NODAL DISTANCE AND NODAL STRUCTURE EFFECTS ON THE RELATEDNESS OF STIMULI IN EQUIVALENCE CLASSES

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Abstract

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Three experiments were conducted to evaluate the effects of nodal distance using within-class-preference tests. In Experiment 1, two 2-node 4-member equivalence classes were established using the simultaneous protocol. In this procedure all of the baseline relations were trained together, after which all emergent relations probes were presented together. During equivalence class training and testing, trials were presented using match-to-sample trials that contained two comparisons. After class formation, the effects of nodal distance were evaluated using within-class preference tests which yielded inconsistent test performances. Experiment 2 replicated Experiment 1 with one exception. A third comparison was used in the establishment of the two equivalence classes under the simultaneous protocol. The subsequent within-class probes then produced the immediate emergence of performances that were consistent with the predicted effects of nodal distance. Experiment 3 was conducted to test for the generality of the findings observed in Experiment 2. The participants formed two 3-node 5-member classes under the simultaneous protocol, and once again demonstrated the effects of nodal distance using probes that assessed larger nodal spreads than those found in 4-member classes.

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Introduction

An equivalence class contains a finite number (N) of physically disparate stimuli that become related through training of conditional discriminations among some of the stimuli. A set of N stimuli, contains N^2 stimulus-stimulus relations, of which N-1 stimulus-stimulus relations are established by direct training. The remaining $N^2 – (N-1)$ stimulus-stimulus relations are presented as derived relations probes to assess class formation. An equivalence class has formed when all of these probes occasion the selection of the other stimuli from the same set (Fields & Verhave, 1987).

Once an equivalence class has been established it is commonly assumed that the stimuli in that class are interchangeable or substitutable for each other. The terms interchangeable or substitutable imply that the stimuli in the class are all equally related to each other (Sidman, 1994; Fields & Verhave, 1987).

An alternative view of class membership is that stimuli may be differentially related due to the training structure used to form equivalence classes. The way in which the conditional discriminations are trained establishes the nodal structure of the class. A five member equivalence class may be established by training AB, BC, CD, and DE, resulting in a class with the following nodal structure of A→B→C→D→E. A node is a stimulus that links two stimuli in a class by training. For example, the stimulus B acts as a node for the A→C and C→A relations, B and C act as nodes for the A→D and D→A relations (Fields, Adams, & Verhave, 1993). Nodal distance is defined as the minimum number of nodes that link two stimuli within an equivalence class (Fields & Verhave, 1987).

According to the nodal distance view of equivalence classes, under the appropriate testing conditions, the relatedness of stimuli in an equivalence class should be an inverse function of nodal distance (Fields & Verhave (1987). This notion of nodal distance and its effects on responding was based on the results of derived list experiments (Ebbinghaus, 1913), serial learning experiments (Slamecka, 1985), and the analysis of semantic memory networks (Collins, & Loftus, 1975; Collins, & Quillian, 1969).

The effects of nodal distance have been demonstrated in many different ways. The results of some studies demonstrated that nodal distance influences the order of emergence of derived relations during the delayed emergence of equivalence classes. Delayed emergence occurs when a participant does not respond in a class-consistent manner during the initial derived relations probes, but begins to respond in a class-consistent manner on subsequent probes thereby forming an equivalence class (Sidman, 1994). Nodal distance effects can be evaluated by measuring accuracy of responding during the delayed emergence of equivalence classes. In some experiments the gradual or delayed emergence of class-consistent responding produced by derived relations probes was an inverse function of nodal distance that separated the stimuli in each derived relation (Fields, Adams, Verhave, & Newman, 1990; Sidman, Kirk, & Willson-Morris, 1985; Kennedy, 1991; Kennedy, Itkonen, and Lindquist, 1994; Bentall, Jones, & Dickins, 1998; Spencer & Chase, 1996).

Nodal distance has also been shown to influence the response latencies occasioned by derived relations probes. The results of many experiments have demonstrated a direct function between nodal distance and response latencies (Bentall, Jones, & Dickins, 1998; Kennedy, 1991; Spencer & Chase, 1996; Wulfert & Hayes, 1988; Tomanari, Sidman, Rubio, & Dube, 2006).

Lastly, equivalence classes may act as function transfer networks in which a function acquired by one member of the class transfers to the remaining members in that class, but not to members of the opposing class. Fields, Adams, Verhave, and Newman (1993) studied response transfer after a response was trained to one member of an equivalence class. In this experiment equivalence classes were established through training conditional discriminations between AB, BC, CD, and DE, and testing of the emergent relations. After equivalence classes were established, participants were trained to emit a response in the presence of the A stimulus. The remaining members of the class were then presented alone and under extinction conditions to determine if the response trained to the A stimulus generalized to the remaining members of the class. If participants did not show immediate and complete transfer of responding, the likelihood of emitting the response trained to the A stimulus was an inverse function of nodal distance for the other stimuli in the class. With repeated testing, the accuracy of responding increased to 100% in an order that was an inverse function of nodal distance.

With many of these experiments, nodal distance effects have been shown to have an initial effect on response accuracy and/or speed while the derived relations were acquiring stimulus control; however, with repeated testing nodal distance effects dissipated. Although nodal distance effects may not be apparent, that does not necessarily mean that nodal structure no longer influences the strength of relations among the stimuli in an equivalence class. It may mean that, in this situation, the effects of nodal distance are not currently influencing the accuracy or speed of responding. The participants' responses may simply be under the stimulus control of the training and testing procedures used to establish equivalence classes. Perhaps, other measures would show the permanent effects of nodality, i.e. after the classes have been formed.

In addition, in many of the foregoing studies the baseline relations were trained in a serial manner. Similarly, in the derived relations testing blocks the number of trials that were presented for equivalence and transitivity relations of each nodal number and the number of trials for each relational type were not equal. Therefore, there was a potential confound between the effects of nodal distance on accuracy and response speed and the order of stimulus introduction during training and the number of each type of trial used during the training and testing. One way to avoid having these serial order effects would be to use a simultaneous protocol to train and test formation of equivalence classes. When the simulateous protocol is used, all baseline relations are trained in the same test block and presented an equal number of times. In addition, all emergent relations are tested in the same test block and are presented an equal number of times.

