomized across blocks. Finally, the 18/1-PRGM schedule also involved the serial presentation of 18 blocks, but the probe presented in each block differed systematically from the probes presented in the adjacent test blocks. For example, if one block contained Aa–Bm, the next block contained Aa–Bb, where the only change was the value of the comparison and the change involved the introduction of a comparison in the latter probe that was only one step removed from the comparison used in the former probe. Only 50% of the classes emerged when testing was conducted with the first three schedules. In contrast, more than 90% of classes formed when testing was conducted with the 18/1-PRGM schedule. Thus, testing schedule had a large effect on the formation of linked perceptual classes.

As noted above, only one mode of training was used to establish linked perceptual classes by subjects in all four groups in Fields et al. (2005). Just as there are many testing schedules that can track the emergence of linked perceptual classes, myriad conditional discriminations can be established to link two separate perceptual classes. Many studies have shown that parameters of training have influenced the formation of perceptual classes (Bhatt, Wasserman, Reynolds, & Knauss, 1988; Malott & Sidall, 1972; Pluchino, 1997; Reeve & Fields, 2001; Wasserman, Kiedinger, & Bhatt, 1988; Wright, Cook, Rivera, Sands, & Delius, 1988) and equivalence classes (Adams, Fields, & Verhave, 1993a; Arntzen & Holth, 2000a, 2000b; Buffington, Fields, & Adams, 1997). Thus, in what we report here, one experiment was conducted to induce four perceptual classes, and two subsequent experiments used those perceptual classes to determine how different modes of training influenced the immediate and delayed emergence of linked perceptual classes.

Experiment 1 induced a generalized categorization repertoire that led subjects to spontaneously categorize stimuli into two perceptual classes in each of two novel domains, Domain A and Domain B. The classes that emerged in Experiment 1 (A1`, A2`, B1`, and B2`) then were used in Experiment 2. Experiment 2 explored the immediate and delayed emergence of linked perceptual classes after training that utilized only one of four single conditional discriminations (Aa→Ba, Ab→Bb, Aa→Bb, and Ab→Ba) to link the A` and B` classes. Experiment 3 explored the immediate and delayed emergence of linked perceptual classes after training in which two different pairs of conditional discriminations were used during training to link the A` and B` classes. The results obtained in Experiments 2 and 3 illustrated how the effects of training two conditional discriminations could be accounted for by the (a) combined effects of training the conditional discriminations alone and (b) values of the sample and comparison stimuli in the conditional discriminations used to link the two perceptual classes.

EXPERIMENT 1

Perceptual classes, like those that are components of a linked perceptual class, can be established by multiple exemplar training (Barnes & Keenan, 1993; Fields, Reeve, et al., 2002; Reeve & Fields, 2001; Wright et al., 1988), or can emerge without any direct training (Fields, Reeve, et al., 2002). In the latter case, the perceptual classes would be spontaneously emergent. Fields, Reeve, et al. (2002) found that the spontaneous categorization of stimuli into two perceptual classes could be induced by the prior establishment of a generalized categorization repertoire. This procedure was used in Experiment 1 and led to the spontaneous categorization of stimuli into two perceptual classes in each of two novel stimulus domains: Domain A and Domain B. These perceptual classes, A1`, A2`, B1`, and B2`, then were used in Experiments 2 and 3 to form linked perceptual classes.

Method

Participants

Participants were 48 undergraduate students enrolled in a course in advanced experimental psychology taught at Queens College/CUNY. Although all subjects finished Experiment 1, 2 dropped out of the subsequent phases of the research that involved participation in Expeirments 2 or 3. Thus, we reported the data for the 46 who continued in the research and completed their participation in Experiments 2 or 3. The students reported no familiarity with the research area and had not participated in prior experiments in our laboratory. Upon completion of the experiment, students received course credit from their instructors. The experiment was completed in a single session that varied in duration from 1 to 1.5 hr.

Apparatus and Stimuli

The experiment was conducted with an IBM-compatible computer that displayed all stimuli on a 15'' color monitor. Responses consisted of touching specific keys on a standard QWERTY keyboard. The experiment was controlled by custom software that programmed all stimulus presentations and recorded all keyboard responses.

All stimuli were presented in 5 × 5 cm colored squares without a contrasting border on the computer monitor against a black background. Sets of English words were used for keyboard familiarization. Pictorial stimuli from six domains were used for preliminary training and the main part of the experiment, and are illustrated in Figure 1. The stimuli were presented to subjects as multicolored RGB 24-bit images.

Domains W, X, Y, Z, A, and B are referred to as Female–Male, Abstract Pictures, Truck–Car, North Korea–Germany, Tree–Cat, and Haiti–California, respectively. The stimuli in the North Korea–Germany and Haiti–California domains were banded elevation satellite images of 100 km × 100 km of the indicated geographical regions. In these images, elevation is represented by a color gradient.

The stimuli that are the endpoints (anchor stimuli) of each domain are depicted in rows 1a and 2a in Figure 1. Stimuli that varied systematically between the endpoints of each domain were created with a commercially

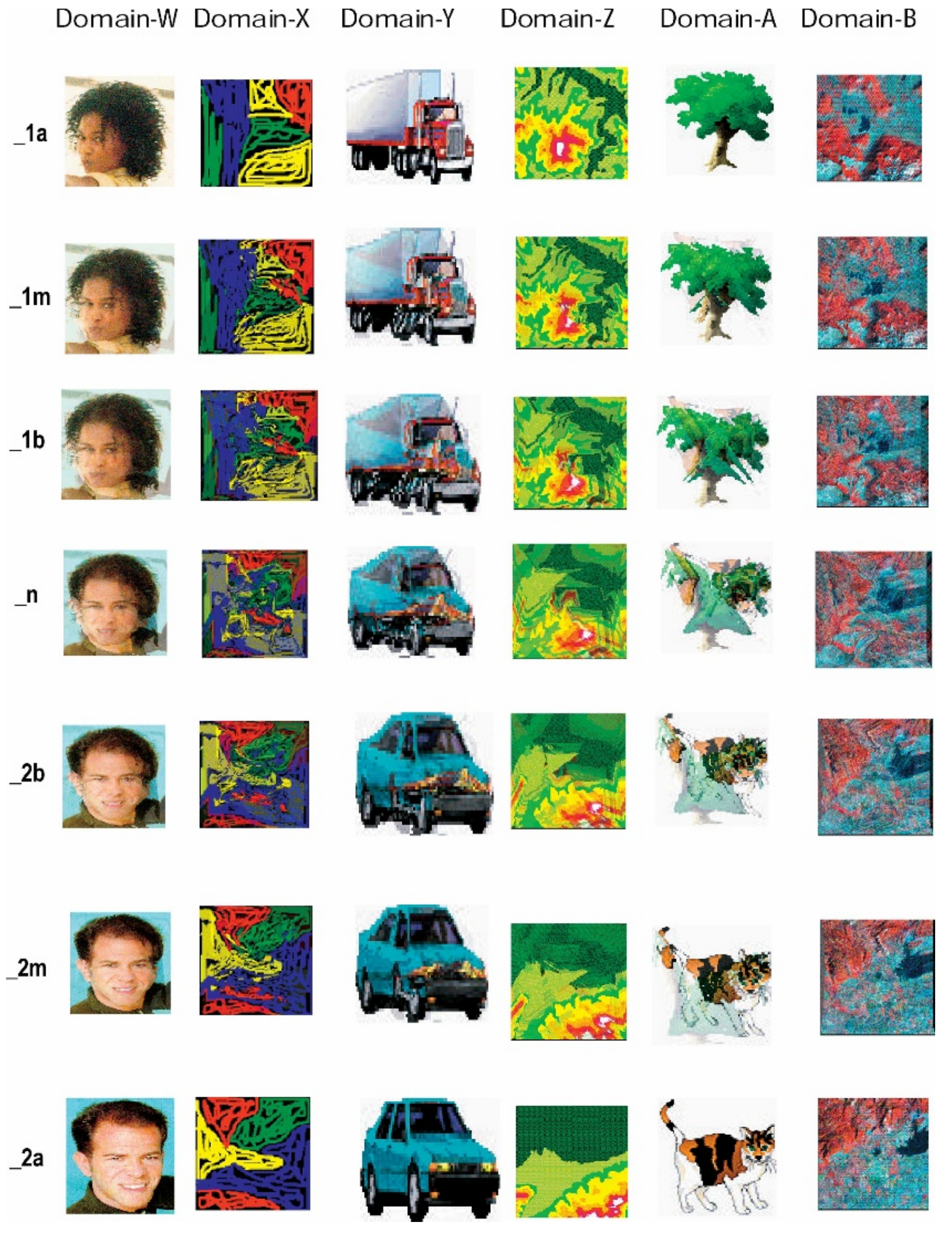

Fig. 1. The anchor, midpoint, boundary, and neither used as stimuli in Experiment 1. The stimuli in Domains W, X, Y and Z (see columns 1 through 4) were used in preliminary training, whereas those in Domains A and B (see columns 5 and 6) were used in the remainder of the experiment. The endpoints of Domains W, X, Y, Z, A, and B were images of a male and a female face, two abstract pictures, a truck and a car, banded-elevation satellite images of areas of North Korea and Germany, a tree and a cat, and banded-elevation satellite images of areas of Haiti and California, respectively. These endpoint stimuli were unmorphed images and are depicted in rows _1a and _2a. The endpoint stimuli in rows _1a

available morphing software program (Figuracion, 1998). Called variants, these intermediate stimuli in a domain were produced by superimposing the endpoint stimuli and changing their relative saliences. Each variant was assigned a unit value that indicated its relative position along a continuous program-generated dimension.

