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# *THE FORMATION OF LINKED PERCEPTUAL CLASSES*

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Multiple-exemplar training with stimuli in four domains induced two new fill-based (A1′ and A2′) and satellite-image-based (B1′ and B2′) perceptual classes. Conditional discriminations were established between the endpoints of the A1′ and B1′ classes as well as the A2′ and B2′ classes. The emergence of linked perceptual classes was evaluated by the performances occasioned by nine cross-class probes that contained fill variants as samples and satellite variants as comparisons, along with nine other cross-class probes that consisted of satellite variants as samples and fill variants as comparisons. The 18 probes were first presented serially and then concurrently. Class-consistent responding indicated the emergence of linked perceptual classes. Of the linked perceptual classes, 70% emerged during the initial serial test. An additional 20% of the linked perceptual classes emerged during the subsequently presented concurrent test block. Thus, linked perceptual classes emerged on an immediate or delayed basis. Linked perceptual classes, then, share structural and functional similarities with equivalence classes, generalized equivalence classes, cross-modal classes, and complex naturally occurring categories, and may clarify processes such as intersensory perception.

*Key words:* linked perceptual classes, cross-class probes, generalized equivalence classes, intersensory perception, keyboard responding, college students

A perceptual class is a set of stimuli that can be arrayed along some continuum, all of which occasion the same response after it has been trained to occur in the presence of only some of the stimuli in the set (Fields & Reeve, 2001; Keller & Schoenfeld, 1950; Wasserman, Kiedinger, & Bhatt, 1988). This functional definition specifies class membership in the context of training and testing conducted using a simple discrimination paradigm. Perceptual classes, however, can also be defined in the context of a conditional discrimination paradigm. In this case, stimuli in at least two different experimenter-designated classes are presented as samples along with at least two comparison stimuli, each of which is drawn from one of the to-be-established classes. Reinforcement is provided for the selection of the comparison that comes from the same set as a prevailing sample. The stimuli in a set are acting as members of a category or a class when new stimuli in a set occasion the selection of the other stimuli in the same set (Astley & Wasserman, 1998; Fields & Reeve, 2001; Reeve & Fields, 2001). Regardless of paradigm, the control of behavior exerted by perceptual class is of substantial adaptive utility because it enables an individual to respond appropriately to novel stimuli encountered in the natural environment without benefit of direct training (Bruner, 1957, 1983; Margolis & Laurence, 1999; Pikas, 1966; Tiemann & Markle, 1990).

The stimuli in a perceptual class can be arrayed along a variety of continua that vary in complexity. For example, some classes, such as short and long line length, are defined as stimuli that are located in regions of simple physical continua (Reeve & Fields, 2001). Other classes, such as compactness, consist of stimuli that are located in regions of complex mathematically derived continua (Hrycenko & Harwood, 1980). Yet other classes, such as the pictures of human faces (Malott & Siddall, 1972) are defined in terms of the confluence of regions located along multiple continua (Shepard, 1987).

Although the stimuli in a perceptual class are related to each other, they can also become related to the stimuli in another perceptual class. For example, many pictures may constitute the class of images of a moth-

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er's face, and many sounds of the mother speaking may constitute a class of the mother's voice. If all of the faces occasion selection of the voices and vice versa, the stimuli in both classes constitute a single *linked perceptual class*. The two classes, however, need not come from different sensory modalities. Thus, a unimodal example of a linked perceptual class would be the pictures of a parent and the name of the parent written in different fonts, sizes, and degrees of handwritten clarity. The conditions needed to establish linked perceptual classes and to measure their existence have not been studied. The purpose of the current experiment was to document the establishment of linked perceptual classes.

After inducing four perceptual classes (A1′, A2′, B1′, and B2′), two classes were linked by the establishment of conditional discriminations between specific members of each class ($A^x \rightarrow B^x$). Thereafter, cross-class tests were conducted in an A′→B′ and a symmetrical B′→A′ format. For example, in the A1′-B1′ tests, three of the stimuli in the A1′ class were presented as samples along with three of the stimuli from B1′ and B2′ classes as comparisons. In the B2′-A2′ test, three of the stimuli in the B2′ class were presented as samples along with three stimuli from the A2′ and A1′ classes as comparisons. Performances occasioned by these tests documented the emergence of new cross-class relations among the stimuli in the nominally linked classes, thereby demonstrating the emergence of linked perceptual classes.

## METHOD

### *Participants*

Five undergraduate students at Queens College participated in the study. They were recruited from advanced psychology classes and were not familiar with the research area. Students received partial course credit upon completion of the experiment, regardless of performance. All participants were required to read and sign an informed consent statement prior to participation. The entire experiment lasted for about 3.5 hr and was completed in two sessions.

### *Apparatus and Stimuli*

The experiment was conducted with IBM-compatible personal computers that displayed all stimuli on 15-in. SVGA color monitors. Responses consisted of pressing specific keys on a standard keyboard. The experiment was controlled by custom software that programmed all stimulus presentations and recorded all keyboard responses.

All stimuli were presented in borderless squares (2.5 cm by 2.5 cm) on the computer monitor. Stimuli from six domains were used. Preliminary training was conducted with stimuli in four domains: female–male, abstract pictures, truck–car, and banded-elevation satellite images of areas of North Korea or Germany. These domains were referred to as W, X, Y, and Z, respectively. The main part of the experiment involved the presentation of stimuli from Domains A and B, which were fill-based stimuli and banded-elevation satellite images of areas of California and Haiti, respectively. The endpoints of each domain were the images illustrated in Figure 1. Although presented as black-and-white images in Figure 1, the stimuli in the W through Z and B domains were presented as multicolored RGB 24-bit images in the experiment. The stimuli in the A domain were presented as black-and-white images.

The stimuli that varied systematically between the endpoints of the W through Z and B domains were created with a commercially available morphing software program (Figuracion, 1998). The program produced the intermediate stimuli, called variants, by superimposing the endpoint stimuli of a domain on each other and changing their relative saliences. The resulting variants were located systematically along a dimension between the endpoint stimuli of a domain. Figure 2 illustrates the results of this process for the female–male domain. The software assigned values 000 and 500 to the endpoint stimuli on each domain and generated 498 intermediate stimuli that were arrayed between these endpoints. The intermediate morphed images had numerical values that varied between 000 and 500. The variants used in various parts of the experiment were the morphed images with values of 030, 070, 100, 130, 170, 210, 250, 280, 310, 340, 370, 390, 430, and 470.