Fields, Landon-Jimenez, Buffington, and Adams, (1995) conducted an experiment in which they used the simultaneous protocol to establish equivalence classes and then measured nodal distance effects after the formation of the equivalence classes. They established two five-member equivalence classes by training conditional discriminations between AB, BC, CD, and DE in the same test block, after which the emergence of all derived relations was assessed in the same test blocks Consistent with other experiments that utilized the simultaneous protocol, the training and testing resulted in low liklihood of equivalence class formation; only two of the 12 participants formed equivalence classes. Following equivalence class formation these two participants were trained to emit two different and incompatible responses in the presence of the A stimulus and the E stimulus in the same class. This training is referred to as dual-option discrimination training (Fields, et al., 1995). Dual-option response transfer tests, in which each member of the equivalence class was presented alone without feedback, were then conducted to determine if the responses trained to these stimuli would generalize to the remaining members of the class and to the other class. The results demonstrated that generalization of responding was an inverse function of nodal distance. The frequency with which the A- based response was occasioned by the B, C, and D stimuli was an inverse function of nodal distance. Similarly, the frequency with which the E-based response was occasioned by the B, C, and D stimuli was an inverse function of nodal distance. This responding was stable with test repetition. The dual-option response transfer tests were conducted after the equivalence classes had been established and responding had stabilized. These data, then, provided a post-class formation steady state measure of the effects of nodal distance on responding. These performances could not have occurred if nodal structure was not a determinant of relations among the stimuli in the parent equivalence classes.

Finally, the responses trained to the A and F stimuli in one class rarely occurred in the presence of the stimuli from the other class. This observation demonstrated that the two parent equivalence classes were being discriminated from each other and were intact even though differential responding was evoked by class members during the dual-option generalization test.

Fields and Watanabe-Rose (2008) also conducted an experiment in which they demonstrated nodal distance effects using a dual-option discrimination procedure. In this experiment two 4-node 6-member equivalence classes were established. First, conditional discriminations were trained between AB, BC, CD, DE, and EF. Following training of these conditional discriminations emergent relations tests were presented in a match-to-sample format. All training and testing was conducted using a simultaneous protocol.

Only four of 15 participants demonstrated class-consistent responding during the emergent relations probes, thus, showing the emergence of the equivalence classes**.** Thereafter, different responses were trained to the C stimuli of each class. The response trained to the C1 stimulus generalized completely to all members of Class 1, and the response trained to the C2 stimulus generalized completely to all members of Class 2. Thus, each of the two equivalence classes was acting as a 6-member functional class. A repetition of the emergent relations test demonstrated that the original equivalence classes remained intact. Next, a different response was trained to the D stimuli of the two classes, while the responses trained to the C stimuli continued to result in informative feedback. The D-based response was incompatible with that trained to the C-stmuli in both classes. Once this training was complete, all stimuli in the equivalence classes were presented alone and in the absence of feedback and the responses evoked by these stimuli was measured.

Four participants demonstrated the emergence of the equivalence classes. Two classes were formed by each four participant, resulting in the establishment of eight classes. For five of the eight equivalence classes, the response trained to the C stimulus in a class generalized essentially completely to the A and B stimuli in that class and rarely to the D, E, and F stimuli in that class or any of the stimuli in the opposing class. The response trained to the D stimulus generalized essentially completely to the E and F stimuli and rarely generalized to the A, B, and C stimuli. Therefore, the two six-member equivalence classes were bifurcated into two 3-member equivalence classes each: A1--B1--C1, A2--B2--C2, D1--E1--F1, and D2--E2--F2 as predicted by nodal structure. Results for the three remaining classes, however, did not demonstrate bifurcation by nodal structure.

Although the experiments reported by Fields et al. (1995) and Fields and Watanabe-Rose (2008) provided definitive demonstrations of the post-class formation steady state effects of nodal distance, each study had an important and distinct limitation. First, the percentage of participants who formed equivalence classes was very low: only 17% of participants (2 out of 12) in the Fields et al. (1995) experiment, and 17% of participants (4 of 15) in the Fields & Watanabe-Rose (2008). Because the tests of nodal distance were conducted with a small sampling of participants who formed equivalence classes, it is possible that the effect of nodal distance may not be a general phenomenon.

Another method for showing the permanent post-class formation effects of nodal distance is to use a within-class preference test (Fields, Adams, & Verhave, 1989, May; as cited in Fields, Adams, Verhave, & Newman, 1993). Fields, Adams, and Verhave (1989) conducted an experiment in which two 3-node 5-member equivalence classes were established by using the simple-to-complex (STC) protocol. First, a baseline relation was trained, which was followed by testing for the emergence of all new relations that could be derived from the trained relation. After, the participant responded in a class-consistent manner on these emergent relations tests a new baseline relation was trained, and was followed by testing of all of the possible emergent relations that could be derived from both trained relations. This training and testing cycle continued until all baseline relations were trained and all emergent relations were tested. In this experiment, the baseline conditional discrimination, AB, BC, CD, and DE, were trained for two classes and the structure of these equivalence classes can be represented as A→B→C→D→E.

After the formation of these classes, test trials were presented in a match-to-sample format in which each trial contained one sample and two comparisons from the same class; i.e., within-class preference tests. For example, the B1 stimulus would be presented as a sample with the D1 and E1 stimuli presented as comparisons. The relation between the B1 and D1 stimuli in the trial was a 1-node transitive relation (B1-D1), while the B1 and E1 stimuli in the trial constituted a 2-node transitive relation (Fields, Adams, Verhave, & Newman, 1993). Nodal distance effects would not be demonstrated if the participant responded to all comparison stimuli with equal probability in the presence of all sample stimuli. Alternatively, nodal distance effects would be demonstrated if in the presence of a sample stimulus the participant consistently chose the comparison that was nodally proximal or closest to the sample stimulus in the training structure. For example, in the presence of the B1 stimulus as the sample and the D1 and E1 stimuli as comparisons the participant would choose the D1 stimulus.

In this study, many such tests were presented, for example the A2 stimulus was presented as a sample with the C2 and D2 stimuli as comparisons. In this example, a 1-node transitive relation was pitted against a 2-node transitive relation. In this, and all other tests, the participants always selected the comparison stimulus that was most proximal to the sample stimulus. This, then, also demonstrated the post-class formation steady state effects of nodal distance.

In this experiment, however, a number of factors were potentially confounded with nodal distance. The equivalence classes were formed using the STC protocol. Due to the serialized presentation of the training and testing trials, nodal distance was procedurally confounded with order of presentation of stimuli and the number of presentations of each stimulus. Specifically, the order in which the stimuli were introduced was: B followed A, C followed B, D followed C, etc. Therefore, when an A-C-E probe is presented, the nodally closer stimulus, C, was introduced earlier after A than E during training. Thus, selection based on order of introduction would predict outcome as well as nodal distance.

In addition, the AB trials were presented most frequently, with successively fewer presentations of the BC, CD, and DE trials. Similarly, in the derived relations test blocks the number of trials that were presented for equivalence and transitive relations of each nodal number and the number of trials for each relational type were not equal. Therefore, there was a potential confound between the effects of nodal distance and number of each type of trial used during the training and testing. (Imam, 2006). To summarize, to demonstrate the unconfounded effects of nodal distance on the relatedness of stimuli in an equivalence class, the equivalence classes would have to be established with procedures that ensured an equal number of presentations of the baseline relations and an equal number of trials for each type of emergent relation.