For stimuli in Domains W, X, Y, Z, and B, the software assigned values 000 and 500 to the endpoint stimuli and generated 498 variants between these endpoints. The variants used in the experiment had unit values of 030, 070, 100, 130, 170, 210, 250, 280, 310, 340, 370, 390, 430, and 470. For stimuli in Domain A, the software assigned unit values 00 and 50 to the endpoint stimuli and generated 49 variants between these endpoints. The variants used in the experiment had unit values of 03, 06, 09, 12, 15, 18, 21, 25, 28, 31, 34, 37, 40, 43, and 47.

The variants at the ends of the domains that were assigned the lowest and highest unit values were designated as members of Classes 1 and 2, respectively. For each class, the endpoint was referred to as its anchor (a) stimulus. Thus, the anchor stimuli in Classes 1 and 2 in Domain W were designated W1a and W2a. The anchor stimuli in Classes 1 and 2 for each domain are illustrated in the top and bottom rows of Figure 1. The variant most distant from the anchor stimulus of a class that was judged (see below for procedure) to be related to the anchor of that class was referred to as its boundary (b) stimulus. Thus, the boundary stimuli in Classes 1 and 2 in Domain W were designated as W1b and W2b, respectively. The boundary stimuli for Classes 1 and 2 for each domain are illustrated in rows 1b and 2b in Figure 1. The variant judged to be perceptually equidistant between the anchor and boundary of a class was referred to as its midpoint (m) stimulus. The midpoint stimuli in Classes 1 and 2 in Domain W were designated as W1m and W2m, respectively. The midpoint stimuli for Classes 1 and 2 for each domain are illustrated in rows 1m and 2m in Figure 1.

The variants between the boundaries of the two classes in a domain were not members of either class. Thus, the variant judged to be perceptually equidistant between the boundaries of the two classes in a domain was called the neither (n) stimulus for the domain (Adams, Fields, & Verhave, 1993b; Fields, Adams, Brown, & Verhave, 1993). For Domain W, the neither stimulus was designated as Wn and appears for each domain in row n in Figure 1.

The unit values assigned to the variants used as midpoint, boundary, and neither stimuli in Domains W through Z were defined by a group of independent observers using a bisection procedure. For a given domain, an observer was shown the anchor stimulus for Class 1 then asked to sort through the remaining variants and select the variant that was most distant from the anchor but was still related to that anchor. The unit value of that variant was then designated as the boundary stimulus for Class 1. The observer was then shown the anchor and boundary stimuli of Class 1 and asked to sort through the variants between them and select the variant that was perceptually equidistant from each. The unit value of that variant was the midpoint stimulus of Class 1. After doing the same for Class 2, the observer was presented with boundary stimuli from Classes 1 and 2 and asked to sort through the variants between the boundaries and select the variant that was equidistant from each. The

and _2a also are designated as the anchor stimuli in classes 1 and 2 in their respective domains. The midpoint and boundary stimuli for Class 1 of Domains W through Z are shown in rows _1m and _1b, respectively. The variants assigned as the neither stimuli in the domains are shown in row _n for Domains W through Z, respectively. The boundary, midpoint, and anchor stimuli in Class 2 in Domains W through Z are shown in rows _2b, _2m, and _2a, respectively. Variants in Domains A and B are illustrated in the last two columns. Variants that represent the midpoint and boundary stimuli in Domains A and B are illustrated in rows _1m and _1b for Class-1, and in rows _2m and _2b for Class 2, respectively. Variants that represent the neither stimuli in Domains A and B are illustrated in row n. The variants used to represent the midpoint, boundary, and neither stimuli in Domains A and B are illustrative only because the particular variants that served those functions were determined by each subject's performance in the three-choice generalization tests and thus were unique for each subject. The underscores in the row designators, _a, _m, _b, and _n, are place holders that are filled with the letter designating a domain. Thus, Wn would be the designation for the neither stimulus in Domain W.

unit value of that variant was the neither stimulus for that domain. The unit values selected by the five observers were averaged for each midpoint and each boundary stimulus for each class and domain and for the neither stimulus in a domain. The variants with these averaged values then were used as the midpoints and boundaries for classes 1 and 2 and as the neither stimulus for a domain and are the stimuli illustrated in rows 1m through 2m in Figure 1 for the Domains W, X, Y, and Z.

Figure 1 also shows variants that approximated the midpoints, boundaries, and neither stimuli in Domains A and B. These are approximations because the actual unit values assigned to these stimuli varied with each subject and were based on performances measured in Phase 3, as described below.

Procedure

Trial format and responses within a trial. All trials used a matching-to-sample format (Cumming & Berryman, 1965). A trial began when ''Press ENTER'' appeared on the screen. Pressing the enter key cleared the screen and displayed a sample stimulus at the top center of the monitor. Pressing the space bar displayed two comparison stimuli at the bottom left and right corners while the sample remained on the screen. During trials in which a third comparison stimulus was presented, the words ''If NEITHER press 4'' appeared between the two other comparisons. The comparison that was designated as belonging to the same class as the sample is referred to as a positive comparison (Co+) and the comparison that was designated as not belonging to the same class as the sample is referred to as the negative comparison (Co−).

During a trial, the left or right comparison stimulus was selected by pressing the 1 or 2 key, respectively. Pressing the 4 key was the response that selected the neither comparison stimulus, when it was available. A comparison selection cleared the screen and immediately displayed a feedback message centered on the screen. When informative feedback was scheduled, the messages ''RIGHT'' or ''WRONG'' appeared, depending on the accuracy of the comparison selection. The message remained on the screen until the R (for ''RIGHT'') or W (for ''WRONG'') key was pressed. During some training and all testing trials, uninformative feedback was scheduled following a comparison selection. This consisted of a dashed line on both sides of the letter E (- - E - -) that signaled the end of a trial. This cue remained on the screen until the participant pressed the E key, which was used as an observing response for the uninformative feedback. After an appropriate observing response, the screen was cleared, and the next trial began (Fields, Landon-Jimenez, Buffington, & Adams, 1995).

Trial block structure and feedback contingencies. Each phase was conducted with blocks of trials. In all phases, the trials in a block were presented in a randomized order without replacement. At the start of training, a block was presented repeatedly with informative feedback after each comparison selection until the trials within the block occasioned 100% correct responding. Thereafter, the percentage of trials in a block that occasioned informative feedback was reduced to 75%, 25%, and finally to 0%, as long as comparison selections on all trials were accurate.

During feedback reduction, the trials that were followed by informative feedback were randomly determined. Each block ended with the presentation of an on-screen message that said, ''Press ENTER to begin the next block.'' If 100% correct responding was not achieved within three blocks at a given feedback level during training, the participant was returned to the previous feedback level for the next block. In practice, this was a very infrequent occurrence.

Phase 1: Instructions and keyboard familiarization. Prior to the experiment, participants were presented with the following instructions on the screen:

> Thank you for volunteering to participate in this experiment. PLEASE DO NOT TOUCH ANY OF THE KEYS ON THE KEYBOARD YET! In this experiment you will be presented with many trials. Each trial contains three or four CUES. These will be familiar and unfamiliar picture images. YOUR TASK IS TO DISCOVER HOW TO RESPOND CORRECTLY TO THE CUES. Initially, there will also be INSTRUCTIONS that tell you how to respond to the cues, and LABELS that will help you to identify the cues on the screen. The labels and the instructions that tell you which KEYS to press will slowly disappear. Your task will be to RESPOND CORRECTLY to the CUES and the INSTRUCTIONS by pressing certain keys on

the computer's keyboard. The experiment is conducted in phases. When each phase ends, the screen will sometimes tell you how you did. If you want to take a break at any time, please call the experimenter.

All labels and instructional prompts were presented on the computer monitor and were deleted serially across trials. After pressing the space bar, participants were trained to emit the appropriate keyboard responses to complete a trial. Sixteen trials, each containing three English words, such as KING, QUEEN, and CAMEL, were presented. The semantic relatedness between the sample word (e.g., KING) and one of the comparisons (e.g., QUEEN) was used to prompt the selection of the correct comparison. The words RIGHT or WRONG followed each comparison selection (for additional details, see Fields et al., 1997).

Correct responding to the stimuli in a trial during Phase 1 also was facilitated by instructional prompts (e.g., ''Make your choice by pressing 1 or 2'' or ''Press the E key'') that were deleted in a serial manner across trials (see Fields et al.,1997, or Fields, Adams, Verhave, & Newman, 1990, for further details). Phase 1 ended once the stimuli were presented without prompts and performance was at least 88% accurate (14 of 16 correct trials) during a single block. In the remaining phases, whenever a participant pressed a nonexperimentally-defined key during a trial, the instruction that prompted the appropriate key press during Keyboard Familiarization (Phase 1) reappeared on the screen for three subsequent trials.

Phase 2: Generalized categorization repertoire: WXYZ(amb-a) training. In this phase, participants had to categorize the stimuli in Domains A and B into two functionally independent perceptual classes on a spontaneous basis. The spontaneous categorization of stimuli in these domains was ensured by the prior establishment of a generalized categorization repertoire. That repertoire was induced in Phase 2 by use of multiple-exemplar training with stimuli in Domains W through Z, as described by Fields, Reeve, et al. (2002).