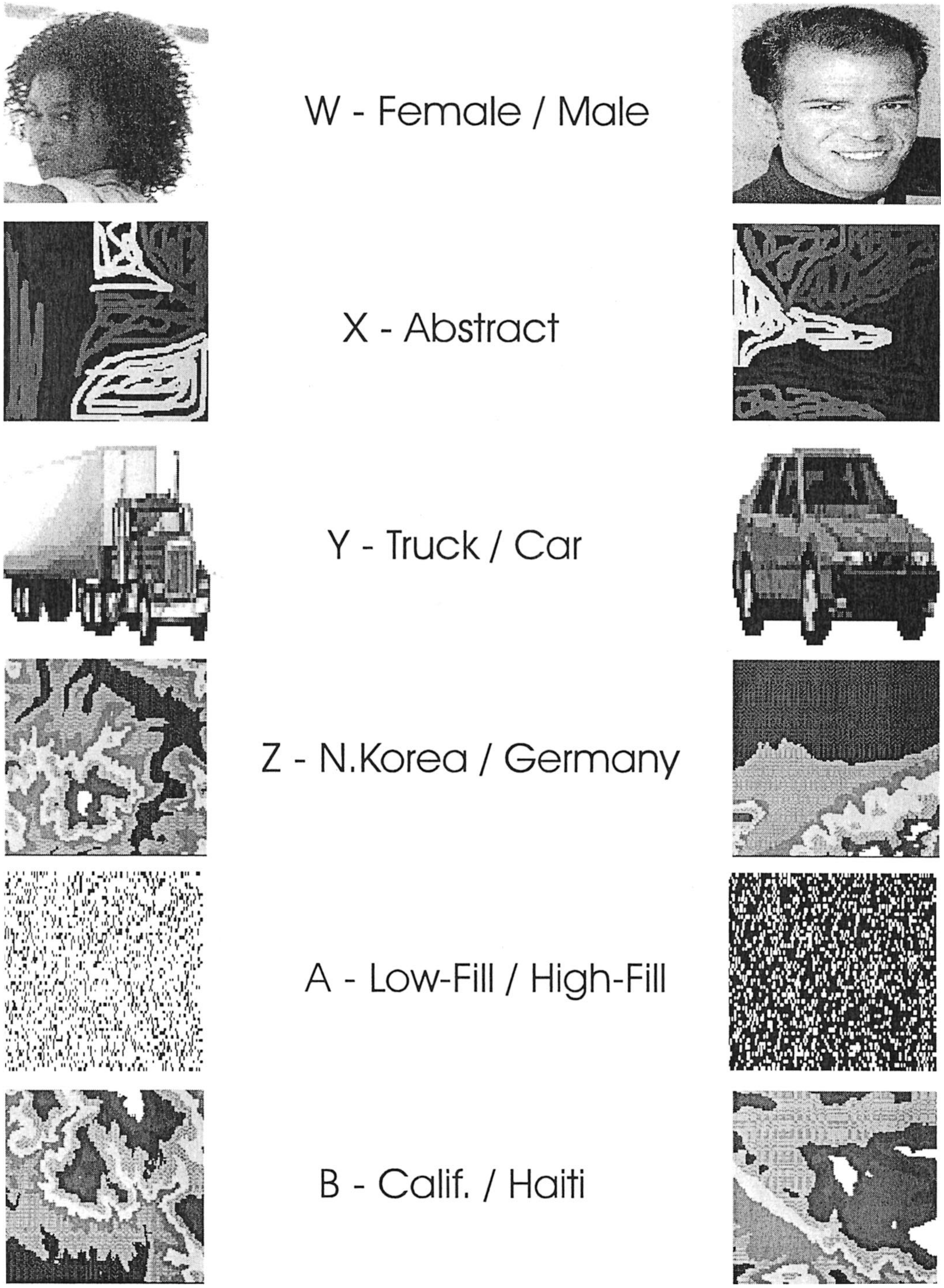


Fig. 1. The endpoints of all of the stimulus domains used in the experiment. Domains W, X, Y, and Z were used in preliminary training. The stimuli in Domains A and B were used in the experiment proper.

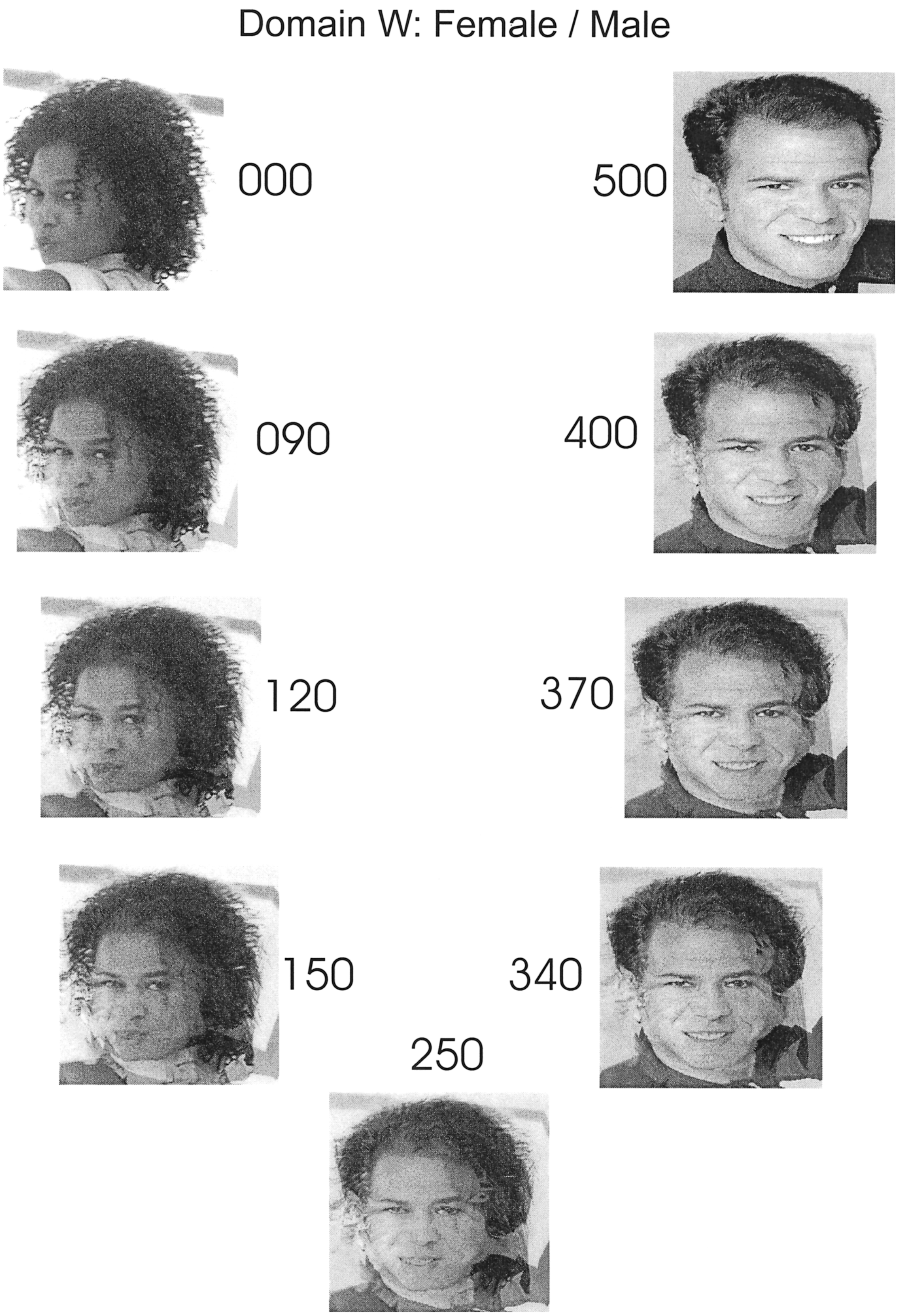


Fig. 2. Examples of the endpoints of the female–male dimension along with some of the morphed images on the morphed dimension. The numbers next to the stimuli are the values assigned to the images by the morphing software.

Domain A consisted of fill-based stimuli. These stimuli consisted of squares containing different percentages of dark pixels on a white background. The pixels were large enough that the squares did not appear as different shades of gray. The stimulus dimension was produced by varying the percentage of darkened pixels in the square. The fill values in the square ranged from 22% (Fill 22) to 78% (Fill 78) in 4% increments. For each fill value, the pattern of pixels was randomly generated with a customized utility developed in our laboratory and remained fixed throughout the experiment. Fill 22 and Fill 78 defined the endpoints of the fill dimension. Fill 50 was the physical midpoint of the dimension.

The stimuli at one end of a domain were assigned lower numerical values and will be referred to collectively as Class 1 stimuli. The stimuli at the other end of a domain were assigned higher values and will be referred to collectively as Class 2 stimuli. Preliminary training involved the use of stimuli in the W, X, Y, and Z domains. The identification of the variants that functioned as members of Classes 1 and 2 in each of these domains was accomplished in the following manner. Graduate laboratory assistants were asked to sort pictures (2.5 cm by 2.5 cm) of 15 variants for each domain. The endpoints of a domain were referred to as the anchor stimuli (a) of Classes 1 and 2 and were designated $X1^a$ and $X2^a$, respectively. One anchor stimulus was placed on a table, and the laboratory assistants selected the variant most distant from the anchor in the morphed dimension that were still viewed as being related to that anchor stimulus. The same procedure was repeated with the other anchor stimulus. The variants that were selected were referred to as the boundary (b) stimuli of each class and were designated as $X1^b$ and $X2^b$ for Classes 1 and 2, respectively. The anchor and boundary stimuli from one class were then placed on the table, and the assistants selected the variant that was perceptually equidistant from the anchor and boundary for that class. These stimuli that were selected were referred to as the midpoints (m) and were designated as $X1^m$ and $X2^m$ for Classes 1 and 2, respectively. Finally, the boundary stimuli for the two classes were placed on the table, and the assistants selected the variant that was perceptually equidistant from the boundaries of the respective classes. This stimulus was referred to as the *neither* stimulus (n) for the domain and was designated as $X^n$. It was called the neither stimulus because it was not a member of Class 1 or Class 2.

Assignment of specific variants as midpoint and boundary stimuli for both classes in the W, X, Y, and Z domains and the neither stimuli in these domains was based on the consensus of the sorts conducted by the laboratory assistants. Figure 3 contains the anchor, midpoint, and boundary stimuli for Classes 1 and 2 and the neither stimulus for the W, X, Y, and Z domains. Figure 3 also contains some representative stimuli in the A and B domains that are not necessarily the midpoint, boundary, and neither stimuli in those domains. The stimulus values assigned as the midpoint, boundary, and neither stimuli in these domains varied with each participant and were based on individual performance in Phase 3 of the experiment.

### *Procedure*

*Trial format and responses within a trial.* All trials used a matching-to-sample procedure (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 the third comparison was programmed, the words ''If NEITHER press 4'' appeared between the two other comparisons.