Alligood and Chase (2007) addressed the issue of unequal number of training trials by the establishment of equivalence classes where the number of training trials was held constant for each of the baseline conditional relations. Thereafter, they assessed the effect of nodal distance by use of within-class preference tests. In Experiments 1 and 2, three four-node six-member (A-B-C-D-E-F) equivalence classes were established using serialized training and testing. The AB conditional discriminations were trained and once criterion was met, the BC conditional discriminations were trained. Thereafter, the formation of 3-member equivalence classes was assessed by the presentation of a mixed test block that contained reflexivity, symmetry, transitivity, and equivalence probes. Once these probes produced performances indicative of the emergence of the 3-member classes, one more baseline conditional discrimination (CD) was trained in each class. Thereafter, each participant was presented with a test block that contained all of the emergent relations probes needed to track the expansion of the 3-member class (ABC) to the 4-member class (ABCD). This serialized training and testing cycle was repeated until 6-member classes had been formed. In each of the training phases, the baseline conditional discrimination trials were presented an equal number of times. Consequently, any nodal distance effects could not be confounded by differences in number of presentations of the baseline relations trials.

Once the 6-member equivalence classes were established, the effects of nodal distance were evaluated using within-class nodal distance tests trials, each of which contained a sample with three comparisons all from the same class. The comparisons were all related to the sample by the same relational type (i.e. transitivity or equivalence), but, each varied from the sample by different nodal spreads. For example, a nodal test trial might consist of presenting the A1 stimulus as a sample with the C1, D1, and E1 stimuli as comparisons. The relation between the A1 sample and all of the comparisons was a transitive relation, however, the C1, D1 and E1 stimuli were separated from the A1 stimulus by 1-node, 2-node, and 3-nodes, respectively. On these tests, participants chose the stimulus that was related to the sample by the fewest nodes more often than the other two comparisons. On many tests, however, fewer than 70% of the trials evoked the selection of the nodally proximal comparisons and the remaining comparisons were selected in an order that declined with their nodal distances from the prevailing sample.

These results extended the previous findings by demonstrating nodal distance effects that were not confounded with an unequal number of presentations of training trials. However, because the baselines were trained in the serial order, AB, BC, CD, DE, and EF, the order in which the stimuli were presented during training was still confounded with the number of nodes that separated the stimuli in the class, as in Fields et al. (1989; May; as cited in Fields, Adams, Verhave, & Newman, 1993). Thus, the effects attributed to nodal distance could have been governed by serial order.

To summarize, previous research has demonstrated nodal distance effects. These effects, however, were either restricted to the few participants who formed equivalence classes under the simultaneous protocol, or were confounded with the number of presentations of training and testing trials, or were confounded with serial order of presentation (Fields & Watanabe-Rose, 2008; Fields et al., 1989; and Alligood & Chase, 2007). The current dissertation will address each of these shortcomings and will use within-class preference tests to assess the effects of nodal distance. Preliminary training procedures will be used to increase the number of participants who form classes under the simultaneous protocol, thereby, increasing the generality of the findings to a large number of participants. Additionally, since equivalence classes were established using the simultaneous protocol, the effects of nodal distance will not be confounded with the number of presentations of training trials, or serial order of presentation of stimuli.

Experiment 1

As noted earlier, the establishment of equivalence classes under the simultaneous protocol eliminates the potential confounding effects of nodal distance and the serial order of training of baseline relations. However, there is a problem that arises when equivalence classes are established using the simultaneous protocol. Previous research has indicated that training and testing under the simultaneous protocol results in low yields, or a small percentage of participants who form classes. In one experiment using the simultaneous protocol only 58% of participants formed 1-node 3-member classes (Fields, Reeve, Rosen, Varelas, Adams, Belanich, & Hobbie, 1997), and only about 20% of participants formed 3-node 5-member classes under the simultaneous protocol (Fields, et al., 1995; Buffington, Fields, & Adams, 1997). Therefore, any effects of nodal distance might be limited to the small percentage of individuals who can form equivalence classes under the simultaneous protocol. To overcome that possibility and measure the effects of nodal distance effects in a broad range of participants, the present experiment implemented a pretraining procedure designed to increase the percentage of participants in a group who formed new multi-nodal equivalence classes under the simultaneous protocol. Thus, any effects of nodal distance would be demonstrated with a larger sample of individuals who would be more representative of the general population.

Fields et al. (1997) increased the percentage of participants who formed equivalence classes under the simultaneous protocol by use of preliminary training in which participants formed other equivalence classes using the simple-to-complex protocol. A similar approach was used in the present experiment to increase the likelihood of equivalence class formation under the simultaneous protocol. Experiment 1 began with the formation of two equivalence classes using the simple-to-complex protocol. Thereafter, two new 4-member 2-node equivalence classes were established under the simultaneous protocol. Then, nodal distance effects were examined using the within-class preference tests. The experiment ended with re-exposure to emergent relations tests to determine whether the within-class tests disrupted the parent equivalence classes.

Method

Participants

Ten undergraduate students enrolled in a Psychology 101 course at Queens College served as the participants to fulfill a course requirement. All participants read and acknowledged the Informed Consent Statement given to them before the start of the experiment. The experiment lasted from 2.5 to 3.5 hours and was conducted in 1 session.

Apparatus

Hardware and software. 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.

Stimuli.

During Preliminary Training, in which equivalence classes were established using the simple-to-complex protocol, one set of stimuli was used; another set of stimuli was used during training of equivalence classes using the simultaneous protocol. The stimuli used during equivalence class formation during the simple-to-complex protocol were 10 nonsense syllables presented in the color black in a 5 x 5 cm square with a black border against a white background on the computer monitor. The stimuli in class 1 were: U1 = BAK, V1 = NUC, W1 = WEX, X1 = HUZ, Y1 = SIV; in class 2 the stimuli were U2 = REJ, V2 =TUD, W2 = GIP, X2 = DIH, and Y2 = MEL. These stimuli have been used in previous pilot work in the laboratory. The stimuli used during equivalence class formation using the simultaneous protocol were 8 trigrams presented in the same manner as in preliminary training. The stimuli in class 1 were A1 = QIJ, B1 = TUW, C1 = COH, D1 = MEP; in Class 2, they were: A2 = VIF, B2 = KUY, C2 = XOL, and D2 = GEZ. These stimuli were the same as those used by Fields and Watanabe-Rose (2008).