Training began with stimuli in Domain W. The anchor, midpoint, and boundary stimuli from Classes 1 and 2 and the neither stimulus were presented as sample stimuli in a randomized order across trials in the training block. On all trials, the comparisons consisted of the pair of anchor stimuli and the neither comparison from the domain. Informative feedback (''RIGHT'' or ''WRONG'') was presented for the selection of W1a when either W1a, W1m, or W1b were the sample stimuli, the selection of W2a when either W2a, W2m, or W2b were the sample stimuli, and selection of the neither option when Wn was the sample. The training block was repeated until all trials occasioned correct comparison selections. Once completed, the procedure was repeated with the stimuli in Domains X, Y, and Z. The performances across stimulus domains demonstrated that the stimuli at each end of the domain occasioned the selection of the anchor stimulus from the same end of the domain, and the neither stimulus occasioned the selection of a comparison that was not at either end of the domain. Thus, this training procedure resulted in the formation of two functionally independent classes (Reeve & Fields, 2001) in each of the four domains.

Phase 3: Identifying emergent perceptual classes. Perceptual classes that emerge from Domains A and B were used in the main part of the experiment to form two linked perceptual classes. As mentioned in the Introduction, the stimuli from the A` and B` classes are used as samples and comparisons in the cross-class probes that track the formation of linked perceptual classes. Fields, Matneja, Varelas, and Belanich (2003) showed that the unit values of midpoint and boundary stimuli of a perceptual class can differ when they serve as sample or comparison stimuli. In this experiment, the unit values of midpoint and boundary stimuli used as samples were obtained from generalization tests conducted in variant-to-base tests. Similarly, the unit values of midpoint and boundary stimuli used as comparison stimuli were obtained from generalization tests conducted in the base-to-variant format

During the variant-to-base tests, each variant in a domain (e.g., Tree-Cat-00 through Tree-Cat-50) was presented as a sample stimulus on different trials. In addition, the anchor stimuli from that domain (e.g., Tree-Cat-00 and Tree-Cat-50) and the neither option were presented as comparisons on all trials. Contiguous variants at one end of the domain were considered to be members of a class if each of them occasioned the selection of the anchor stimulus at the same end of the domain on at least 88% of the generalization test trials. The boundary stimulus for that class was the variant most removed from the anchor that occasioned the selection of the anchor on at least 88% of the trials. The midpoint stimulus for a class was the variant that was numerically equidistant in value between the anchor and the boundary stimuli for a class. Thus, the results of these tests established the unit values for the midpoint and boundary stimuli that were used as sample stimuli.

During the base-to-variant tests, one of the anchor stimuli (e.g., Tree-Cat-00 or Tree-Cat-50) was presented as a sample on different trials. For each sample, the other anchor stimulus and the neither option were presented as two of the three comparisons on all trials. The third comparison on a trial was one of the variants. Different variants were presented on a random basis across trials. The members of a class were the contiguous variants that were selected in the presence of the anchor stimulus on at least 88% of the generalization test trials. The boundary stimulus for that class was the variant most removed from the anchor stimulus of that class. The midpoint stimulus for a class was the variant that was numerically equidistant in value between the anchor and the boundary stimuli for a class. Thus, the results of these tests established the unit values for the midpoint and boundary stimuli that were used as comparison stimuli.

The variant-to-base and base-to-variant tests were conducted in separate blocks of trials, each of which included two presentations of all variants. Each block was presented four times in each test format for a total of eight presentations of each variant in each test format. Participants were presented first with the eight test blocks that contained stimuli in the A domain, and then with eight blocks that contained stimuli from the B domain. For stimuli in a given domain, the variant-to-base and base-to-variant test blocks were presented in simple alternation.

As mentioned above, participants had access to, and could have used a neither comparison during generalization test trials in both formats. In the next section, we describe how the selection of the neither comparison during these tests was used to document the functional independence of the two classes that emerged in Domain A and Domain B.

Results and Discussion

Perceptual class width. A set of stimuli that can be arrayed along a continuum function as a perceptual class when the members of the set occasion the selection of a common stimulus with essentially similar high probabilities and in the absence of direct training. Figure 2 shows the results of the generalization tests that were used to identify the widths of two perceptual classes in the Tree–Cat domain for one participant. Since the patterns of responding are quite similar to those found for all subjects in the experiment, these data can be viewed as representative. The only essential differences across subjects were the particular variants that functioned as the midpoint and boundary stimuli in the perceptual class.

When variant-to-base tests were conducted, the widths of perceptual classes were identified with the data presented in the three panels in the left-hand column. As seen in the top panel, Tree-Cat-50, the anchor stimulus in the A2′ class, was selected on at least 88% of trials in the presence of variants Tree-Cat-37 through Tree-Cat-50. Thus, those variants functioned as members of the A2′ class with Tree-Cat-37 as its boundary stimulus. A similar pattern was occasioned by the variants at the other end of Domain A, which was used to define membership in the A1′ class. As seen in the bottom panel, Tree-Cat-00, the anchor stimulus in the A1′ class, was selected on at least 88% of trials in the presence of variants Tree-Cat-00 through Tree-Cat-18. Thus, those variants were functioning as members of the A1′ class with Tree-Cat-18 as its boundary.

When the base-to-variant tests were conducted, the width of the A1′ class was identified using the data presented in the panels in the center column. During these tests, each trial involved the presentation of Tree-Cat-00 as the sample with a different variant as one comparison across trials, and Tree-Cat-50 and the neither option as the other comparisons on all trials. As seen in the bottom panel, the variants from Tree-Cat-00 to Tree-Cat-21 were selected on at least 88% of trials in the presence of Tree-Cat-00, the anchor stimulus in the A1′ class. Thus, those variants were functioning as members of the A1′ class with Tree-Cat-21 as its boundary.

The width of the A2′ class in the base-to-variant tests was identified using the data presented in the panels in the right-hand

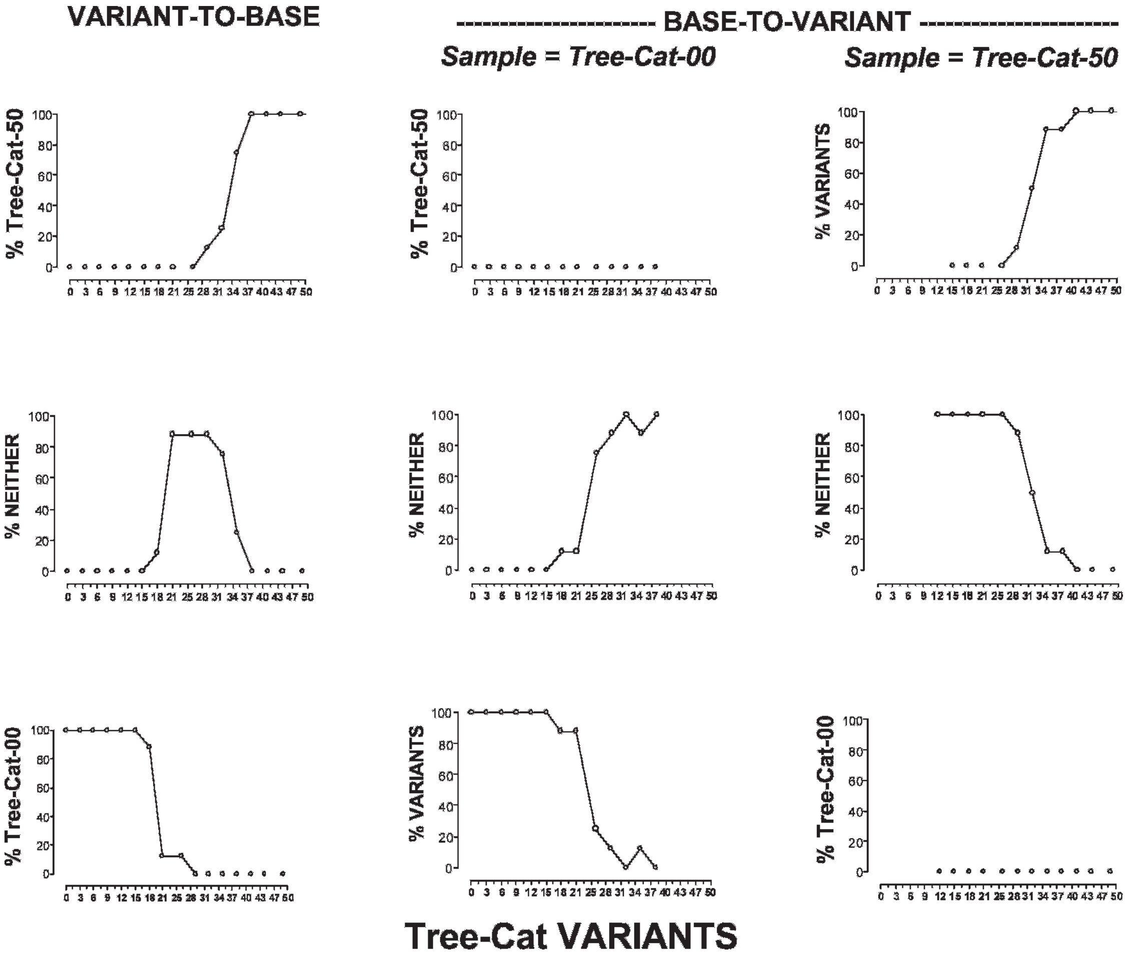

Fig. 2. The results of the variant-to-base and base-to-variant tests for Subject 40 in Phase 3 of Experiment 1. The three graphs in the left column indicate results of the variant-to-base tests and plot the percentage of selecting Tree-Cat-00 (bottom), the neither comparison (middle), and Tree-Cat-50 (top) as functions of the value of the Tree–Cat variants presented as samples. The results of the base-to-variant tests are presented in the two remaining columns. The graphs in the middle column plot the likelihoods of selecting the Tree–Cat variants (bottom), the neither comparison (middle), or the negative comparison (top) in the presence of Tree-Cat-00 as functions of the values of the Tree–Cat variants presented as comparisons. The right column plots likelihoods of selecting the Tree–Cat variants (top), the neither comparison (middle), or the negative comparison (bottom) in the presence of Tree-Cat-50 as functions of the values of the Tree–Cat variants presented as comparisons.

column. During this test, each trial involved the presentation of Tree-Cat-50 as the sample with a different variant as one comparison across trials, along with Tree-Cat-00 and the neither option as the other comparisons on all trials. As seen in the top panel, the variants from Tree-Cat-50 to Tree-Cat-34 were selected on at least 88% of trials in the presence of Tree-Cat-50. Thus, those variants were functioning as members of the A2` class with Tree-Cat-34 as its boundary.