During a trial, the left or right comparison was selected by pressing the 1 or 2 key, respectively. Pressing the 4 key was the response that selected the neither comparison, when available. A comparison selection cleared the screen and concurrently 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 test trials, noninformative feedback was scheduled following a compar-

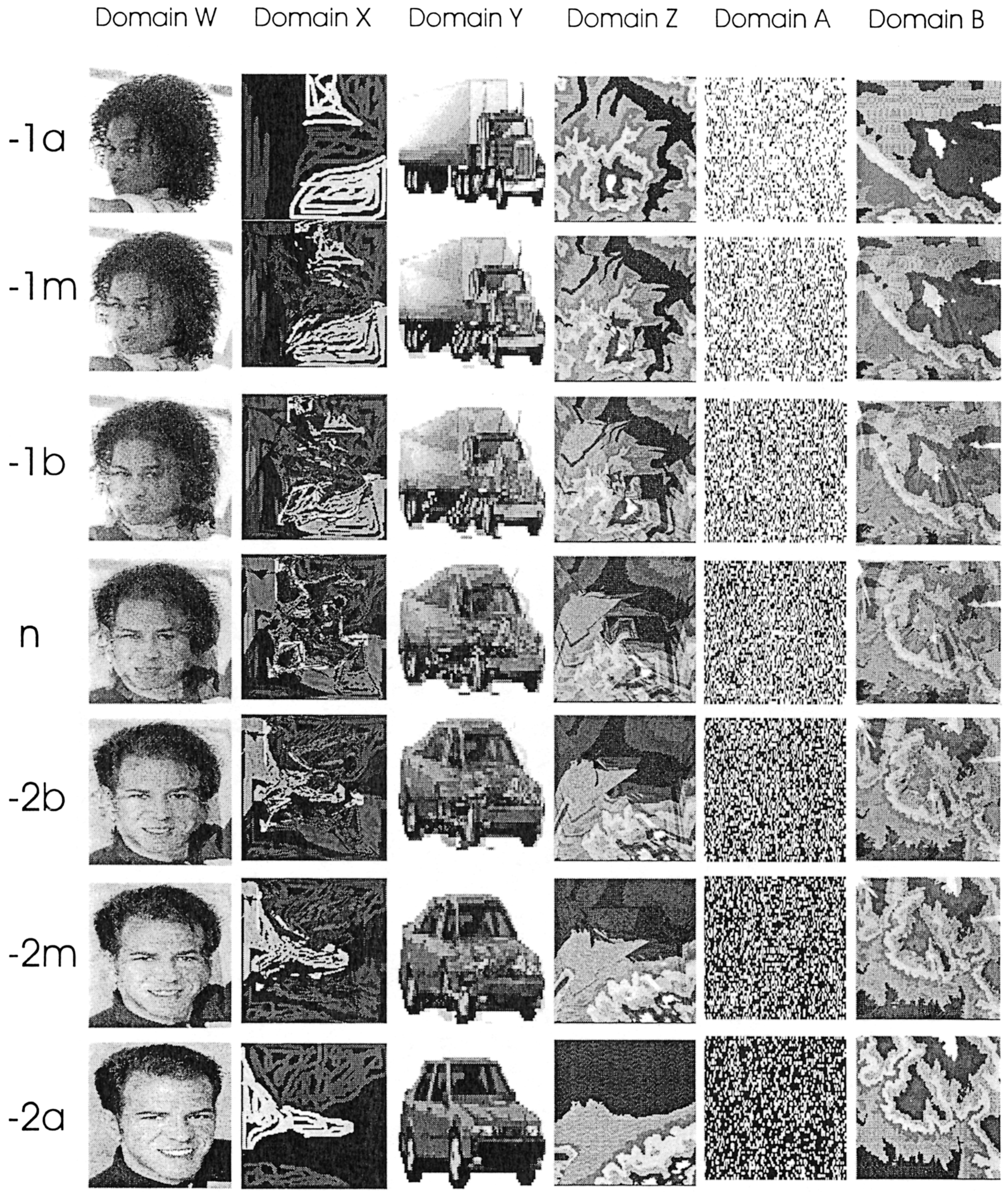


Fig. 3. Anchor, midpoint, and boundary stimuli for the classes at each end of the W, X, Y, and Z domains along with the neither stimulus in the respective domains. The anchor, midpoint, and boundary stimuli in the low classes in the W, X, Y, and Z domains are shown in rows 1 through 3, respectively. The variants assigned as the neither stimuli in the domains are shown in the fourth row for the W, X, Y, and Z domains. The boundary, midpoint, and anchor stimuli in the high classes in the W, X, Y, and Z domains are shown in rows 5 through 7, respectively. Variants in the A and B domains are illustrated in the last two columns. The anchor stimuli for the low and high classes in these two domains are illustrated in rows 1 and 7. The stimuli illustrated in columns 2 through 6 are variants that fall between the anchor stimuli but are not necessarily the midpoints, boundaries, or neither stimuli for the A and B domains. The variants that served those functions were determined by a participant's performance in the three-choice generalization tests.

ison selection. This consisted of a dashed line surrounding 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 noninformative 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 of training and testing was conducted with blocks of trials. Within each block in all experimental phases, the trials were presented in a random order without replacement. At the start of training, a block was presented repeatedly with informative feedback after each comparison selection until all trials within the block occasioned 100% correct responding. Thereafter, the percentage of trials that occasioned informative feedback was reduced to 75%, 25%, and finally to 0% over successive blocks as long as comparison selections on all trials were accurate. During feedback reduction, the trials that were followed by informative feedback were randomly determined. 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 that particular block.

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

> Thank you for volunteering to participate. PLEASE DO NOT TOUCH ANY KEYS ON THE KEYBOARD YET! You will be presented with many trials. Each trial contains three or four CUES that are shapes, symbols, or common words. YOUR TASK IS TO DISCOVER HOW TO RESPOND CORRECTLY TO THE CUES BY PRESSING CERTAIN KEYS ON THE COMPUTER'S KEYBOARD. Initially, INSTRUCTIONS will tell you how to respond to the cues, and LABELS will help you identify the cues on the screen. The labels and instructions will slowly disappear. The experiment is conducted in phases. When each phase ends, the computer will sometimes tell you how you did. If you want to take a break at any time, call the experimenter. Thank you for your cooperation! Press the space bar to continue.

After pressing the space bar, students learned to emit the appropriate keyboard responses to complete a trial. To accomplish this, 16 trials, each containing three English words (e.g., *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. Informative feedback followed each comparison selection (see Fields, Reeve, Adams, Brown, & Verhave, 1997, for further details).

Correct responding to the stimuli in a trial during Phase 1 was also facilitated by instructional prompts (e.g., ''Make your choice by pressing 1 or 2'') that were deleted in a serial manner across trials (see Fields, Reeve, Adams, Brown, & Verhave, 1997, or Fields, Adams, Verhave, & Newman, 1990, for further details). Phase 1 ended once the stimuli were presented without prompts and performance exceeded 87.5% accuracy (14 of 16 correct trials) during a single block. In the remaining phases, the instruction used to prompt the appropriate key press during keyboard familiarization (Phase 1) reappeared on the screen for three subsequent trials whenever a participant pressed a nonexperimentally defined key during a trial.

*Phase 2: Generalized categorization repertoire: WXYZ(amb-a) training.* The goal of the experiment was to link perceptual classes, each of which was spontaneously emergent. Fields et al. (2002) found that multiple-exemplar training with stimuli in a number of different domains induced the spontaneous categorization of stimuli in new domains. That approach was used in the current experiment.

Multiple-exemplar training was conducted with the stimuli in the W, X, Y, and Z domains to induce a generalized categorization repertoire. In each domain, the anchor, midpoint, and boundary stimuli from the two experimenter-defined classes were presented as samples. The comparisons consisted of the pair of anchor stimuli from the same domain. Reinforcement was presented for the selection of the comparison from the same class as the sample. All trials also contained a neither option, also called a default option (Innis, Lane, Miller, & Critchfield, 1998), as a third comparison. Reinforcement was presented for the selection of the neither comparison when the neither stimulus was presented as the sample. Training was conducted with the stimuli in the W domain first, and was then repeated with the stimuli from the X, Y, and Z domains. This procedure made it likely that the stimuli in the A and B domains would be categorized without direct training.

*Phase 3: Emergence of fill-based and satellite-based classes.* Fields, Matneja, Varelas, and Belanich (in press) showed that the width of the same nominal perceptual class differed when variants were presented as sample stimuli in *variant-to-base* tests or as comparison stimuli in *base-to-variant* tests. In the current experiment, the widths of the fill-based classes and the satellite-based classes were identified with tests conducted in both the variant-to-base and base-to-variant formats.

Fields and Reeve (2001) showed that the functional separation of classes along a continuum could be documented by the selection of a neither comparison during generalization test trials. Specifically, if stimuli beyond the boundaries of the classes at opposite ends of a continuum occasioned the selection of a neither comparison, the two classes were functionally separable and independent of each other. In the current experiment, the widths of the classes at each end of the fill- and satellite-based domains were also determined with generalization test trials that included two stimuli that were members of different classes and a neither option as comparisons. Thus, the widths of the classes could be documented along with their functional independence.

*Variant-to-base tests.* In the variant-to-base tests conducted with fill-based stimuli (i.e., $A'$-A tests), all of the fill-based variants were presented as samples with the Fill 22, the Fill 78, and the neither options presented as comparisons. The same procedure was used in the variant-to-base tests conducted with satellite-based stimuli (i.e., $B'$-B tests), all of the variants of the satellite stimuli were presented as samples with the Satl 000, the Satl 500, and the neither option presented as comparisons.