Procedure

Trial format and contingencies. All trials in the experiment were presented in a matching-to-sample format (Cumming & Berryman, 1965). Each trial involved the presentation of a sample and two comparison stimuli. The samples were drawn from one of two sets. One comparison was drawn from the same set as the sample on that trial, and is called the positive comparison. Another comparison was related to the sample from the other set and is called the negative comparison.

The sample was presented on the upper portion of the monitor and was centered horizontally. The positive and negative comparisons were presented below the sample and to the left and right of the sample. The upper edges of the comparisons were below the lower edge of the sample. The location of the positive comparison was randomly assigned with the stipulation that it would appear the same number of times on the left and on the right. The right edge of the left comparison was to the left of the left edge of the sample, and the left edge of the right comparison was to the right of the right edge of the sample.

Although many studies have shown that the presentation of three or more comparisons is needed to establish a corresponding number of classes, other studies have shown that the use of two comparisons is sufficient to establish two equivalence classes (Saunders, Chaney, & Marquis, 2005; Fields, Travis, Yadlovker, Roy, de Aguiar-Rocha,

& Sturmey, in press). In this experiment, then, training and testing trials contained only two comparisons.

Trial block organization and feedback reduction. Each phase of the experiment consisted of blocks of trials. In all phases, the trials in a block were presented in a randomized order without replacement. A trial began when "Press ENTER" appeared on the screen. Pressing the ENTER key cleared the screen and a sample stimulus was displayed. Pressing the space bar displayed two comparison stimuli while the sample remained on the screen. During a trial, the comparisons on the left and the right were selected by pressing the 1 or 2 key, respectively. A comparison selection cleared the screen and immediately displayed a feedback message centered on the screen.

When *informative* feedback was presented, a "RIGHT" or “WRONG” message appeared on the monitor, depended on the accuracy of the comparison selection. The message remained on the screen until the participant pressed the R key (R for RIGHT) in the presence of the word “Right” or the W key (W for WRONG) in the presence of the word “Wrong.” These responses demonstrated that the participant discriminated the feedback information. During some training and all testing trials, *uninformative* feedback was presented after a comparison selection. This consisted of a dashed lines that brackets the letter E (i.e., - - E - -), and signaled the end of a trial. This cue remained on the screen until the participant pressed the E key, which served as an observing response for the uninformative feedback. The occurrence of an appropriate R, W, or E response cleared the monitor, signaled the end of the trial, and enabled the start of the next trial (Fields, et al. 1995).

At the start of training, all of the trials in a block resulted in the presentation of informative feedback after each comparison selection, i.e. 100% feedback. The block was presented repeatedly with 100% feedback until the trials within the block produced 100% correct responding. This is referred to as the mastery criterion. Thereafter, the percentage of trials in a block that produced informative feedback was reduced to 75%, 25%, and finally to 0% as long as the mastery criterion was maintained in a block. During feedback reduction, the trials that produce informative feedback were randomly determined. Each block ended with the presentation of an on-screen message, "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 during the next block.

Experimental Phases

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

> 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. PRESS THE SPACEBAR TO CONTINUE.

After pressing the space bar, participants were trained to emit the appropriate keyboard responses to complete a trial. This phase involved the repeated presentation of a block of 16 trials. Trials contained three English words, such as KING, QUEEN, and CAMEL. The semantic relation 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. Correct responding to the stimuli in a trial was facilitated by the presentation of instructional prompts (e.g., “Make your choice by pressing 1 or 2”, “Press R to continue”, “Press W to continue”, or “Press E to continue”) which was systematically deleted across trials as long as the participant made correct responses. For further details, see Fields, et al. (1990) or Fields, et al. (1997). Phase 1 ended when the sample and comparison stimuli were presented without prompts, and performance was at 100% accuracy during a single block.

Phase 2: Preliminary Training using the simple-to-complex protocol. The participants in each group received preliminary training similar to that used by Fields, et al. (1997). The preliminary training consisted of training a 3-node 5-member equivalence class using a simple-to-complex protocol. See Table 1 for the trials and procedures used in preliminary training. The procedure for the simple-to-complex (STC) protocol was that a baseline relation was trained followed by serialized presentations of test blocks for all emergent relations that contained the new training stimuli. If responding on any of the emergent relations test blocks was below mastery criterion of 87% accuracy, the test block was repeated with 100% feedback until responding on the test block met mastery criterion. Training consisted of: 1) training baseline conditional discriminations, 2) testing symmetry, 3) testing transitivity, 4) testing equivalence, and 5) testing all emergent relations that include the new training stimulus/stimuli. Tests of transitivity and equivalence relations were presented in one or more test blocks. All relations of a given relational type (transitivity or equivalence) with the same nodal spread were presented in the same test block and the test blocks were presented successively beginning with the smallest nodal spread and ending with the largest nodal spread. For example, after CD was trained, a test block was presented to assess the symmetrical relation DC. Next, the 1-node transitivity (AC and BD) relations were assessed in a test block followed by a test block of 2-node transitivity probes (AD). Then, the 1-node equivalence relations (CA and DB) were tested, followed by testing of the 2-node equivalence relations (DA). Finally, a mixed test block was presented which included random presentation all of the previously tested relations (DC, AC, BD, AD, CA, DB, and DA).

Table 1. Training and testing trials using the simple-to-complex protocol to train two 3-node 5-member equivalence classes

Step	Relation	% Feedback	Class 1 Sa	Class 1 Co+	Class 1 Co-	Class2 Sa	Class2 Co+	Class2 Co-	# of trials
Train AB	Baseline	100	A1	B1	B2	A2	B2	B1	12
Train AB	Baseline	75, 25, 0	A1	B1	B2	A2	B2	B1	8
Test BA	Symmetry	0	B1	A1	A2	B2	A2	A1	8
		0	A1	B1	B2	A2	B2	B1	4
Train BC	Baseline	100	B1	C1	C2	B2	C2	C1	12
Train BC	Baseline	75, 25, 0	B1	C1	C2	B2	C2	C1	8
Test CB	Symmetry	0	C1	B1	B2	C2	B2	B1	4
		0	A1	B1	B2	A2	B2	B1	4
		0	B1	C1	C2	B2	C2	C1	8
Test BA/CB	Symmetry	0	A1	B1	B2	A2	B2	B1	4
		0	B1	C1	C2	B2	C2	C1	4
		0	B1	A1	A2	B2	A2	A1	8
		0	C1	B1	B2	C2	B2	B1	8
Test AC	Transitivity	0	A1	B1	B2	A2	B2	B1	4
		0	B1	C1	C2	B2	C2	C1	4
		0	A1	C1	C2	A2	C2	C1	8
Test CA	Equivalence	0	A1	B1	B2	A2	B2	B1	4
		0	B1	C1	C2	B2	C2	C1	4
		0	C1	A1	A2	C2	A2	A1	8
3 MIX test	S, T,	0	B1	A1	A2	B2	A2	A1	2
		0	A1	C1	C2	A2	C2	C1	2
		0	C1	A1	A2	C2	A2	A1	2
Train CD	Baseline	100	C1	D1	D2	C2	D2	D1	12
		100	A1	B1	B2	A2	B2	B1	4
		100	B1	C1	C2	B2	C2	C1	4