Functional independence of perceptual classes. It could be argued that only one perceptual class emerged in each domain while the presumed second class actually reflected responding to all stimuli that were not members of the first class. Whether one or two classes had emerged can be determined by measuring the responses evoked by the stimuli beyond the boundary stimuli in either of the classes.

The presentation of stimuli beyond the boundary of a class resulted in a systematic decline in the selection of the stimuli from that class. That decline could be accompanied by a complementary increase in the selection of variants from the remainder of the domain. Such a performance would support the view that only one class had emerged and the other class merely reflected the complementary responding to stimuli that were not in the one class.

Alternatively, the decline in selection of stimuli from one class could be accompanied by a complementary increase in the selection of a comparison stimulus that was not a member of the other class (i.e., the neither comparison). Such a performance would demonstrate that two functionally independent perceptual classes were located at the ends of a given stimulus domain.

These options were evaluated in the generalization tests by considering the comparisons that were selected in the presence of the variants that were beyond the boundary stimuli of each class. When variant-to-base tests were conducted, as the variants moved below the boundary of the A2` class, the selection of Tree-Cat-50 declined systematically and was accompanied by a complementary increase in the selection of the neither comparison (see the top and middle panels in Figure 2). This is seen by comparing the performances occasioned by the same variants in the top and middle panels. In contrast, there were very few selections of Tree-Cat-00 (see the bottom panel).

In a similar manner, as the variants moved above the boundary of the A1` class, the selection of Tree-Cat-00 declined systematically and was accompanied by a complementary increase in the selection of the neither comparison (see the bottom and middle panels). In contrast, there were very few selections of Tree-Cat-50 (see the top panel).

When base-to-variant tests were conducted with Tree-Cat-00 as the sample, a decline in selecting variants greater than Tree-Cat-21 was accompanied by a complementary increase in the selection of the neither stimulus (see the bottom and middle panels), but no selection of Tree-Cat-50 (see the top panel). In a similar manner, when Tree-Cat-50 was the sample, a decline in the selection of variants less than Tree-Cat-34 was accompanied by a complementary increase in the selection of the neither stimulus (see the bottom and middle panels) and no selection of Tree-Cat-00 (see bottom panel).

To summarize, the decline in the selection of stimuli from one class was accompanied by a complementary increase in the selection of the neither stimulus in the variant-to-base and the base-to-variant tests. Therefore, four functionally independent perceptual classes emerged in Experiment 1: two each at the opposite ends of Domains A and B.

Discriminability of stimuli in perceptual classes. To say that stimuli are functioning as the members of a class, some behavior must generalize completely among the class members, and some of the class members must also be discriminable from each other (Fields, Reeve, et al., 2002; Fields & Reeve, 2001; Keller & Schoenfeld, 1950; Lashley & Wade, 1946; Lea, 1984; Wasserman et al., 1988). If the stimuli were not discriminable from each other, functionally they would be the same stimuli even though they are physically different. To claim that they were acting as the members of a class would be essentially meaningless because it would be akin to saying that a response trained to one class member generalized to itself.

The discriminability of stimuli can be demonstrated in many ways. For example, stimuli are discriminable from each other if they occasion different responses, the same response with different likelihoods (Belanich & Fields, 2003; Reeve & Fields, 2001), different reaction times (Bentall, Jones, & Dickins, 1999; Blough, 1978; Flynn, 1943), or different response speeds (Fields, et al., 2005; Fields, Reeve, et al., 2002; Spencer & Chase, 1996). Response speed is the reciprocal of the time that separates the response emitted in the presence of a sample to the selection of a comparison stimulus on the same trial (Spencer & Chase, 1996).

Discriminability of the stimuli in the A1`, A2`, B1`, and B2` classes was documented with response speeds occasioned by the anchor, midpoint, and boundary stimuli in the putative A1`, A2`, B1`, and B2` classes during the generalization tests. Average response speeds were computed separately for the anchor, midpoint, and boundary stimuli. The averaging involved the aggregation of data across participants, domains, classes in a domain, test type, as well as sample or comparison function of the stimuli because systematic

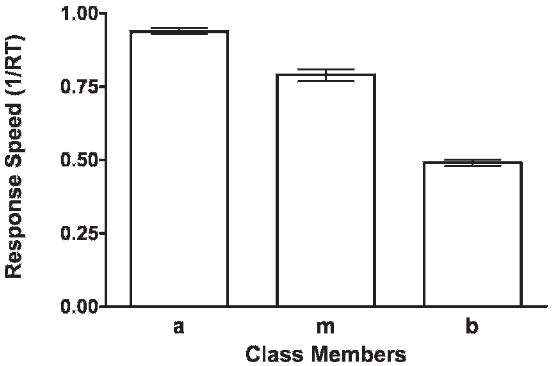

Fig. 3. Average response speeds to the anchor (a), midpoint (m), and boundary (b) stimuli presented as the variants during the variant-to-base and base-to-variant tests for perceptual class formation. The I-beams at the top of each bar represent +/− one standard error. Data were averaged for each type of stimulus across classes, subjects, test formats, and Domains A and B, because there were no systematic differences across these variables. RT stands for Reaction Time. (See text for more details.)

differences were not correlated with any of these factors.

Figure 3 shows that the average response speed was fastest for the anchor stimuli, slower for the midpoint stimuli, and slowest for the boundary stimuli of the perceptual classes. An analysis of variance showed a significant difference in the response speeds that were occasioned by the anchor, midpoint, and boundary stimuli in the perceptual classes, $F(2) = 207.8$, $p < .0001$). Newman-Keuls posthoc tests of pairwise comparisons showed significant differences in the response speeds occasioned by the anchor and midpoint ($q = 9.593$, $p < .001$), midpoint and boundary ($q = 18.75$, $p < .001$), and anchor and boundary stimuli ($q = 28.34$, $p < .001$). Thus, the anchor, midpoint, and boundary stimuli in a class were all discriminable from each other, and the anchor through boundary stimuli in each set functioned as members of separate perceptual classes.

Boundary stimuli of perceptual classes. The boundary stimuli obtained from the variant-to-base and base-to-variant generalization tests for each class are listed in Table 1. For Domain A, which had endpoint values of 0 and 50 units, the boundary stimuli of the A1` and A2` classes averaged 15 and 40 units, respectively, and were separated by an average of 25 units. For Domain B, which had endpoint values of 0 and 500 units, the boundary stimuli of the B1` and B2` classes averaged 149 and 336 units, respectively, and were separated by an average of 187 units. For some classes, the same unit values were obtained for the boundary stimulus when measured using the variant-to-base and the base-to-variant tests. For other classes, the unit values obtained for the boundary stimulus using the variant-to-base tests was greater than that obtained using the base-to-variant tests. For yet other classes, the unit values obtained for the boundary stimulus using the variant-to-base tests was less than that obtained using the base-to-variant tests.

Summary. Stimuli act as members of a perceptual class when (a) they occasion the selection of a given comparison stimulus with similarly high probabilities, (b) they are very unlikely to occasion the selection of comparisons from other stimulus sets, and (c) many of them are discriminable from each other. Since these criteria were satisfied, the stimuli at the ends of each domain were functioning as members of perceptual classes. Since the stimuli between the boundaries of the classes in the same domain occasioned the selection of a stimulus that was not in either class, the stimuli at each end of a domain were acting as members of functionally independent perceptual classes. The performances that demonstrated class membership occurred without direct training, that is, the classes emerged spontaneously. Experiments 2 and 3 established linked perceptual classes by linking one A` class with one B` class.

EXPERIMENT 2

Experiment 2 explored the immediate and delayed emergence of linked perceptual classes after the training of single conditional discriminations to link an A` class and a B` class. When establishing a linked conditional discrimination, the samples and comparisons can use either the anchor or the boundary stimuli of the A` and B` classes, which give rise to four training options. In **aa** training, the sample was the anchor from the A` class, and the comparison was the anchor from a B` class. In **bb** training, the sample was the boundary from the A` class, and the comparison was the boundary from the B` class. In **ab** training, the sample was the anchor from the A` class and the comparison was the boundary from the B` class. In **ba** training, the sample was the

Table 1

Boundaries of perceptual classes A1`, A2`, B1`, and B2` measured with variant-to-base (VB) and base-to-variant (BV) tests for participants in each group.