For each fill variant presented as a sample, we measured the likelihood of selecting each of the low-fill, high-fill, and neither comparisons. For each satellite variant presented as a sample, we measured the likelihood of selecting the low-satl, high-satl, and neither comparisons. These performances were used to identify the values of the midpoint ($A^m$) and boundary ($A^b$) stimuli for the two fill-based and two satellite-based classes.

For example, when Class A1 is considered, the anchor stimulus was $A1^a$ and had a value of Fill 22. The boundary stimulus of the class, $A1^b$, was the variant of A most distant from A1 that occasioned the selection of A1 on at least 88% of trials. The midpoint of the class, $A1^m$, was the variant value that was approximately half way between $A1^a$ and $A1^b$. The midpoint and boundary variants for the high-fill or $A2'$ class were defined similarly. In addition, the neither stimulus, or $A^n$, was the variant that was approximately half way between the boundary stimuli from the high-fill and low-fill classes, or Classes $A1'$ and $A2'$. The same criteria were used to identify the midpoint and boundary stimuli for the low- and high-satl classes, or Classes $B1'$ and $B2'$ and the neither stimulus on the B domain.

*Base-to-variant tests.* In all base-to-variant tests conducted with fill-based stimuli (i.e., A-$A'$ tests), one of the endpoint stimuli on the fill dimension was presented as a sample, the other endpoint fill-based stimulus was presented as the nominal negative comparison, and all trials also contained the neither comparison. The variants of the fill patterns were presented as the other comparison. Half of the trials contained Fill 22 as the sample with Fill 78 and the neither option as constant comparisons and variants from Fill 22 to Fill 66 as the other comparisons. The other trials contained Fill 78 as the sample with Fill 22 and the neither option as constant comparisons and the variants from Fill 78 to Fill 34 as the other comparisons.

The performances generated by these tests identified the values of the midpoint ($A^m$) and boundary ($A^b$) stimuli for the two fill-based classes. With regard to the A1 class, $A1^b$ (the boundary stimulus of the class) was the variant that was most distant from $A1^a$ that was selected on at least 88% of trials in the presence of the A1 sample. $A1^m$ (the midpoint stimulus of the class) was the fill value closest to being half way between $A1^a$ and $A1^b$. The midpoint and boundary variants for the other class were designated similarly. In contrast, the anchor stimulus for each class was the same for all participants. The availability of the neither comparison permitted the functional separation of the range of fill variants that functioned as members of the low-and high-fill classes.

When base-to-variant tests were conducted with the stimuli in the satellite domain (i.e., B-B′ tests), half of the base-to-variant test trials contained Satl 000 as the sample, with Satl 500 and the neither option as constant comparisons and Satl 000 to Satl 370 as the other comparison. The remaining base-to-variant trials contained Satl 500 as the sample, with Satl 000 and the neither option as constant comparisons and Satl 500 to Satl 130 as the other comparison. The variants that were the midpoints and boundaries of the satellite-based classes and the neither variant were identified as described in Phase 3. The criteria used to identfy the midpoint, boundary, and neither stimuli in the satellite domain were the same as those used for stimuli in the fill domain.

*Presentation schedule of variant-to-base and base-to-variant tests.*The variant-to-base and base-to-variant test blocks were presented with stimuli from the fill-based domain first and then with stimuli from the satellite-based domain. For stimuli in a given domain, the variant-to-base and base-to-variant test blocks were presented four times each in simple alternation. Regardless of test format, each test block included two presentations of each variant for a total of eight presentations of each variant in each test format.

*Phase 4: Establishment of fill and satellite relations.* Linkages between two distinct perceptual classes were nominally formed by the establishment of $A^a \rightarrow B^a$ and $A^b \rightarrow B^b$ conditional discriminations between the anchor stimuli of fill-based and satellite-based classes and the boundary stimuli of the same two classes. On some trials, the anchor stimuli $A1^a$ and $A2^a$ were presented as samples with the anchor stimuli from Classes B1 and B2 as comparisons. Reinforcement was presented for the selection of the comparison with the same class number designation as the sample. On the other trials, the boundary stimuli $A1^b$ and $A2^b$ were presented as samples with the boundary stimuli from Classes $B1^b$ and $B2^b$ as comparisons. Reinforcement was presented for the selection of the comparison with the same class number designation as the sample. Training was conducted in 16-trial blocks and was completed when a participant made no errors during a block that contained no informative feedback.

Table 1

Symbolic representation of stimuli used in the cross-class probes. Each line indicates the stimuli used in two cross-class probes. Both probes share the same set of comparison stimuli, but the positive comparison is different for each class. Superscripts designate anchor, midpoint, and boundary functions for each stimulus. NC designated the neither comparison.

| Test format | Class 1 probes | | | | Class 2 probes | | | |
|---|---|---|---|---|---|---|---|---|
| | Sa | Co+ | Co− | Co− | Sa | Co+ | Co− | Co− |
| $A' \rightarrow B'$ | $A1^a$ | $B1^a$ | $B2^a$ | NC | $A2^a$ | $B2^a$ | $B1^a$ | NC |
| | $A1^a$ | $B1^m$ | $B2^m$ | NC | $A2^a$ | $B2^m$ | $B1^m$ | NC |
| | $A1^a$ | $B1^b$ | $B2^b$ | NC | $A2^a$ | $B2^b$ | $B1^b$ | NC |
| | $A1^m$ | $B1^a$ | $B2^a$ | NC | $A2^m$ | $B2^a$ | $B1^a$ | NC |
| | $A1^m$ | $B1^m$ | $B2^m$ | NC | $A2^m$ | $B2^m$ | $B1^m$ | NC |
| | $A1^m$ | $B1^b$ | $B2^b$ | NC | $A2^m$ | $B2^b$ | $B1^b$ | NC |
| | $A1^b$ | $B1^a$ | $B2^a$ | NC | $A2^b$ | $B2^a$ | $B1^a$ | NC |
| | $A1^b$ | $B1^m$ | $B2^m$ | NC | $A2^b$ | $B2^m$ | $B1^m$ | NC |
| | $A1^b$ | $B1^b$ | $B2^b$ | NC | $A2^b$ | $B2^b$ | $B1^b$ | NC |
| $B' \rightarrow A'$ | $B1^a$ | $A1^a$ | $A2^a$ | NC | $B2^a$ | $A2^a$ | $A1^a$ | NC |
| | $B1^a$ | $A1^m$ | $A2^m$ | NC | $B2^a$ | $A2^m$ | $A1^m$ | NC |
| | $B1^a$ | $A1^b$ | $A2^b$ | NC | $B2^a$ | $A2^b$ | $A1^b$ | NC |
| | $B1^m$ | $A1^a$ | $A2^a$ | NC | $B2^m$ | $A2^a$ | $A1^a$ | NC |
| | $B1^m$ | $A1^m$ | $A2^m$ | NC | $B2^m$ | $A2^m$ | $A1^m$ | NC |
| | $B1^m$ | $A1^b$ | $A2^b$ | NC | $B2^m$ | $A2^b$ | $A1^b$ | NC |
| | $B1^b$ | $A1^a$ | $A2^a$ | NC | $B2^b$ | $A2^a$ | $A1^a$ | NC |
| | $B1^b$ | $A1^m$ | $A2^m$ | NC | $B2^b$ | $A2^m$ | $A1^m$ | NC |
| | $B1^b$ | $A1^b$ | $A2^b$ | NC | $B2^b$ | $A2^b$ | $A1^b$ | NC |

At the completion of training, the symmetrical properties of the $A \rightarrow B$ conditional discriminations was assessed in two 24-trial test blocks, each of which contained baseline review trials ($A^a \rightarrow B^a$ and $A^b \rightarrow B^b$) and symmetry probe trials for each trained conditional discrimination ($B^a \rightarrow A^a$ and $B^b \rightarrow A^b$). The $A^a$-$B^a$ trials used Fill 22 and Fill 78 stimuli as samples with Satl 000 and Satl 500 as the comparison pairs on all trials. The $B^a$-$A^a$ trials used the Satl 000 or Satl 500 as samples with Fill 22 and Fill 78 as the comparison pair on all trials. The criterion for demonstrating the emergence of symmetry involved the selection of the set-consistent comparisons on at least 94% of the trials in a test block.

*Phase 5: Emergence of cross-class relations.* The emergence of relations between members of the A′ and B′classes was assessed with cross-class probes conducted in A′- B′ and B′-A′ formats. Table 1 lists all of the trials presented in each test format. All of the A′-B′ probes involved the presentation of samples that were the anchor, midpoint, and boundary variants from the two fill-based classes with comparison pairs of the anchor, midpoint, or boundary stimuli from the two satellite-based classes. Nine different cross-class probes were presented in the A′-B′ format for each linked perceptual class.

All of the B′-A′ probes involved the presentation of samples that were the anchor, midpoint, and boundary variants from the two satellite-based classes with comparison pairs of the anchor, midpoint, or boundary stimuli from the two fill-based classes. Nine different cross-class probes were presented in the B′-A′ format for each linked perceptual class. All A′-B′ and B′-A′probe trials also included the neither option as a third comparison to enable a participant to indicate that the sample did not go with the other two comparison stimuli. The A′-B′ and B′-A′ probes were presented first in a serial manner and second in a concurrent manner.