Train CD	Baseline	75, 25, 0	C1	D1	D2	C2	D2	D1	8
Test DC	Symmetry	0	C1	D1	D2	C2	D2	D1	4
		0	D1	C1	C2	D2	C2	C1	8
Test BD	1-NODE	0	C1	D1	D2	C2	D2	D1	4
	Transitivity	0	B1	D1	D2	B2	D2	D1	8
Test AD	2-NODE	0	C1	D1	D2	C2	D2	D1	4
	Transitivity	0	A1	D1	D2	A2	D2	D1	8
Test DB	1-NODE	0	C1	D1	D2	C2	D2	D1	4
	Equivalence	0	D1	B1	B2	D2	B2	B1	8
Test DA	2-NODE	0	C1	D1	D2	C2	D2	D1	4
	Equivalence	0	D1	A1	A2	D2	A2	A1	8
4MIX test	BL, S, T, E	0	D1	C1	C2	D2	C2	C1	4
		0	B1	D1	D2	B2	D2	D1	4
		0	A1	D1	D2	A2	D2	D1	4
		0	D1	B1	B2	D2	B2	B1	4
		0	D1	A1	A2	D2	A2	A1	4
Train DE	Baseline	100	D1	E1	E2	D2	E2	E1	8
		100	A1	B1	B2	A2	B2	B1	4
		100	B1	C1	C2	B2	C2	C1	4
		100	C1	D1	D2	C2	D2	D1	4
Train DE	Baseline	75, 25, 0	D1	E1	E2	D2	E2	E1	8
Test ED	Symmetry	0	D1	E1	E2	D2	E2	E1	4
		0	E1	D1	D2	E2	D2	D1	8
Test CE	1-NODE	0	D1	E1	E2	D2	E2	E1	4
	Transitivity	0	C1	E1	E2	C2	E2	E1	8
Test BE	2-NODE	0	D1	E1	E2	D2	E2	E1	4
	Transitivity	0	B1	E1	E2	B2	E2	E1	8
Test AE	3-NODE	0	D1	E1	E2	D2	E2	E1	4
	Transitivity	0	A1	E1	E2	A2	E2	E1	8
Test EC	1-NODE	0	D1	E1	E2	D2	E2	E1	4

	Equivalence	0	E1	C1	C2	E2	E2	E1	8
Test EB	2-NODE	0	D1	E1	E2	D2	E2	E1	4
	Equivalence	0	E1	B1	B2	E2	B2	B1	8
Test EA	3-NODE	0	D1	E1	E2	D2	E2	E1	4
	Equivalence	0	E1	A1	A2	E2	A2	A1	8
5 MIX test	S,T,E	0	E1	D1	D2	E2	D2	D1	4
		0	C1	E1	E2	C2	E2	E1	4
		0	E1	C1	C2	E2	C2	C1	4
		0	B1	E1	E2	B2	E2	E1	4
		0	E1	B1	B2	E2	B2	B1	4
		0	A1	E1	E2	A2	E2	E1	4
		0	E1	A1	A2	E2	A2	A1	4

First, the AB relations were trained in a block. The block was repeated until the participant responded with 100% accuracy for one block. Then, 2 overtraining blocks were presented with 100% feedback; however, no mastery criterion was used for these blocks. Once these overtraining blocks were completed, the participant was presented with symmetry tests (BA, the only derived relation). If the participant performed with 87% accuracy or greater they were presented with BC training blocks. If the participant performed with less than 87% accuracy on the BA symmetry test, the symmetrical relation was trained until the participant performed with at least 87% accuracy. Once the participant passed the BA symmetry block the BC relations was trained. Once the BC training trials occasioned 100% accuracy for one block and the participants were presented with 2 overtraining blocks, a combined symmetry test of CB and BA was conducted. Once the symmetry tests were passed, transitivity tests (AC) were conducted, followed by equivalence tests (CA). After the equivalence tests were passed a mixed test was presented that consisted of all the baseline, symmetry, transitivity, and equivalence probes. Once the mixed test was passed the CD relation was trained. The training of this conditional discrimination was followed by a mixed test block in which symmetry, transitivity, and equivalence probes were presented, as well as review trials of the CD relation. This block was repeated until all trials occasioned 100% accuracy, or for a maximum of four blocks. The same procedure of training and testing was repeated with DE. If a participant formed a 5-member class under the STC protocol within two hours they began Phase 2. If the participant took longer than two hours to form the 5-member class, participation was terminated.

Phase 3: Training Conditional Discriminations with the Simultaneous Protocol. Each participant received training to establish two 4-member equivalence classes with the structure A→B→C→D. In this phase equivalence classes were established (with different stimuli than Phase 2) by the concurrent training of 6 conditional discriminations that formed the baselines for two 4-member equivalence classes. Thereafter, participants were presented with all of the derived relations probes that can be formed by the members of the two classes. The conditional discriminations that were trained between the Class 1 stimuli were: A1-B1, B1-C1, and C1-D1. The conditional discriminations that were trained between the Class 2 stimuli are: A2-B2, B2-C2, and C2-D2. Each trial consisted of the presentation of the sample stimulus along with a stimulus from the same class and the stimulus with the same letter designation from the other class. For example, a training trial for the A1-B1 conditional discrimination consisted of the presentation of the A1 stimulus as the sample along with the B1 stimulus (positive comparison) and the B2 stimulus (negative comparison).

During the training block each sample stimulus was presented on two trials. On one trial the positive comparison was presented on the right, and on the other trial the positive comparison was presented on the left. All trials were presented in a block in a randomized order without replacement with feedback on all trials (100% feedback). The block was repeated until all trials in the block occasioned 100% class-consistent responding. This was followed by a maintenance phase in which the percentage of trials in a block that produce feedback was reduced from 75%, to 25%, to 0% as long as 100% accuracy was maintained. If the participant did not meet mastery criterion of 100% after three blocks at a given feedback level, he or she was returned to the prior level of feedback until 100% class-consistent responding was achieved. The maintenance phase ended when a participant responded with 100% accuracy in a block with 0% feedback.