Train Group	Subject	VB		BV		VB		BV	
		A1`	A2`	A1`	A2`	B1`	B2`	B1`	B2`
aa	01	18	34	21	31	170	310	170	310
	02	18	40	18	34	250	340	210	340
	03	09	43	09	43	130	390	100	430
	04	18	34	21	34	130	340	170	310
	05	15	43	15	43	170	340	170	370
	06	15	37	18	40	170	280	210	280
	07	18	40	21	37	170	340	210	310
	08	21	34	28	34	210	340	280	340
bb	09	12	40	15	43	170	340	130	430
	10	09	43	09	43	130	310	130	340
	11	21	34	18	34	130	340	170	340
	12	18	37	18	34	130	280	170	280
	13	15	34	12	37	170	340	170	340
	14	06	43	06	43	130	310	070	390
	15	15	43	15	43	210	430	210	340
ab	16	09	43	09	43	100	340	070	430
	17	18	37	18	34	210	340	210	280
	18	15	40	15	43	210	310	210	250
	19	15	34	18	37	170	340	170	340
	20	18	43	12	43	070	340	070	340
	21	21	34	21	34	170	340	170	340
	22	21	34	18	34	170	310	170	310
	23	18	37	18	37	170	310	170	340
ba	24	18	37	18	40	170	340	170	340
	25	12	37	18	37	130	340	170	370
	26	18	40	18	37	170	340	170	340
	27	18	37	18	40	100	310	170	340
	28	15	34	18	34	170	340	170	340
	29	18	37	18	37	130	340	100	310
	30	18	37	15	34	130	390	130	430
	31	21	34	21	28	210	340	280	340
aa/bb	32	15	40	15	40	210	340	210	340
	33	15	43	15	40	170	340	170	340
	34	15	40	21	37	170	310	170	310
	35	18	37	18	34	070	340	130	340
	36	06	43	09	43	100	430	100	430
	37	18	34	21	34	170	310	210	340
	38	09	43	09	43	130	340	070	370
ab/ba	39	21	34	18	34	210	340	210	310
	40	18	37	21	34	170	340	170	340
	41	15	37	12	37	170	340	170	340
	42	15	40	15	40	170	340	170	340
	43	15	40	15	40	170	340	210	340
	44	15	40	15	43	100	340	070	430
	45	15	43	15	43	170	310	170	310
	46	18	34	18	34	210	280	210	310
	AVG.	15	40	15	40	149	339	149	334
	min-max[@]	00	50	00	50	000	500	000	500
	Avg. Width	15	10	15	10	149	161	149	166
	SE[#]	0.6	0.5	0.6	0.6	5.9	4.3	7.4	6.1

[@] Minimum and maximum values assigned to the respective endpoint stimuli on each domain.
[#] Standard Error

boundary from the A` class and the comparison was the anchor from the B` class.

These four training conditions factorially combined the value (anchor or boundary) and function (sample or comparison) of the stimuli in the conditional discriminations that link distinct perceptual classes. Thus, differences in class formation would reflect the separate or interactive effects of the values and functions of the stimuli in the conditional discriminations used to establish a relation between the two perceptual classes.

METHOD

Subjects

Thirty-two subjects from Experiment 1 were assigned to the four groups in Experiment 2, 8 in each of four groups. One subject, however, dropped out before the start of Experiment 2, leaving three groups with 8 subjects and one with 7 subjects. Experiment 2 was completed in a single session and lasted from 1 to 1.5 hr,

Apparatus

The apparatus was the same as in Experiment 1.

Stimuli

The anchor, midpoint, and boundary stimuli for the A1`, A2`, B1`, and B2` classes that had been identified for each participant in Experiment 1 were used in the present experiment.

Procedure

The trial contingencies were the same as in Experiment 1 with the following additions.

Phase 1: Linkage of classes with cross-class conditional discriminations. The A` and B` classes were nominally linked by the establishment of one of the four following cross-class conditional discriminations. The **aa** training condition involved the establishment of A1a→B1a and A2a→B2a conditional discriminations. The anchor stimuli of Domain A, A1a and A2a, were presented as samples on separate trials, and the pair of anchor stimuli from Domain B, B1a and B2a, were presented as comparisons on all trials (see the corresponding section of Table 2). The **bb** training condition involved the establishment of A1b→B1b and A2b→B2b conditional discriminations. The boundary stimuli of the A domain, A1b and A2b, were presented as samples on separate trials, and the pair of boundary stimuli from Domain B, B1b and B2b, were presented as comparisons on all trials (see the corresponding section of Table 2). The **ab** training condition involved the establishment of A1a→B1b and A2a→B2b conditional discriminations. The anchor stimuli of Domain A, A1a and A2a, were presented as samples on separate trials, and the pair of boundary stimuli from Domain B, B1b and B2b, were presented as comparisons on all trials (see the corresponding section of Table 2). The **ba** training condition involved the establishment of A1b→B1a and A2b→B2a conditional discriminations. The boundary stimuli of Domain A, A1b and A2b, were presented as samples on separate trials, and the pair of anchor stimuli from Domain B, B1a and B2a, were presented as comparisons on all trials (see the corresponding section of Table 2).

Phase 2: Symmetry testing of conditional discriminations. When a linked perceptual class is formed, the stimuli in the two classes must occasion the mutual selection of each other. That is, the stimuli of a class-linking conditional discrimination must be related in a bidirectional basis; that is, the stimuli in the conditional discrimination must have the property of symmetry (Fields & Verhave, 1987; Sidman, 1994; Sidman & Tailby, 1982). Phase 2 therefore assessed the symmetrical property of the class-linking conditional discriminations established in Phase 1.

For example, after training Aa→Ba, Aa must occasion the selection of Ba, and Ba must occasion the selection of Aa. After training Aa→Ba, symmetry was assessed with Ba→Aa symmetry probe trials. The selection of Aa given Ba would demonstrate the symmetrical property of the sample and comparison stimuli used in the trained conditional discrimination.

At the completion of training, the symmetrical properties of each trained Ax→Bx conditional discrimination were assessed in two test blocks, each of which contained review trials of the trained conditional discriminations and their corresponding symmetry probes, all of which are listed in Table 2. All trials in these test blocks were presented with uninformative feedback. The selection of the comparison that was linked by training to the sample during the test would demonstrate the sym-

Table 2

Symbolic representations of stimuli in the cross-class conditional discriminations (Cond. Disc.) trained in Experiments 2 and 3. The rows designated with TRN and SYM list the trial configurations used for training and probing for symmetry. Each row indicates the stimuli used as sample (Sa), positive comparison (Co+), and negative comparison (Co−) for Classes 1 and 2. The lower case letters that follow the numerals designate anchor (a) and boundary (b) values of the stimuli in each class. The Class 1 and Class 2 trial configurations were presented four times per block, with each comparison presented twice on the left and twice on the right for a total of 16 trials per block. The same was done with the symmetry probes. Each symmetry test block (SYM) contained 16 training trials and 16 symmetry probes for a total of 32 trials per block.

			Class 1			Class 2		
Group	Trial Type	Cond. Disc.	Sa	Co+	Co−	Sa	Co+	Co−
aa	TRN	Aa→Ba	A1a	B1a	B2a	A2a	B2a	B1a
	SYM	Ba→Aa	B1a	A1a	A2a	B2a	A2a	A1a
bb	TRN	Ab→Bb	A1b	B1b	B2b	A2b	B2b	B1b
	SYM	Bb→Ab	B1b	A1b	A2b	B2b	A2b	A1a
ab	TRN	Aa→Bb	A1a	B1b	B2b	A2a	B2b	B1b
	SYM	Bb→Aa	B1b	A1a	A2a	B2b	A2a	A1a
ba	TRN	Ab→Ba	A1b	B1a	B2a	A2b	B2a	B1a
	SYM	Ba→Ab	B1a	A1b	A2b	B2a	A2b	A1b
aa/bb	TRN	Aa→Ba	A1a	B1a	B2a	A2a	B2a	B1a
	SYM	Ba→Aa	B1a	A1a	A2a	B2a	A2a	A1a
	TRN	Ab→Bb	A1b	B1b	B2b	A2b	B2b	B1b
	SYM	Bb→Ab	B1b	A1b	A2b	B2b	A2b	A1b
ab/ba	TRN	Aa→Bb	A1a	B1b	B2b	A2a	B2b	B1b
	SYM	Bb→Aa	B1b	A1a	A2a	B2b	A2a	A1a
	TRN	Ab→Ba	A1b	B1a	B2a	A2b	B2a	B1a
	SYM	Ba→Ab	B1a	A1b	A2b	B2a	A2b	A1b

metrical property of symmetry between the stimuli in the trained conditional discrimination. Symmetry was demonstrated by the selection of set-consistent comparisons on at least 94% of the trials in a test block.

Phase 3: Tracking the emergence of linked perceptual classes. The emergence of relations between members of the A′ and B′ classes was assessed with the performances occasioned by the 18 cross-class probes listed in Table 3. Nine of them were conducted in the A′–B′ format and the remaining nine were conducted in the B′–A′ format. In the A′–B′ probes, stimuli in the A′ classes were presented as samples while stimuli in the B′ classes were presented as comparisons, and vice versa in the cross-class probes conducted in the B′-A′ format. For example, Am–Bb would be a probe conducted in the A′–B′ format, while Bb–Am would be a symmetry probe conducted in the B′–A′ format. The same set of cross-class probes were presented to subjects in all groups.