*Serial testing.* In serial testing, the nine A′-B′ probes were presented in three subtests and the nine B′-A′ probes were presented in three other subtests. In the three A′- B′ subtests, the anchor, midpoint, and boundary stimuli from the A domain were presented as samples. In the first subtest, the anchor stimuli from the B domain were presented as comparisons. In the second subtest, the midpoint stimuli from the B domain were presented as comparisons. In the third subtest, the boundary stimuli from the B domain were presented as comparisons. In next three B′-A′ subtests, the anchor, midpoint, and boundary stimuli from the B domain were presented as samples. Thus, in the fourth subtest, the anchor stimuli from the A domain were presented as comparisons. In the fifth subtest, the midpoint stimuli from the A domain were presented as comparisons. Finally, in the sixth subtest, the boundary stimuli from the A domain were presented as comparisons. Each of the six subtests contained 48 trials, eight presentations of each of six sample–comparison combinations. All probes in a subtest were presented with no differential feedback and in a block-randomized order.

*Concurrent testing.* Concurrent testing was divided into two subtests. First, all nine A′- B′ probes were presented in a single block of trials. Second, all nine B′-A′ probes were presented in a single block of trials. The 144 trials presented in each block contained eight presentations of six samples in combination with each of three comparison sets. The comparisons were presented an equal number of times on the left and the right. All probes were presented with no differential feedback and in a block-randomized order without replacement.

*Assignment of stimulus values in cross-class tests.* During the A′-B′ and B′-A′ tests, the anchor, midpoint, and boundary stimuli for a given class were presented as samples in one test and as comparisons in the other. Although the values assigned to the anchor stimuli were constant in all tests, this was not necessarily the case with the midpoint and boundary stimuli. The results of the variant-to-base and base-to-variant tests could have identified different values for the same nominal midpoint stimulus in a given perceptual class, and likewise for the boundary stimuli. Thus, the actual values of the midpoint and boundary stimuli for the same class used in the cross-class tests were those obtained from the results of the variant-to-base and base-to-variant tests. When midpoint or boundary stimuli were presented as samples in cross-class tests, their actual values were those obtained from the variant-to-base tests. When midpoint or boundary stimuli were presented as comparisons in cross-class tests, their actual values were those obtained from the base-to-variant tests.

## RESULTS

*Measurement of perceptual classes.* Figure 4 (left column) illustrates the results of the variant-to-base tests conducted with the satellite-based variants for a representative participant, Subject 2328. Satl 500 was selected on at least 88% of trials in the presence of variants that ranged in value from Satl 500 to Satl 310. Thus, Satl 310 was $B2^b$, the boundary value for the high-satellite class. Satl 390 was $B1^m$, the midpoint stimulus of the high-satellite class. For variants beyond the boundary stimulus, the likelihood of selecting Satl 500 declined systematically with further decreases in the value of the satellite-based samples.

Satl 000 was selected on at least 88% of trials in the presence of variants with values that ranged from Satl 000 to Satl 210. Thus, Satl 210 was $B1^b$, the boundary value for the low-satellite class. Satl 100 was $B1^m$, the midpoint stimulus of the low-satellite class. For variants beyond the boundary stimulus, the likelihood of selecting Satl 000 declined systematically

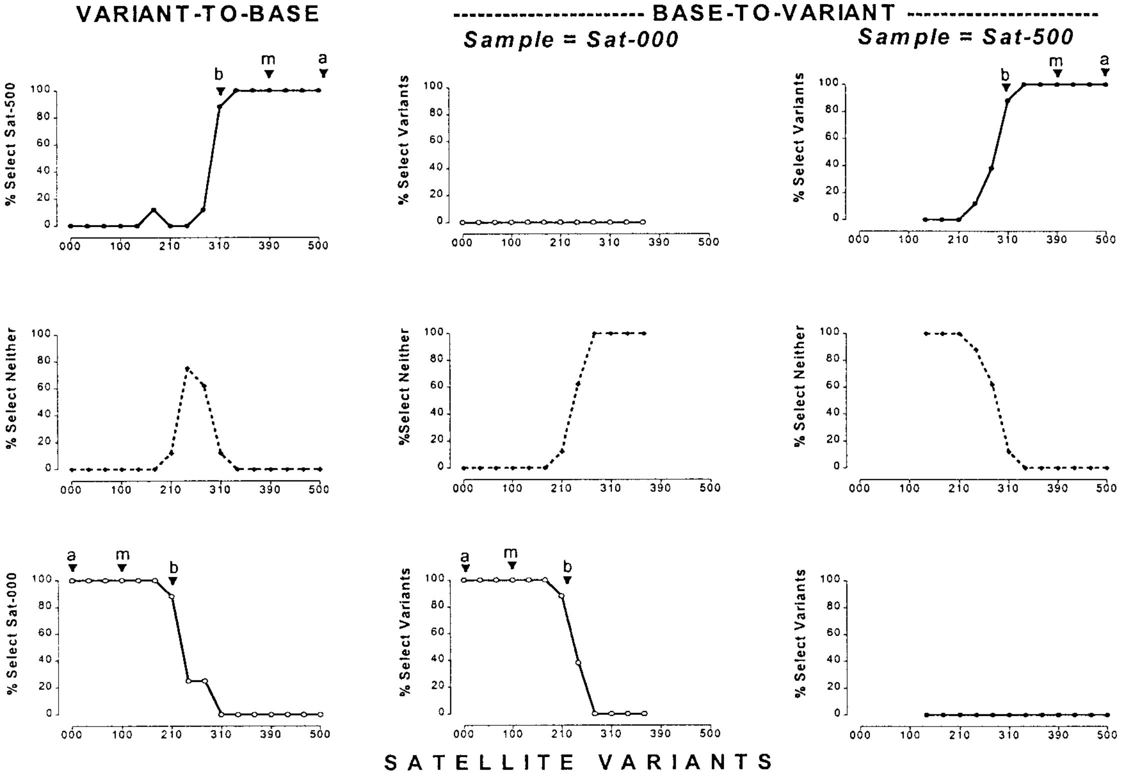


Fig. 4. The results of the variant-to-base and base-to-variant tests during Phase 5 for Subject 2328. The three graphs in the left column indicate results of the variant-to-base tests and plot the likelihood of selecting Satl 22, the neither comparison, and Satl 78 as functions of the value of the satellite 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 satellite variants, the neither comparison, and the negative comparison in the presence of Satl 22 as functions of the values of the satellite variants presented as comparisons. The right column plots likelihoods of selecting the satellite variants, the neither comparison, and the negative comparison in the presence of Satl 78 as functions of the values of the satellite variants presented as comparisons.

with further increases in the value of the fill-based samples.

The likelihood of selecting the neither comparison increased in a complementary manner with decrements in the selection of the other comparisons. Satl-250 occasioned the maximum likelihood of neither comparison selection. Finally, the likelihood of selecting the negative comparison (Co−) was low regardless of sample value.

Figure 4 (middle and right columns) presents the results of a base-to-variant test conducted with the fill variants. The Satl 000 sample occasioned the selection of Satl 000 to Satl 210 on at least 88% of trials. Thus, Satl 210 served as $B1^b$, the boundary value for the low-satellite class. $B1^m$, the midpoint stimulus of the low-satellite class, was Satl 100. The likelihood of selecting the neither comparison increased in a complementary manner with declines in the selection of the variable comparison, and reached asymptote at Satl 280. In addition, there was a very low likelihood of selecting the Co− regardless of sample value.

Satl 500 occasioned the selection of variants Satl 500 to Satl 310 on at least 88% of trials. Thus, Satl 310 served as $B2^b$, the boundary value for the high-satellite class. $B2^m$, the midpoint stimulus of the high-satellite class, was Satl 390. The likelihood of selecting the neither comparison increased in a complementary manner with declines in the selection of the other two comparisons, and reached asymptote at Satl 210. Finally, there was a very low likelihood of selecting the Co− on any trial regardless of Co+ value. The same procedures were used to identify the midpoint and boundary values for low-satellite, low-fill, and high-fill classes for each participant in each test format.

*Perceptual class width.* Figure 5 shows the range of variants that functioned as members of the low-fill (A1′), high-fill (A2′), low-satellite (B1′), and high-satellite (B2′) classes. The ranges were specified by plotting the anchor and boundary values for each class in each test format. Because 5 participants were studied in the experiment, two classes emerged in each of two domains, the width of each class was measured using two test formats, and 20 pairs of class widths were measured. Each pair of class widths was called a *case.* In 10 cases, the same variants functioned as members of a given class under both test formats, as indicated by pairs of bars of equal height. In seven additional cases, more variants functioned as members of a given class during base-to-variant than variant-to-base tests. The height of the base-to-variant bar was higher than the height of the variant-to-base bar. In the three remaining cases, the opposite was observed.