Phase 4: Emergent relations test 1 under the simultaneous protocol. During this phase all of the baseline relations, symmetry relations, 1-, and 2-node transitive and equivalence relations were presented in a test. There were four trials presented for each relation. The trials consisted of the presentation of two trials for the relation from Class 1, in which the position of the comparisons switched on each trial, and two for the relation from Class 2, in which the position of the comparisons switched on each trial. For example, the 2-node A-D transitive relations included A1-D1 and A2-D2. Two trials were presented in which the A1 stimulus was presented as a sample, one trial in which the positive comparison was on the left and the negative comparison was on the right and one in which the positive comparison was presented on the right and the negative comparison was presented on the left. The test consisted of 48 trials. All of the trials that made up the emergent relations test were spread across four test blocks, 12 trials per test block. Each block consisted of one trial for each relational type so that each of the 4 trials mentioned above occurred one time across all four blocks. Within a block all trials were presented in a randomized order without replacement. This test (combination of four blocks) was repeated up to four times or until the participant performed with at least 92% accuracy on each of the four blocks.

Phase 5: Within-Class Preference Tests. Once the participant passed the emergent relations test they were given within-class preference probes to assess the effects of nodal distance. In the preference tests each trial contained a sample and two comparisons, all three of which were in the same class. The comparisons differed in terms of the nodal distance that separated each from the sample. Each probe type is given a three letter designation, the first letter in the designation was the sample that was presented on a trial, the second letter designates the nodally proximal stimulus, and the third letter designates the nodally distant stimulus. For example, in the ACD probe, the A stimulus was separated from the C stimulus by one node while the A stimulus was separated from the D stimulus by two nodes. Trials for each probe type were presented four times, where each comparison was presented two times on the left and two times on the right, in a randomized sequence without replacement. In addition, trials for each probe type were presented for both classes. Likewise, trials from both classes were also presented in a randomized sequence without replacement.

All of the possible within-class probes were not presented, however, the probes administered in the experiment evaluated many comparisons of various nodal spreads. Table 2 lists the within-class probes used to assess the effects of nodal distance on preference among the members of each of the 2-node 4-member classes with a representative set of probes. Each within-class test block consisted of the presentation of two probe types for each class, e.g. the ACD probe type for class 1 and 2 and the DBA probe type for class 1 and 2 were be presented in a test block. Furthermore, four trials were presented for each probe type for each class, for a total of 16 trials per test block. Each within-class test block was presented up to two times. If the participant selected the nodally proximal comparison on at least 94% of the trials in the first test block, the block was not repeated. Performances that did not meet this criterion resulted in a second presentation of the same test block.

Table 2. Within-class preference probes for Experiments 1 and 2. Each probe type was presented for Class 1 and 2 in a test block along with another probe type. The probe pairs that made up a test block are presented together in the table in the order in which they were presented. Each letter designates a member of the equivalence class. The first letter (Sa) depicts the sample in the trial, the second letter (CoP) depicts the nodally proximal stimulus, and the third letter depicts the nodally distal stimulus for that probe. The column labeled TYPES indicates the relation between the sample and each of the comparisons. The number indicates the nodal distance between the sample and the comparison, while the letter indicates the relational type (i.e. BL is baseline, S is symmetry, T is transitivity, and E is equivalence). The TYPE on the left indicates the relation between the sample and the nodally proximal comparison, while the one on the right indicates the relation between the sample and the nodally distal comparison.

Sa	CoP	CoD	---TYPES—	
A	B	D	0-BL	2-T
D	C	A	0-S	2-E
A	C	D	1-T	2-T
A	B	C	0-BL	1-T
A	B	C	0-BL	1-T
D	C	B	0-S	1-E
D	B	A	1-E	2-E
D	C	B	0-S	1-E

The first test block consisted of ABD and DCA probes. The ABD probes consisted of a 0-node baseline relation pitted against a 2-node transitive relation. The DCA probes consisted of a 0-node symmetrical relation pitted against a 2-node equivalence relation. These trials consisted of relations in which the maximal nodal spread separated the two comparisons.

The second test block consisted of ABC and ACD probes. The ABC probes consisted of a 0-node baseline relation pitted against a 1-node transitive relation. The ACD probes consisted of a 1-node transitive relation pitted against a 2-node transitive relation. The probes in this test block consisted of trials in which the sample remained the same and one comparison, C, acted as a nodally proximal stimulus on one trial and a nodally distal stimulus on another trial. The selection of the nodally proximal comparison on the ABC and ACD probes would demonstrate that selections were not based on an unconditional preference for one stimulus, in this case C.

The third test block consisted of the ABC and DCB probes. The ABC probes consisted of a baseline relation pitted against a 1-node transitive relation. The DCB probes consisted of a symmetrical relation pitted against a 1-node equivalence relation. The selection of B in the ABC probes and C in the DCB probes would demonstrate conditional control of comparison selection based on nodal proximity, and rules out control by an unconditional preference for either comparison.

The fourth test block consisted of the DBA and DCB probes. The DBA probes consisted of a 1-node equivalence relation pitted against a 2-node equivalence relation. The DCB probes consisted of a symmetrical relation pitted against a 1-node equivalence relation. As in test block two and three, the selection of B in the DBA probes and C in the DCB probes would demonstrate conditional control of comparison selection based on nodal proximity, and rules out control by unconditional preference for either comparison.

Basis for the ordering of test blocks. Because the nodal spread between the two relations on the first test block is the largest (2-nodes), the two relations should be more discriminable from each other than any other probe types. If a participant would not respond according to nodal distance on these probes, it is very unlikely that they would respond in accordance with nodal distance on the remaining probes. Therefore, these probes were presented first. In the second and fourth test blocks, the sample stimulus was the same in both probe types as was one of the comparison stimuli.The other comparison varied with the probe type. In the third test block, the sample stimuli differed with probe type while the pair of comparisons remained constant for both probe types. Because the third probe block differed from the second and fourth, it was presented in between them.

Phase 6: Emergent Relations Test. This phase consisted of the presentation of the emergent relations test described in Phase 3. This was done to evaluate the maintenance of the two equivalence classes.

Results and Discussion

Equivalence class formation under the simple-to-complex protocol. Of the 10 participants who began Experiment 1, eight formed two 3-node 5-member equivalence classes using the STC protocol. Little variation was found among participants who formed the classes under the simple-to-complex protocol. Baseline relations were acquired in a minimal number of training blocks, and were maintained during feedback reduction. Most of the emergent relations probes were passed on the first test block, showing the immediate emergence of these derived relations. These data then documented the formation of 3-node 5-member equivalence classes under the STC protocol. The remaining two participants formed 4-member classes during the STC protocol but did not have enough time to increase class size to five members in the two hours allocated for this component of the experiment.

Equivalence class formation under the simultaneous protocol. After forming the two 5-member classes under the simple-to-complex protocol, the eight remaining participants were presented with training and testing to establish two new 2-node 4-member equivalence classes under the simultaneous protocol. Although all eight participants formed the baseline relations, only seven passed the emergent relations test. Their performances during the establishment of the baseline relations and the emergent relations tests are detailed in Table 3.