All of the A′–B′ probes contained sample stimuli that were the anchor, midpoint, and boundary variants from the Tree and Cat classes (the A1′ and A2′ classes) and comparison stimuli that were pairs of the anchor, midpoint, or boundary stimuli from the Haiti and California classes (the B1′ and B2′ Satellite-based classes). All of the B′–A′ probes contained sample stimuli that were the anchor, midpoint, and boundary variants from the Satellite-based classes and comparisons that were pairs of the anchor, midpoint, or boundary stimuli from the Tree–Cat classes. All probe trials also included a neither option as a third comparison, which enabled a participant to indicate that the neither of the comparisons was related to the sample stimulus on that trial.

The 18 cross-class probes were presented in a 6/3 testing schedule (Fields et al., 2005). The previous researchers found that an intermediate percentage of linked perceptual classes emerged when testing was conducted with a 6/3 schedule. It was used in the present experiment so that testing would not generate a ceiling performance that would be insensitive to the effects of training on the formation of linked perceptual classes. The 6/3 testing schedule involved the presentation of six test blocks each of which included three probe

Table 3

Probes used to evaluate the emergence of linked perceptual classes. Each row lists the stimuli, represented symbolically, used in two cross-class probes. Sa indicates the sample, Co+ indicates the positive comparison, and Co− indicates a negative comparison. NC designates the neither stimulus which serves as a negative comparison. Each trial had three comparisons: one positive and two negative. On each row, the Class 1 and Class 2 probes share the same set of three comparison stimuli, but the positive comparison and first negative comparison are different for each class. The lower case letters a, m, and b designate anchor, midpoint, and boundary stimuli, respectively. The Class 1 and Class 2 trial configurations were presented four times per block, with each comparison presented twice on the left and twice on the right for a total of 16 trials per block.

		Class 1 Probes				Class 2 Probes			
Test Block	Probes/Block	Sa	Co+	Co−	Co−	Sa	Co+	Co−	Co−
1. Aamb-Aa	Aa→Ba	A1a	B1a	B2a	NC	A2a	B2a	B1a	NC
	Am→Ba	A1m	B1a	B2a	NC	A2m	B2a	B1a	NC
	Ab→Ba	A1b	B1a	B2a	NC	A2b	B2a	B1a	NC
2. Aamb-Bb	Aa→Bm	A1a	B1m	B2m	NC	A2a	B2m	B1m	NC
	Am→Bm	A1m	B1m	B2m	NC	A2m	B2m	B1m	NC
	Ab→Bm	A1b	B1m	B2m	NC	A2b	B2m	B1m	NC
3. Aamb-Bb	Aa→Bb	A1a	B1b	B2b	NC	A2a	B2b	B1b	NC
	Am→Bb	A1m	B1b	B2b	NC	A2m	B2b	B1b	NC
	Ab→Bb	A1b	B1b	B2b	NC	A2b	B2b	B1b	NC
4. Bamb-Aa	Ba→Aa	B1a	A1a	A2a	NC	B2a	A2a	A1a	NC
	Bm→Aa	B1m	A1a	A2a	NC	B2m	A2a	A1a	NC
	Bb→Aa	B1b	A1a	A2a	NC	B2b	A2a	A1a	NC
5. Bamb-Am	Ba→Am	B1a	A1m	A2m	NC	B2a	A2m	A1m	NC
	Bm→Am	B1m	A1m	A2m	NC	B2m	A2m	A1m	NC
	Bb→Am	B1b	A1m	A2m	NC	B2b	A2m	A1m	NC
6. Bamb-Ab	Ba→Ab	B1a	A1b	A2b	NC	B2a	A2b	A1b	NC
	Bm→Ab	B1m	A1b	A2b	NC	B2m	A2b	A1b	NC
	Bb→Ab	B1b	A1b	A2b	NC	B2b	A2b	A1b	NC

types. The first three blocks involved the presentation of A′–B′ probes. Each of these blocks involved the presentation of samples that were the anchor, midpoint, and boundary stimuli from the two classes in Domain A. In the first block, the anchor stimuli from the two classes in Domain B were presented as the comparisons. In the second block, the midpoint stimuli from the two classes in Domain B were presented as the comparisons. In the third block, the boundary stimuli from the two classes in Domain B were presented as the comparisons. The B′–A′ blocks had the same organization as the A′–B′ blocks with one exception; the B′ stimuli served as samples and the A′ stimuli served as comparisons.

The cross-class probes involve the presentation of midpoint and boundary stimuli from the A′ and B′ classes as samples in some trials and as comparisons on other trials. When the midpoint and boundary stimuli were presented as samples, their unit values were those obtained from the variant-to-base tests in Phase 2. This occurred because the midpoint and boundary stimuli were functioning as samples in the cross-class tests and in the variant-to-base tests. Likewise, when the midpoint and boundary stimuli were presented as comparisons, their unit values were those obtained from the base-to-variant tests in Phase 2. This was done because the midpoint and boundary stimuli were functioning as comparisons in the cross-class tests and in the base-to-variant tests.

In each block, trials were presented in a randomized order without replacement. In addition, all of the trials in a block were presented with no differential feedback. Each cross-class probe for a given linked perceptual class was presented eight times in a block for a total of 144 trials (8 trials per probe type × 3 probe types per block × 6 blocks).

Results and Discussion

Class-linking conditional discriminations and symmetry. Conditional discriminations used

Table 4

Performances occasioned by each A`–B` and B`–A` cross-class probe presented to each subject after **aa, bb, ab,** and **ba** training for linked perceptual classes with A1`–B1` on the left half and A2`–B2` on the right. The numeral 1 in a cell indicates 88% or 100% correct, the numeral 2 in a cell indicates from 25 through 81% correct, and the numeral 3 in a cell indicates 0–12% correct. Data highlighted in grey with bold numerals indicate classes that showed immediate emergence. Data highlighted in a box with bold italicized numerals indicate classes that emerged on a delayed basis.

		CL 1																		CL 2																	
Train		A' - B'									B' - A'									A' - B'									B' - A'								
Group	Subject	aa	am	ab	ma	mm	mb	ba	bm	bb	aa	am	ab	ma	mm	mb	ba	bm	bb	aa	am	ab	ma	mm	mb	ba	bm	bb	aa	am	ab	ma	mm	mb	ba	bm	bb
aa	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	3	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	1	2	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	2	3	1	2	3	1	1	2	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1
	6	1	1	2	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	3	3	3	1	1	1	1	1	1	2	1	1
	8	1	1	1	1	2	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	2	3	3	1	1	1	1	1	2	1	1	1
	7	1	1	2	1	1	2	1	1	2	1	1	1	1	1	2	1	1	1	1	2	3	1	1	3	1	1	3	1	1	1	1	1	1	1	1	1
ab	16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	19	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1
	21	1	1	1	1	1	1	1	1	1	1	1	3	1	1	3	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	22	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	2	1	1	1	1	1	1	1	1	3
	23	3	1	1	3	1	1	3	1	2	2	3	3	2	3	3	2	3	3	3	1	1	3	1	1	3	1	1	3	3	3	1	1	1	1	1	1
ba	24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1
	29	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1
	27	1	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	30	3	2	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	1	3	3	3	2	2	1	1	1	1	2	1	1	2	1	1	2	1	1
	31	1	3	3	1	3	3	1	1	1	3	3	1	3	3	1	3	3	1	1	3	3	1	2	3	1	2	1	3	3	1	3	3	3	3	3	3
bb	9	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
	11	2	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1
	12	2	3	3	2	3	3	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	1	1	1	2	1	1	1	1	1	1	1	1
	14	3	3	2	3	3	2	3	3	2	1	1	1	1	1	1	1	1	1	2	3	2	2	3	2	2	3	2	3	3	3	1	1	1	1	1	1
	15	3	3	1	3	3	1	3	3	1	3	3	3	3	3	3	1	1	1	2	3	1	3	3	1	3	3	1	3	3	3	3	3	3	3	3	3
	13	3	3	2	3	3	1	3	3	1	3	2	1	3	1	1	1	1	1	3	3	1	3	3	1	3	3	1	3	1	1	2	1	1	2	1	1

to link the two perceptual classes were acquired rapidly and with no significant differences across training conditions. Most subjects passed the symmetry test on the first test block.

As mentioned above, the emergence of novel relations among the stimuli in a linked perceptual class requires the relation between the sample and comparison stimuli in a class-linking conditional discrimination to be symmetrical. Since the stimuli in the class-linking conditional discriminations were symmetrically related to each other, any failures in the formation of linked perceptual classes could not be attributed to the absence of symmetry between the samples and comparisons in the class-linking conditional discriminations.

The formation of a linked perceptual class was assessed using the performances occasioned by the 18 cross-class probes. Data for all probes for each subject in each training condition are presented in Table 4. The temporal order of probe presentations is reflected in the left-to-right progression of the columns in the table. For example, the probes in the first test block are indicated in the first three columns, etc.

A linked perceptual class was documented when a participant responded with at least 88% accuracy (mastery level) on at least 17 of the 18 cross-class probes presented in the A`–B` and B`–A` probes. When this occurred, the linked perceptual class was considered to have emerged on an immediate basis. Because the temporal sequence of probe presentations is reflected in the construction of Table 4, it also is possible to track the delayed emergence of linked perceptual classes. A linked perceptual class was said to have emerged on a delayed basis when mastery levels of responding occurred in at least the last nine consecutive cross-class probes presented in the 6/3 test schedule. Although this criterion differs from that used for immediate emergence, it would appear to be reasonable since at least 135 of 144 consecutive probe trials would have evoked class-indicative performances.