*Reaction time.* The discriminability of the anchor, midpoint, and boundary stimuli in the emergent classes was measured using reaction time. The reaction times occasioned by the anchor, midpoint, and boundary stimuli in each putative fill- and satellite-based class were measured from the observing response emitted in the presence of a sample to the selection of any comparison. Reaction times were averaged separately for the anchor, midpoint, and boundary stimuli. These reaction times were averaged across participants, domains, and classes in a domain because systematic differences were not found across these factors. Because the variances of the raw reaction time values were not homogeneous across the three types of stimuli, the variances were equalized by conducting a reciprocal transform on the reaction time data. An analysis of variance conducted on those reciprocals confirmed that the reaction times occasioned by the different class members were significant, $F(2, 114) = 22.49$, $p < .0001$.

Figure 6 displays the mean reaction times occasioned by the anchor, midpoint, and boundary stimuli in the emergent fill- and satellite-based classes. The shortest average reaction time was occasioned by the anchor stimuli in the classes. The reaction times oc-

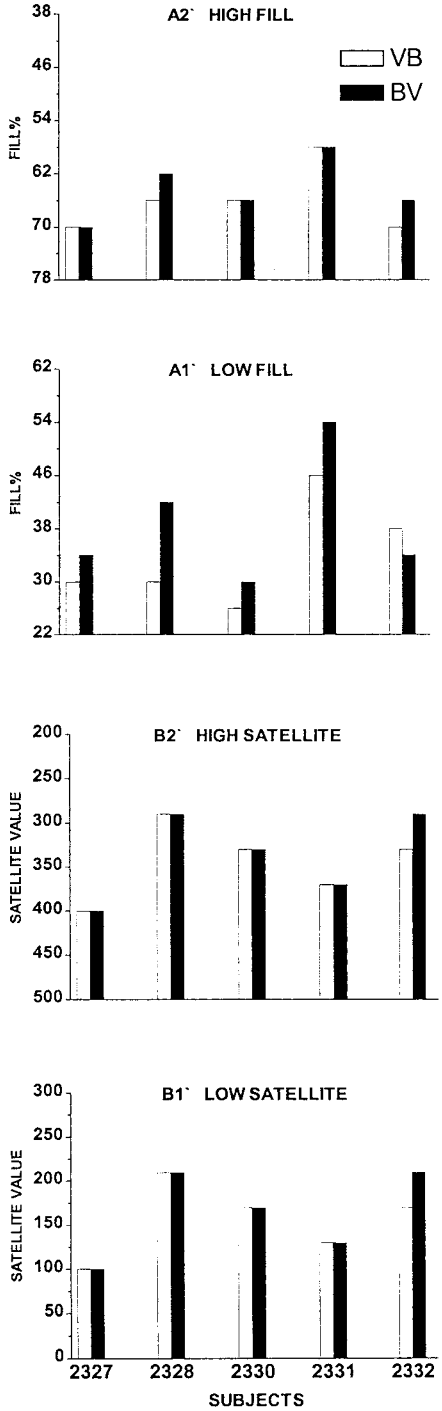


Fig. 5. The widths of the low-fill (A1′), high-fill (A2′), low-satellite (B1′), and high-satellite (B2′) classes for each participant obtained during the variant-to-base and base-to-variant tests. The bottom and top of each bar represent the anchor and boundary variants for each class.

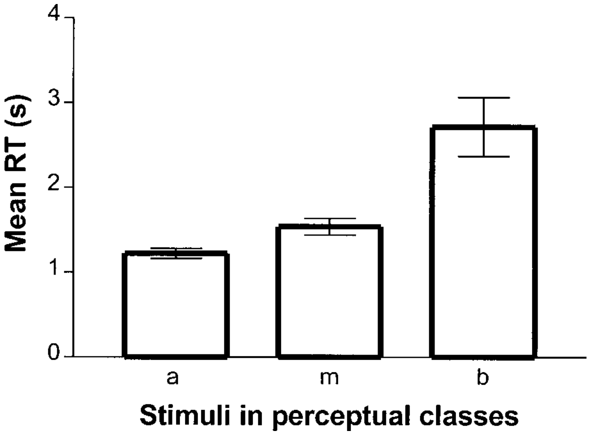


Fig. 6. Average reaction times occasioned by the anchor, midpoint, and boundary stimuli in the perceptual classes. Data were averaged for each type of stimulus across classes in the fill and satellite domains and across the two classes that emerged in each domain. The top and bottom of each I-beam represent ±1 *SE*.

Table 2

Number of blocks needed to acquire the $A^a \rightarrow B^a$ and $A^b \rightarrow B^b$ conditional discriminations and pass the $B^a \rightarrow A^a$ and $B^b \rightarrow A^b$ symmetry tests for each subject. The bottom line lists the percentage of trials that occasioned correct comparison selection during the symmetry test blocks.

| | | Subject | | | | |
|---|---|---|---|---|---|---|
| Condition | %FB | 2330 | 2332 | 2331 | 2328 | 2327 |
| Train | 100 | 5 | 3 | 22 | 5 | 2 |
| | 75 | 1 | 1 | 1 | 2 | 1 |
| | 25 | 1 | 1 | 1 | 1 | 1 |
| | 0 | 1 | 1 | 1 | 2 | 2 |
| Symmetry | 0 | 1 | 1 | 1 | 1 | 1 |
| % correct | | 89[a] | 98 | 100 | 94 | 100 |

[a] Experimenter error.

casioned by the midpoint and boundary stimuli were a direct function of their distance from the anchor stimulus. Newman–Keuls post hoc tests of pair-wise comparisons showed significant differences in the reaction times occasioned by the anchor and midpoint ($q = 3.88$, $p < .01$), midpoint and boundary ($q = 5.555$, $p < .001$), and anchor and boundary stimuli ($q = 9.435$, $p < .001$).

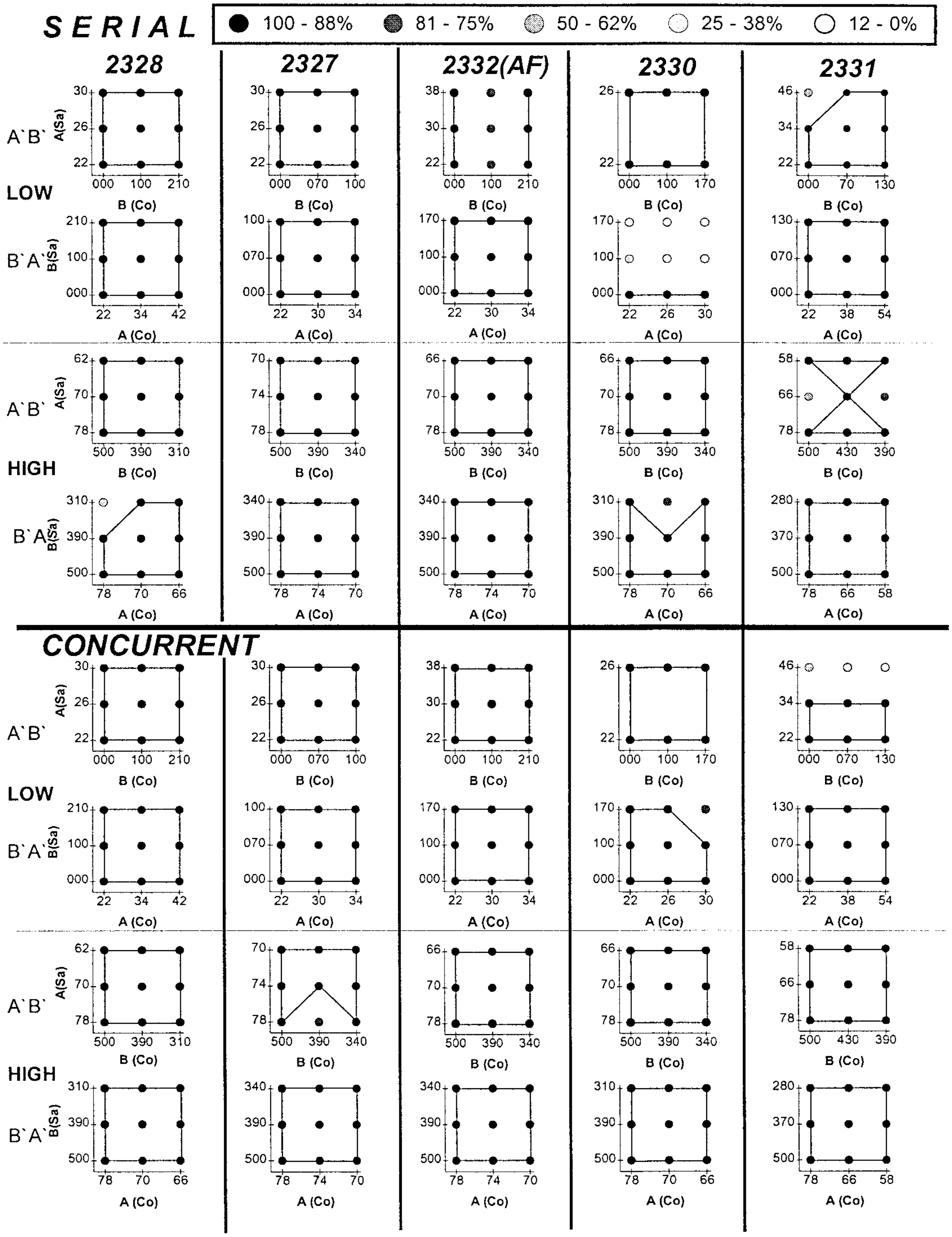
*Acquisition of* $A^a \rightarrow B^a$ and $A^b \rightarrow B^b$ conditional relations. Table 2 shows that most participants learned the $A^a \rightarrow B^a$ and $A^b \rightarrow B^b$ conditional discriminations in a few blocks and maintained mastery level performances during the reduction of feedback. All participants passed the $B^a \rightarrow A^a$ and $B^b \rightarrow A^b$ tests used to evaluate the symmetrical properties of the stimuli in each conditional discrimination. These data, then, demonstrate that bidirectional conditional relations had been established between the anchor stimuli in each pair of A′ and B′ perceptual classes and between the boundary stimuli in the same pairs of classes.