Table 3. Number of blocks needed to acquire the baseline relations, maintain them during the reduction of feedback, and pass the emergent relations test during Experiment 1. The latter measures include the number of blocks to complete the criterion run of 3 consecutive blocks each of which evoked the criterion level of class indicative responding. An asterisk indicates failure to reach criterion, and thus no class formation.

Participant	Blocks To 100% Accuracy	Maintenance Blocks	Emergent Relations Blocks
3589	7	5	4
3596	7	4	4
3595	10	3	4
3588	12	3	4
3594	14	4	4
3592	2	3	12
3598	6	5	14
3593	67	4	16*
Average	7	3.9	6.6
Minimum	1	3	4

Acquisition of the baseline relations was conducted where all trials occasioned informative feedback. For the participants who formed classes a mean of 8.3 blocks was required to acquire the baseline relations with a standard error of the mean of 1.3. A minimum of 1 block was scheduled for acquisition with 100% feedback. The number of blocks needed to acquire the baseline conditional discriminations varied from 2 to 14 blocks. For most participants who eventually formed classes, then, acquisition of the baselines occurred relatively quickly. Participant 3593 required 67 blocks to learn the baseline conditional discriminations and did not go on to form equivalence classes.

Once acquired, performances were maintained during the reduction in the percentage of trials that occasioned reinforcement. A minimum of 3 blocks was scheduled for the reduction of feedback from 100 to 0 percent of the trials in a block. Since the number of blocks actually used for feedback reduction was close to or at the minimum for most participants, the baseline conditional discriminations were maintained with a minimum of transient breakdowns during the maintenance phase of the experiment.

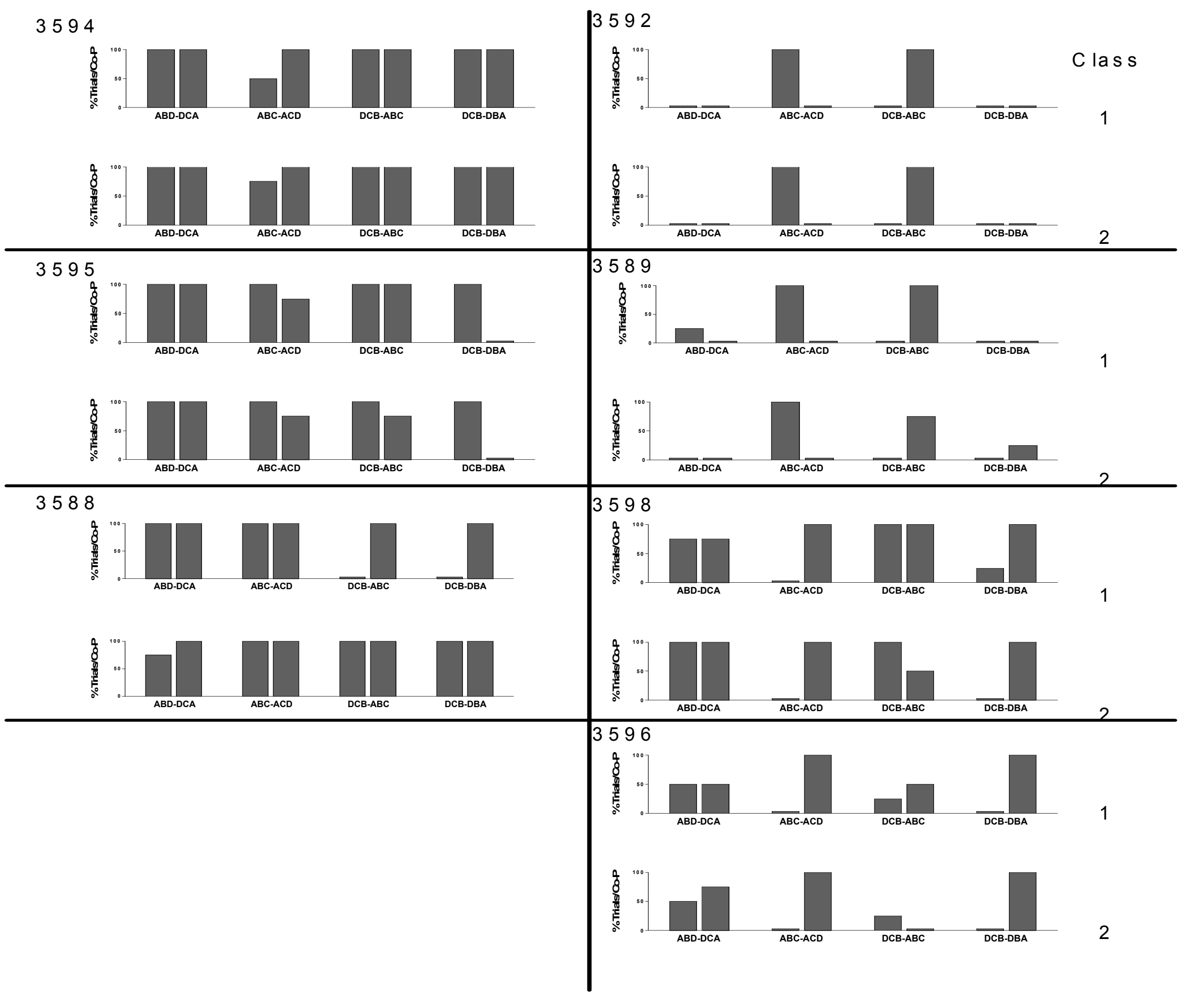
When the emergent relations tests were administered, 5 participants responded in a class-consistent manner to all probes and the baselines in the minimal number of test blocks. These participants showed the immediate emergence of the 2-node 4-member equivalence classes. Two participants required more than the minimum number of presentations of the emergent relations test block before responding involved the selection of comparisons from the same class as the prevalent sample, which documented the delayed emergence of the equivalence classes.

Preliminary training and class formation under the simultaneous protocol. Of the ten participants who began the experiment, eight formed equivalence classes under the simple-to-complex protocol. Of the eight, seven formed the new 2-node 4-member equivalence classes under the simultaneous protocol. Of the participants who began the experiment, 70% formed classes under the simultaneous protocol (7 of 10). Of those who began the simultaneous protocol, 88% formed classes under that condition (7 of 8).

These yields are similar to those reported by Fields et al. (1997) who found that approximately 80% of participants formed classes under the simultaneous protocol when preliminary training was conducted with 3-node 5-member classes. In addition, the percentage of participants who formed classes under the simultaneous protocol in the present experiment was much higher than Fields and Watanabe-Rose (2008) and the Fields et al. (1995) who found that 27% and 17% of participants, respectively, formed classes under the simultaneous protocol without preliminary training Therefore, the post-class formation measures of nodal distance effects to be obtained from these participants should demonstrate performances that are representative a large participant pool, and would not be restricted to individuals who can form classes without preliminary training.