The data from certain subjects illustrate the variety of outcomes in Experiment 2. For example, for Subject 1, mastery levels of responding were occasioned by all A`–B`, B`–A` probes for classes 1 and 2, thereby showing the immediate emergence of linked perceptual classes A1`–B1`, A2`–B2`. Subject 26 showed the immediate emergence of two linked perceptual classes where mastery levels of responding were occasioned by all 18 probes in the A1`–B1` class and by 17 of the 18 probes in the A2`–B2` class. Subject 3 showed the immediate emergence of the A2`–B2` class and the delayed emergence of the A1`–B1` class. Subject 29 showed the delayed emergence of both linked perceptual classes. Subject 5 showed the immediate emergence of the A2`–B2` class and did not show the formation of the A1`–B1` class. Subject 13 did not form either linked perceptual class.

Figure 4 presents the results of Experiment 2 in a form that identifies the interactive effects of the values and functions of the stimuli used in each training condition on the immediate and delayed emergence of linked perceptual classes. The effect of training on the formation of linked perceptual classes was indexed by the percentage of participants in a group who formed both linked perceptual classes. This constant-performance approach has been used in other studies of linked perceptual class formation (Fields et al., 2005; Fields, Matneja, et al., 2002) and in psychophysical experiments that use thresholds (a constant performance index) to evaluate the effects of independent variables on sensory or perceptual phenomena (Graham, 1950).

The top panel illustrates the effect of each training condition on the percentage of subjects who showed the emergence of both linked perceptual classes on an immediate basis. That percentage was highest after **ab** training, intermediate after **ba** training, and lowest after **aa** and **bb** training. When the comparisons were anchor stimuli (**aa** and **ba**),

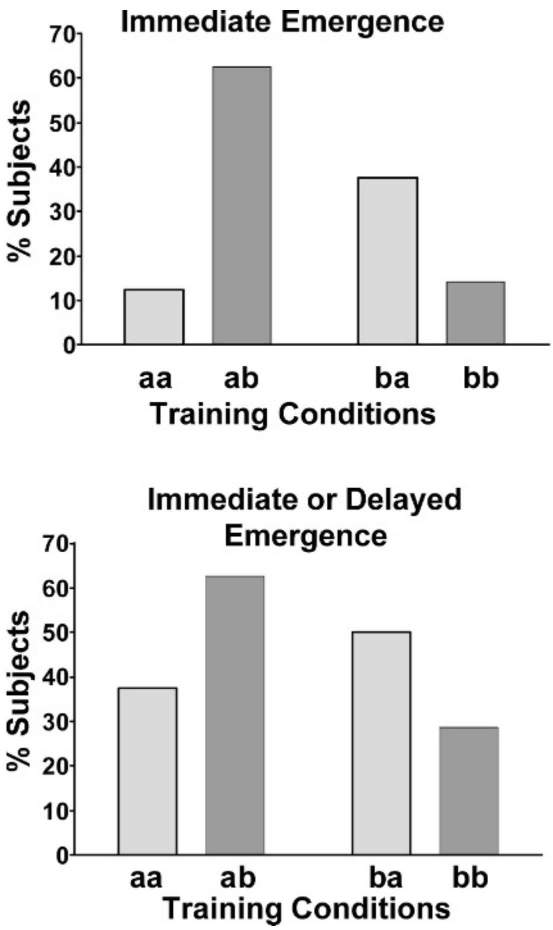

Fig. 4. The effect of four training conditions on the emergence of linked perceptual classes in Experiment 2. Each panel shows the effects of **aa**, **ab**, **bb**, and **ba** training on the percentage of subjects in each training condition who formed both potential linked perceptual classes. The upper panel shows the immediate emergence of linked perceptual classes. The lower panel shows the emergence of both classes in any combination of immediate and delayed emergence.

a larger percentage of classes emerged immediately if the samples were boundary instead of anchor stimuli. In contrast, when the comparisons were boundary stimuli (**ab** and **bb**), a larger percentage of classes emerged immediately if the samples were anchor instead of boundary stimuli. In other words, the percentage of immediately emergent linked perceptual classes was influenced in one way by the values of the sample stimuli in the trained relations when the comparisons were anchor stimuli and in the opposite way when the comparisons were boundary stimuli. Thus, the percentage of subjects who showed the immediate emergence of both linked perceptual classes was determined by a crossover interaction of the values and functions of the stimuli used in the trained relations.

The bottom panel in Figure 4 shows the effects of each training condition on the percentage of subjects who formed classes on an immediate or delayed basis. Although the ordinal effects of each training condition were the same as those for immediate emergence, the delayed emergence of some classes for some participants increased the results somewhat after **aa**, **ba**, and **bb** training but not for **ab** training.

The formation of linked perceptual classes was influenced by the interactive effects of the values and functions of the stimuli used in the conditional discriminations that linked two isolated perceptual classes. Additional research will be needed to determine the basis for these interactions and their differential effects on the immediate and delayed emergence of linked perceptual classes. The results also showed the delayed emergence of linked perceptual classes. This phenomenon was correlated with the presentation of a succession of probes. Additional research would be needed to determine whether additional testing would increase the percentage of subjects who show the delayed emergence of linked perceptual classes.

EXPERIMENT 3

The results of Experiment 2 demonstrated that the formation of linked perceptual classes was determined by the interactive effects of the values and functions of the stimuli in the conditional discriminations that linked two distinct perceptual classes. Regardless of training condition, however, a maximum of only 63% of the subjects formed both linked perceptual classes.

Several studies have shown that the formation of many kinds of stimulus classes can be facilitated by the use of multiple exemplar training (Barnes & Keenan, 1993; Fields, Reeve, et al., 2002; Reeve & Fields, 2001; Wright et al., 1988). If the establishment of a linked perceptual class by the prior training of one cross-class conditional discrimination is considered to be single exemplar training, linkage of the A\` and B\` perceptual classes by the training of more than one cross-class conditional discrimination could be considered a form of multiple exemplar training. This form of multiple exemplar training, then, might increase the likelihood of forming linked perceptual classes. Experiment 3 probed this possibility by establishing two cross-class conditional discriminations by which to link perceptual classes A\` and B\`.

Class-linking conditional discriminations can be established using many combinations of anchor and boundary stimuli. Two such combinations were studied in Experiment 3. In one group, subjects received **aa/bb** training, wherein the effort to link classes involved the establishment of Aa–Ba and Ab–Bb conditional discriminations. In this condition, the values of the samples and comparisons were the same in both conditional discriminations. In another group, subjects received **ab/ba** training, wherein the Aa–Bb and Ab–Ba conditional discriminations were trained. In this condition, the values of the samples and comparisons differed in the two conditional discriminations.

Similarities between the two combinations in the likelihood of class formation would indicate that the values of the samples and comparisons used in training did not influence the formation of linked perceptual classes. Differences in the likelihood of class formation would indicate the importance of the values of the training stimuli used as samples and comparisons in the conditional discriminations. In addition, a comparison of the outcomes of Experiments 2 and 3 would show whether the number of class-linking conditional discriminations (one or two) used in training influences the formation of linked perceptual classes.

Method

Subjects

Of the 48 subjects in Experiment 1, 16 were assigned to Experiment 3. Of the 16, 8 were assigned to each of two groups. One subject, however, dropped out before the start of Experiment 3, leaving the groups with 8 and 7 subjects, respectively. Experiment 3 was completed in a single session and lasted from 1 to 1.5 hr.

Table 5

Performances occasioned by each A`–B` and B`–A` cross-class probe presented to each subject after **aa/bb and ab/ba** training for linked perceptual classes with A1`–B1` on the left half and A2`–B2` on the right. The numeral 1 in a cell indicates 88% or 100% correct, the numeral 2 in a cell indicates from 25 through 81% correct, and the numeral 3 in a cell indicates 0 or 12% correct. Data highlighted in grey with bold numerals indicate classes that showed immediate emergence. Data highlighted in a box with bold italicized numerals indicate classes that emerged on a delayed basis.

Train		CL 1																	
		A' - B'									B' - A'								
Group	Subject	aa	am	ab	ma	mm	mb	ba	bm	bb	aa	am	ab	ma	mm	mb	ba	bm	bb
aa/bb	32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	34	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	35	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	36	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	38	3	1	1	3	1	1	3	1	1	1	1	1	1	1	1	1	1	1
	37	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2
ab/ba	39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	40	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	41	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	42	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	43	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	45	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	2
	46	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	2

Train		CL 2																	
		A' - B'									B' - A'								
Group	Subject	aa	am	ab	ma	mm	mb	ba	bm	bb	aa	am	ab	ma	mm	mb	ba	bm	bb
aa/bb	32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	34	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	35	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	36	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
	38	3	1	1	3	1	1	3	1	1	1	1	1	1	1	1	1	1	1
	37	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1
ab/ba	39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	40	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	41	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	42	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	43	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
	45	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	1	2
	46	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2

Apparatus

The apparatus was the same as Experiment 2.

Procedure

The **aa/bb** training condition involved the establishment of A1a→B1a, A2a→B2a, A1b→B1b, and A2b→B2b conditional discriminations (see the corresponding section of Table 2). The **ab/ba** training condition involved the establishment of A1a→B1b, A2a→B2b, A1b→B1a, and A2b→B2a conditional discriminations (see the corresponding section of Table 2). At the completion of training, all subjects were exposed to the 6/3 testing schedule that was described in Experiment 2 in order to track the emergence of the linked perceptual classes.