*Cross-class test performances.* Each graph in Figure 7 illustrates the emergence of cross-class relations among the stimuli in the nominally linked A′ and B′ classes. The stimulus domain indicated on each axis differs with testing format. In the A′-B′ tests, the fill and satellite stimuli were displayed on the ordinate and abscissa, respectively. In the B′-A′ tests, the satellite and fill stimuli were displayed on the ordinate and abscissa, respectively.

The stimuli on each axis are scaled in an ordinal manner, with the anchors at the origins of each axis. The actual values of each stimulus are listed at the positions represented by the anchor, midpoint, and boundary for each class on each axis. The black bar on each axis indicates the range of variants that functioned as members of the fill- or satellite-based class, as determined in the within-class test conducted in Phase 3.

All graphs contain nine data points, each of which represents the performance occasioned by different combinations of fill and satellite variants. The darkness of each data point indicates the likelihood of selecting the comparison from a given class in the presence of the sample drawn from the other class to which it was nominally linked by training. The continuous line that connects the data points demarcates all of the variants from one class that occasioned the selection of all of the variants of the nominally linked class on at least 88% of trials.

The upper half of Figure 7 presents the results of the serially conducted A′-B′ and B′-A′ tests for each class for each participant. In 14 of the 20 cases, all of the stimuli in one class occasioned the selection of all of the stimuli in the linked perceptual class. In three other cases (e.g., Subject 2328, high B′-A′), the stimuli in one class occasioned the selection of the stimuli in the linked classes in eight of the nine cross-class probes. In the


SERIAL
● 100 - 88%
● 81 - 75%
● 50 - 62%
○ 25 - 38%
○ 12 - 0%
2328
2327
2332(AF)
2330
2331
A`B`
LOW
B`A`
A`B`
HIGH
B`A`
CONCURRENT
A`B`
LOW
B`A`
A`B`
HIGH
B`A`
A(Sa)
B(Sa)
B (Co)
A (Co)

three remaining cases, the stimuli in one class occasioned the selection of the stimuli in the linked classes in three to seven of the nine cross-class probes.

The lower half of Figure 7 presents the results of the concurrently conducted A′-B′ and B′-A′ tests. In 17 of the 20 cases, all of the stimuli in one class occasioned the selection of all of the stimuli in the linked perceptual class. In two cases, the stimuli in one class occasioned the selection of the stimuli in the linked classes in eight of the nine cross-class probes. In the one remaining case, only the anchor and midpoint stimuli in one class occasioned the selection of all of the stimuli in the linked perceptual class in the B′-A′ test.

*Conditional discriminations.* A conditional discrimination is demonstrated when a given comparison is selected in the presence of one sample from one class and is not selected in the presence of sample drawn from another unrelated class. In the low A′-B′ trials, Class B1′ comparisons were selected in the presence of Class A1′ samples. In the high A′-B′ trials, the Class B2′ comparisons were selected in the presence of the Class A2′ samples. Therefore, the Class B1′ comparisons were not selected in the presence of the Class A2′ samples. The same can be said for the B′-A′ trials. Performances occasioned by the A1′-B1′ and A2′-B2′ probes, then, demonstrated the emergence of conditional discriminations during the cross-class tests.

Errors occurred relatively infrequently during these cross-class test trials. When they did occur, however, participants most frequently selected the neither comparisons rather than the stimuli from the unrelated class. These results demonstrated the functional independence of the conditional discriminations that emerged during the cross-class tests.

*Immediate and delayed emergence.* Serial tests were followed by concurrent tests. A comparison of the performances occasioned by the two tests documented the immediate and delayed emergence of cross-class relations and the maintenance of those performances for particular tests for a given class for individual participants. In 14 of 20 cases, the initial serial tests resulted in the selection of all of the stimuli in one perceptual class when presented with all of the stimuli in the related perceptual class. These cases demonstrated the immediate emergence of cross-class relations. In 13 of these 14 cases, performances were maintained in the subsequent test, which demonstrated the maintenance of cross-class relations. In the one remaining case, one of the nine probes showed a small decrement in cross-class responding with test repetition (Subject 2327, high A′-B′).

In six additional cases, the initial serial tests yielded performances that were not at criterion. In four of these cases, test repetition resulted in the selection of all of the stimuli in one perceptual class when presented with stimuli in the related perceptual class. In one additional case (Subject 2330, low B′-A′), the level of comparison selection increased from serial to concurrent testing but narrowly

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Fig. 7. Performances occasioned by all cross-class probes presented in the A′-B′ and B′-A′tests. Each column contains the data for 1 participant. The graphs in the four top rows contain the results of the serially presented variant-to-variant tests. Rows 1 through 4 depict the outcomes of the A′-B′ test for the low A/B classes, the B′-A′ test for the low A/B classes, the A′-B′ test for the high A/B classes, and the B′-A′ test for the high A/B classes, respectively. The graphs in the four bottom rows contain the results of the concurrently presented variant-to-variant tests. Rows 5 through 8 depict the outcomes of the A′-B′ test for the low A/B classes, the B′-A′ test for the low A/B classes, the A′-B′ test for the high A/B classes, and the B′-A′ test for the high A/B classes, respectively. Each graph or "dot plot" contains an abscissa that lists the values of the anchor, midpoint, and boundary stimuli from left to right for the stimuli presented as comparisons. The ordinate lists the values of the anchor, midpoint, and boundary stimuli from bottom to top for stimuli presented as samples. Each axis lists stimulus values for one class arrayed on an ordinal scale. These values indicate the range of stimuli that functioned as members of the fill- and satellite-based classes as measured in Phase 3. The nine data points represent the performances occasioned by tests consisting of combinations of anchor, midpoint, and boundary stimuli for two linked classes. The darkness of each data point indicates the likelihood of selecting a given comparison in the presence of a given sample. These values are listed at the top of the figure. The continuous line that connects the data points encompasses all combinations of fill-based stimuli that occasioned the selection of the linked satellite-based stimuli on at least 88% of the cross-class test trials. The same holds for all combinations of satellite-based stimuli that occasion the selection of the linked fill-based stimuli on at least 88% of the cross-class test trials. The width of the low A′ class was too narrow to specify a midpoint stimulus; thus, the dot plots for the low A′-B′ tests contain only anchor and boundary stimuli as samples.

missed the mastery criterion. All of these tests, then, showed the delayed emergence of cross-class relations. In the one remaining case (Subject 2331, low A′-B′), test repetition resulted in a substantial decrement in test performance.

*Emergence of linked perceptual classes.* To conclude that a linked perceptual class has been formed, all or most of the members of one class should occasion the selection of all or most of the members of the nominally related class in both the A′-B′ and B′-A′ tests. Because the A′-B′ and B′-A′ tests evaluated 18 different cross-class relations, we defined the emergence of a linked perceptual class when all of the sample stimuli in 17 of the 18 cross-class tests occasioned the selection of a comparison for the class linked to the sample stimulus on at least 88% of the test trials. Because two linked perceptual classes could emerge for each participant and there were 5 participants, a maximum of 10 linked perceptual classes could have emerged in this experiment.

In the serial tests, the immediate emergence of linked perceptual classes occurred in seven of the 10 cases. In four of these (e.g., the low A′B′class for Subject 2328), all of the stimuli in one class occasioned the selection of all of the stimuli in the linked class in the A′-B′ and B′-A′ tests. In the three remaining cases (e.g., the high A′B′ class for Subject 2327), all but one of the cross-class stimulus pairs in the A′-B′ and B′-A′ tests occasioned the selection of all of the stimuli in the related class.

In the concurrent tests, linked perceptual classes emerged in nine of 10 cases. In seven of these cases (e.g., the low A′B′ class for Subject 2332), all of the members of one class occasioned the selection of all members of the nominally related class in both the A′- B′ and B′-A′ tests. In the two remaining cases (e.g., the low A′B′ class for Subject 2330), all but one of the cross-class stimulus pairs in the A′-B′ and B′-A′ tests occasioned class-consistent comparison selections.

Because two sets of cross-class tests were conducted, these data also illustrate the immediate or delayed emergence of linked perceptual classes for individual participants. In six cases, the linked perceptual classes emerged immediately in the serial tests and were maintained with test repetition. In one case (the low A′B′ class for Subject 2331), the serial test performances demonstrated the immediate emergence of a linked perceptual class that then broke down with test repetition. In the three remaining cases, linked perceptual classes emerged with test repetition, thereby demonstrating delayed emergence.

## DISCUSSION

*Fill- and satellite-based classes.*Three performance criteria must be satisfied to conclude that the stimuli in a set are functioning as members of a class (Fields & Reeve, 2001; Fields, Reeve, Adams, Brown, & Verhave, 1997; Honig & Stewart, 1988; Keller & Schoenfeld, 1950; Lea, 1984; Reeve & Fields, 2001; Wasserman et al., 1988; Wright, Cook, Rivera, Sands, & Delius, 1988). First, all of the stimuli in a set must occasion the selection of the same comparison with similar high probabilities. Second, the stimuli in different sets must occasion the selection of different comparisons. Third, many of the stimuli in a set must be discriminable from each other. Although they are physically different, if the stimuli in a putative class were not discriminable from each other, all of them would be functioning as a single stimulus and the generalization of responding among the stimuli becomes a triviality (Bhatt, Wasserman, Reynolds, & Knauss, 1988; Fields & Reeve, 2000).

In the present experiment, the selection of each endpoint fill-based stimulus was occasioned by one range of fill-based variants and not by fill-based variants in another region of the corresponding dimension. In addition, each endpoint stimulus occasioned the selection of a range of fill-based variants along one portion of the fill domain and did not result in the selection of fill-based variants in another region of the fill dimension. Similar results were obtained with the variants of the satellite-based stimuli. These performances satisfied the first two criteria needed to demonstrate the emergence of stimulus classes.

The stimuli in a class are discriminable from each other if they occasion the same response with different likelihoods, or if the same response is occasioned with different reaction times. Indeed, reaction time has been used to measure differences in the detectability of pitch (Flynn, 1943), wavelength (Blough, 1978), and luminance (Raben, 1949), and differential strength of relations among the stimuli in semantic memory networks (Balota & Lorch, 1986; Collins & Quillian, 1969) and multinodal equivalence classes (Bentall, Jones, & Dickins, 1999; Fields et al., 1995; Spencer & Chase, 1996). In the current experiment, differential reaction times were occasioned by the anchor, midpoint, and boundary stimuli in a class, which demonstrated their discriminability from each other. Therefore, the fill and satellite variants that occasioned common responding were functioning as members of perceptual classes (see also Fields et al., 2002).

*Linked perceptual classes.* The range of stimuli beyond the boundaries of each perceptual class occasioned the selection of the neither comparison and not the comparison stimulus from the other end of the continuum. Thus, the two perceptual classes located at opposite ends of the A domain were functionally independent of each other, as were the classes at the opposite ends of the B domain (Fields et al., 2002; Innis et al., 1998; Reeve & Fields, 2001; Wasserman et al., 1988). The mutual selection of members of two perceptual classes demonstrated the emergence of a linked perceptual class. The perceptual classes that constituted the members of each linked perceptual class, however, were functionally independent of each other. Therefore, the linked perceptual classes at the low and high ends of the A′ and B′ domains were also independent of each other. This inference is supported further by the fact that most errors on the cross-class test trials, when they occurred, involved the selection of the neither comparisons.

In the current experiment, linked perceptual classes emerged after linking the anchor stimuli of the two classes and the boundary stimuli of the same two classes. These procedures, then, did not identify the minimal training conditions needed to establish linked perceptual classes. Future experiments will determine whether the reliable formation of linked perceptual classes depends on the training of conditional discriminations between anchor stimuli alone, boundary stimuli alone, both, or other combinations of stimuli in the to-be-linked classes.

In 70% of the cases in the current experiment, linked perceptual classes emerged immediately. A number of studies have shown that the immediate emergence of equivalence classes was facilitated by the presentation of only one emergent relations probe per test block (Buffington, Fields, & Adams, 1997; Fields, Reeve, Rosen, Varelas, et al., 1997). In the present experiment, the initial cross-class test blocks each contained clusters of three different cross-class probes in each test block. Thus, it is possible that the presentation of one cross-class probe per test block would maximize the immediate emergence of linked perceptual classes. Subsequent research, then, should evaluate the validity of this notion.

*Linked perceptual classes and other categories.* The classes that become related to each other in a linked perceptual class need not come from the same sensory modality. When a linked perceptual class contains stimuli from two sensory modalities, it has been called a cross-modal class. The study of cross-modal classification has been used to elucidate the processes of cross-modal perception and intersensory integration (Bahrick & Pickens, 1994; Lewkowicz, 1994). Thus, the procedures described in the present experiment could be used to track the development of cross-modal classification and the processes of cross-modal perception and intersensory integration. It is also plausible that training and testing variables that are found to influence the formation of unimodal linked perceptual classes may have similar effects on the development of cross-modal classes, and should also influence cross-modal perception and intersensory integration.

In 90% of cases, all members of one perceptual class occasioned the selection of all members of another perceptual class to which it was linked by training. These test performances reflected the merger of two perceptual classes. Generalized equivalence classes are also characterized by the merger of classes: in this case, of a perceptual class and an equivalence class (Adams, Fields, & Verhave, 1993; Barnes & Keenan, 1993; Belanich & Fields, in press: Branch, 1994; Cowley, Green, & Braunling-McMorrow, 1992; DeGrandpre, Bickel, & Higgins, 1992; Fields & Reeve, 2000; Fields, Reeve, Adams, & Verhave, 1991; Fields, Reeve, Adams, Brown, & Verhave, 1997; Haring, Breen, & Laitinen, 1989; Lane, Clow, Innis, & Critchfield, 1998; Mackay, Stromer, & Serna, 1997; Rehfeldt & Hayes, 2000). This property of class extension by merger supports the view that linked perceptual classes are functionally related to generalized equivalence classes (Fields & Reeve, 2001). These similarities also suggest that the establishment of some conditional discriminations between members of two classes may lead to class merger, regardless of class type.

After the establishment of two cross-class conditional discriminations, 70% of the linked perceptual classes emerged immediately and another 20% emerged with test repetition. When linked perceptual classes emerged immediately, they did so in the context of serially presented cross-class probes. Those classes were maintained when the cross-class probes were subsequently presented on a concurrent basis. The maintenance of class-indicative performances in these latter test blocks, then, demonstrated the stability of linked perceptual classes when challenged by the presentation of many cross-class probes in a single test block. These patterns of immediate and delayed emergence are similar to those reported during the formation of equivalence classes (Devany, Hayes, & Nelson, 1986; Fields, Adams, Verhave, & Newman, 1990, 1993; Fields, Hobbie, Reeve, & Adams, 1999; Fields, Reeve, Rosen, et al., 1997; Hayes, Thompson, & Hayes, 1989; Holth & Arntzen, 1998; Pilgrim & Galizio, 1990; Saunders, Wachter, & Spradlin, 1988; Sidman, Kirk, & Willson-Morris, 1985; Spradlin, Cotter, & Baxley, 1973). In addition, the stability of emergent relations when challenged with the presentation of many probes concurrrently has also been observed after the formation of equivalence classes (Buffington et al., 1997; Fields, Adams, Newman, & Verhave, 1992; Fields, Adams, & Verhave, 1993; Sidman et al., 1985). Thus, linked perceptual classes appear to share a number of the functional properties of equivalence classes.

A fully elaborated generalized equivalence class (Fields & Reeve, 2000, 2001) consists of a basal equivalence class along with perceptual variants of *every* member of the basal equivalence class. An example of a such a class would include the word *dog* written in many fonts, many pictures of the same and different dogs, and the sounds made by dogs. All of these stimuli function as a class when each occasions the selection of all others. These structural and functional properties of the stimuli in a generalized equivalence class are shared by the stimuli that constitute fuzzy superordinate categories (Rosch & Mervis, 1975), natural kinds (Gelman, 1988), and the complex categories that emerge in natural settings (Branch, 1994; Fields & Reeve, 2000, 2001; Lane et al., 1998; Rehfeldt & Hayes, 2000). Thus, gaining an understanding of the variables that influence the formation and extent of generalized equivalence classes should also clarify our understanding of the properties of fuzzy superordinate categories, natural kinds, and the complex categories that emerge in natural settings.

To date, the generalized equivalence classes that have been studied, however, have included variants of only one member of the basal equivalence class (Adams et al., 1993; Barnes & Keenan, 1993; Cowley et al., 1992; DeGrandpre et al., 1992; Fields, Adams, Brown, & Verhave, 1993; Fields & Reeve, 2000; Fields et al., 1991; Haring et al., 1989; Lane et al., 1998; Mackay et al., 1997; Rehfeldt & Hayes, 2000). Thus, our knowledge of generalized equivalence classes is limited. Perhaps, fully elaborated generalized equivalence classes have not yet been studied, in part, because procedures needed to measure the emergence of relations among the variants of all members of the basal equivalence class have not been available. The cross-class probes described in this experiment could be used for that purpose and would lead to the identification of variables that influence the formation of fully elaborated generalized equivalence classes, and by extension other complex categories that govern wide ranges of human behavior.

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