Results and Discussion

Table 5 has the same format as Table 4. Data from representative subjects are noted here. For Subject 32, mastery levels of responding were occasioned by all A`–B`, B`–A` probes for classes 1 and 2, thereby showing the immediate emergence of linked perceptual classes A1`–B1` and A2`–B2`. Subject 38 showed the delayed emergence of both linked perceptual classes. Subject 37 did not form either linked perceptual class.

Effects of training different sets of two conditional discriminations. Table 6 lists the percentage of subjects who showed the emergence of both linked perceptual classes for both conditions in Experiment 3 and the four conditions in Experiment 2. After **aa/bb** and **ab/ba** training in Experiment 3, approximately the same percentage of subjects showed the immediate emergence of both linked perceptual classes. Only one participant (Subject 38) showed the delayed emergence of both classes, which occurred after **aa/bb** training (see Table 5). Thus, the small difference in the percentage of subjects who formed two linked perceptual classes regardless of the speed of emergence (86% vs. 75%) was not of consequence. The percentage of subjects who formed both linked perceptual classes was not influenced by the combination of conditional discriminations that were used for training.

The fact that **aa/bb** and **ab/ba** training produced similar results could reflect the following operational commonality between the two training conditions. In both, the class-linking conditional discriminations contained samples that were the anchor stimuli and the boundary stimuli from Domain A whereas the comparisons were the anchor stimuli and boundary stimuli from Domain B.

Table 6

The effect of each training condition used in Experiment 2 (**aa**, **bb**, **ab**, and **ba**), and Experiment 3 (**aa/bb** and **ab/ba**) on the percentage of subjects who showed the immediate emergence of both linked perceptual classes (IE) or any combination of the immediate or delayed emergence (DE) of both classes (IE+DE),

Rate of Emergence	Training Conditions					
	aa	bb	aa/bb	ab	ba	ab/ba
IE	**13**	**14**	**71**	**63**	**38**	**75**
IE&DE	**37**	**29**	**86**	**63**	**50**	**75**

Effect of number of trained relations on class formation. An effect of the number of trained cross-class conditional discriminations on the immediate emergence of both linked perceptual classes was addressed by comparing the results obtained in Experiments 2 and 3 (see Table 6). Two sets of comparisons were made: **aa/bb** vs. **aa** alone and **bb** alone, and **ab/ba** vs. **ab** alone and **ba** alone.

When **aa/bb, aa,** and **bb** training were considered, the immediate emergence of both perceptual classes occurred for 71% of subjects after **aa/bb** training, for 13% of subjects after **aa** training and 14% of subjects after **bb** training. Thus, the formation of linked perceptual classes was directly related to the number of trained cross-class conditional discriminations.

In addition, the training of **aa** and **bb** together (71%) had a greater effect on class formation than the combined effects of training of **aa** alone (13%) and **bb** alone (14%). Indeed, training of **aa** and **bb** together produced a large synergistic effect (44%) on class formation relative to training involving each alone (71% ≫ 27%). In contrast, a lesser degree of synergy was seen (20%) when viewing the combination of immediate and delayed emergence (86% > 66%).

When **ab/ba, ab,** and **ba** training were considered, the immediate emergence of both perceptual classes occurred for 75% of subjects after **ab/ba** training, for 63% of subjects after **ab** training and for 38% of subjects after **ba** training. The effects of training with two conditional discriminations (i.e., **ab/ba**), was approximated by **ab** training alone (75% vs 63%). Thus, it is reasonable to conclude that the success of **ab/ba** training is primarily attributable to the establishment of the Aa–Bb conditional discriminations in **ab/ba** training. For **ab/ba, ab,** and **ba** training, then, the establishment of two class-linking conditional discriminations instead of one did not have a large effect on the immediate emergence of linked perceptual classes. In addition, the effect of training these two conditional discriminations together did not have the synergistic effect seen during **aa/bb** training.

To summarize, the emergence of linked perceptual classes can be influenced by the number of conditional discriminations that link two isolated perceptual classes. That effect, however, is influenced by the particular conditional discriminations that are trained. Under some conditions, the training of two class-linking conditional discriminations rather than one had a synergistic effect on the formation of linked perceptual classes. In other cases, the synergistic effect was absent. The effect was a function of the values of the sample and comparison stimuli used in the conditional discriminations.

GENERAL DISCUSSION

Functional independence of linked perceptual classes. The majority of subjects formed two linked perceptual classes in Experiments 2 and 3. It could be argued, however, that only one linked perceptual class emerged per domain as the differential responding to the other variants in the domain reflected complementary responding to all stimuli that are not members of one linked perceptual class. This interpretation, however, is inconsistent with the neither-comparison data obtained in Experiment 1. There, the selection of the neither comparison was occasioned by the variants that were between the boundaries of the perceptual classes at the opposite ends of each domain. Thus, the two perceptual classes were functionally independent of each other. Since each linked perceptual class consisted of two functionally independent perceptual classes, if two linked perceptual classes emerged in Experiments 2 and 3, those classes would also have been functionally independent of each other.

Spontaneously emergent perceptual classes. The perceptual classes that were the components of the linked perceptual class formed in Experiments 2 and 3 were spontaneously emergent; they were not established through direct training. Because the perceptual classes were spontaneously emergent, the linked perceptual classes reflected the merger of two perceptual classes. In contrast, perceptual classes can also be established directly by multiple exemplar training (Barnes & Keenan, 1993; Fields, Reeve, et al., 2002; Reeve & Fields, 2001; Wright et al., 1988). The use of classes formed in this manner, however, could lead to an interpretive ambiguity because the emergence of the linked perceptual class could reflect the merger of two equivalence classes instead of the merger of two perceptual classes.

To illustrate, an A` class could be established by training the conditional discriminations Am–Aa, and Ab–Aa. The emergence of untrained relations such as Am–Ab could be viewed as the formation of a perceptual class. However, it also could be viewed as the emergence of novel relations in an equivalence class that consists of Aa, Am, and Ab and has the structure Am–Aa–Ab. Similar training could be used with the anchor, midpoint, and boundary stimuli in Domain B, producing an equivalence class that has the structure Bm–Ba–Bb. Thus, the emergence of novel relations among the stimuli in the A` and B` classes after training Ab–Bm could reflect the merger of two three-member equivalence classes to one six-member equivalence class that has the structure Am–Aa–Ab—Bm–Ba–Bb. The use of spontaneously emergent perceptual classes avoided the interpretive ambiguity that would have been engendered by the use of multiple exemplar training to form the perceptual classes. Specifically, relations among the stimuli in a domain were not established by direct training. Consequently, it seems reasonable to conclude that the linked perceptual classes formed in Experiments 2 and 3 reflect the merger of two perceptual classes.

Training and testing effects on linked perceptual class formation. The present experiment explored the effects of six training conditions on class formation. These effects, however, were investigated in the context of a single testing schedule to track the formation of linked perceptual classes. Fields et al. (2005) explored the effects of four testing schedules on the formation of linked perceptual classes. These effects, however, were investigated in the context of a single training condition that was used to link the two perceptual classes. A comprehensive understanding of the effects of the six training conditions and four testing schedules on the immediate and delayed formation of linked perceptual classes could be obtained by conducting a 6x4 factorial experiment, the outcome of which would characterize the effects of the 24 combinations of training and testing.

Before embarking on an enterprise of that scope, however, it may be desirable to explore the boundary conditions of the combined effects of training and testing on the formation of linked perceptual classes. This could be achieved by conducting a 2x2 factorial experiment that used the most and least effective training conditions identified in the present experiment (i.e., **ab** and **bb**, respectively) in combination with the most and least effective testing schedules identified by Fields et al. (2005) (i.e., the 18/1-PRGM and 9/2 schedules, respectively). The outcomes of these conditions would indicate the interactive effects of training and testing on the formation of linked perceptual classes. Large differences in the outcomes of these conditions would warrant a more comprehensive research endeavor.

Linked perceptual classes and other complex categories. The structure of a typical linked perceptual class can be represented as {Ab.... Aa→Bb.... Ba}, where {Ab…Aa} and {Bb…Ba} designate the range of stimuli in the A` and B` classes, and Aa→Bb designates the conditional discrimination that is established by training to link the two perceptual classes. In other words, the relations that emerge among members of the A` and B` classes that were not used in training are linked through Aa and Bb. Thus, these cues were acting as nodal stimuli. A node is a stimulus linked by training to at least two other stimuli (Fields & Verhave, 1987). In this example, then, the members of the A` and B` perceptual classes would be linked through two intervening nodes, Aa and Bb. When the directionality of training is taken into consideration, probes such as Am–Bm and Ab–Ba would be generalization tests of two-node transitive relations, and probes such as Bm–Am or Ba–Ab would be generalization tests of two-node equivalence relations. As such, a linked perceptual class can be viewed as a type of generalized equivalence class (Fields & Reeve, 2000).

Finally, Fields and Reeve (2000) noted that generalized equivalence classes have essentially similar formal and structural properties as superordinate categories (Rosch & Mervis, 1975) and natural kinds (Gelman, 1988). These two phenomena have been used as cognitive models of the complex categories that are found in real-world settings. Since a linked perceptual class is a form of generalized equivalence class, it is possible that the training variables that affected the emergence of linked perceptual classes would have similar effects on the establishment of superordinate categories and natural kinds. Empirical confirmation would be a step toward the integration of the study of categorization from behavior analytic and cognitive perspectives.

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