Within-class probes. Figure 1 depicts the data for the within-class preference probes, in the order in which they were presented, for all participants. Although each probe was presented up to two times, the data in Figure 1 include the performances evoked by the last presentation of each probe block. Each section depicts the data for one participant. The participants are ordered for ease of description. The top and bottom panels depict data for the probes in Classes 1 and 2, respectively. The probe types are depicted on the abscissa in the order in which they were presented. In addition, the clustered columns within each graph depict data from the two probe types presented together. The values on the ordinate represent the percentage of trials that occasioned selection of the nodally proximal stimulus. Conditional control of responding based on nodal proximity is defined as the selection of the nodally proximal stimulus on at least seven of eight trials for a given probe pair for a given class. Although not consistent with the reported effects of nodal distance, conditional selection based on nodal proximity can also be manifested by the selection of the nodally distal stimulus. This is defined as the selection of the nodally proximal stimulus on no more than one of the eight trials in a probe pair, which is the same as the selection of the nodally distal stimulus on at least 7 of the eight trials in a given probe for a given class. Because the performances were rather variable across probes for the same participant, and across participants, the data for each participant will be presented separately. Thereafter, all of the results will be considered together.

Figure 1. Performances on all within-class preference probes for all participants in Experiment 1. The data for each participant are depicted in separate sections. The data for three participants are presented on the left of the page, while the data for four participants are presented on the right. The top and bottom graphs within each section depict the data for the probes in Class 1 and 2, respectively. Each type of probe is represented by one bar. The two probe types that were included in a given probe block are presented as a clustered pair of bars. The clusters of probes are depicted on the abscissa in their order of presentation. The values on the ordinate are the percentage of trials that occasioned selection of the nodally proximal stimulus.



Participant ***3594***. For this participant, three of the four probe pairs for Class 1 and all four such pairs for Class 2 always evoked the selection of the comparison that was nodally closer to the sample stimulus, with the exception of one trial in one probe. Therefore, responding on seven out of eight probe pairs demonstrated conditional control by nodal proximity.

In Class 1, the ABC and ACD probes resulted in 50% and 100% selection of the nodally proximal stimulus, respectively. The 50% value reflected selections of the nodally proximal and distal stimuli once each on the right and the left, in no systematic order. These performances then did not demonstrate any form of stimulus control. In contrast, the ACD probe always evoked the selection of the nodally proximal comparison stimulus. Although these performances suggest conditional control by nodal proximity, the 50% performances evoked by the ABC probes make it difficult to confirm that the responding evoked by the ACD probe reflects conditional control by nodal proximity.

Participant ***3595***. For this participant, three of the four probe pairs in Classes 1 and Class 2 (ABD-DCA, ABC-ACD, and DCB-ABC), predominantly evoked the selection of the comparison that was nodally closer to the sample stimulus. Therefore, responding on six of the eight probe pairs demonstrated conditional control by nodal proximity.

During the DCB-DBA probe blocks, on the DCB probes for both classes, the participant selected the nodally proximal stimulus, i.e. C, on all trials and the nodally distal stimulus, i.e. A, on all of the DBA trials. Because the B stimulus was never selected on any of the trials in the block, this participant may have been responding away from the B stimulus during the DCB-DBA test block.

Participant ***3588***. For this participant, two of the probe pairs for Class 1 and four of them for Class 2 always evoked the selection of the comparison that was nodally closer to the sample stimulus. Therefore, six of the eight probe pairs reflected conditional control of responding based on nodal proximity.

When presented with the DCB-ABC probe block, the DCB trials in Class 1 always evoked selection of B, the nodally distal comparison, while the ABC trials always evoked the selection of B the nodally proximal comparison. In addition, during the DCB-DBA block, on the DCB trials for Class 1 the participant selected B, the nodally distal stimulus, while the DBA trials always evoked the selection of B, the nodally proximal distal stimulus. For both of these probe pairs, the consistent selection of the B comparison demonstrated an unconditional preference for that stimulus. These performances then reflect the simple discriminative control of responding by a particular comparison stimulus.

Participant ***3592***. For this participant, none of the probe pairs produced responding indicative of conditional control by nodal proximity. Instead, the ABD-DCA and DCB-DBA probe pairs in Classes 1 or 2 always evoked the selection of the nodally distal comparison stimuli. Therefore, responding on these four probe pairs demonstrated conditional control by nodally distal stimuli instead of nodal proximal stimuli.

On the ABC-ACD probe block, the ABC probe trials for both classes always evoked the selection of the nodally proximal stimulus, B. The ACD trials always evoked the selection of D, the nodally distal stimulus. On all of the trials mentioned above, the participant never selected the C stimulus. Therefore, the selections made by the participant would appear to have been control by the rejection of the C stimulus.

On the DCB-ABC probe block, all of the DCB and the ABC trials evoked the selection of the B comparison. Therefore, the selection of B could reflect an absolute stimulus preference for B or a systematic rejection of the C comparison.

Participant ***3589.*** For this participant, none of the probe pairs produced responding indicative of conditional control by nodal proximity. Instead, the ABD-DCA and DCB-DBA probe pairs in Classes 1 or 2 predominantly evoked the selection of the nodally distal comparison stimuli. Therefore, responding on these four probe pairs demonstrated conditional control by nodally distal stimuli instead of nodal proximal stimuli.

This participant responded in the same manner as participant 3592 on the ABC-ACD and DCB-ABC probes in Classes 1 and 2. On the ABC-ACD probe pair, the comparison selections probably reflected control by the rejection of the C stimulus. On the DCB-ABC probe pair, the selection of B could reflect an absolute stimulus preference for B or a systematic rejection of the C comparison.

Participant ***3598.*** For this participant, responding on one of the probe pairs (DCB-ABC) in Class 1 and one in Class 2 (ABD-DCA) demonstrated conditional control by nodal proximity. Responding on the remaining probes indicated that other stimulus control topographies were the determinants of responding.

On the ABC-ACD probe block, the ABC and the ACD probe trials for both classes always evoked the selection of the C stimulus. On the DCB-DBA probe block, the DCB and DBA probe trials for both classes evoked the selection of the B stimulus, with the exception that one DCB trial for Class 1 evoked selection of the C stimulus. For the ABD-DCA probe pair for Class1, this participant selected the nodally proximal stimulus on 3 of the 4 trials for each probe type, thus, responding did not meet the definition of control by nodal proximity.

Finally, on the DCB-ABC probe pair for Class 2, the DCB and ABC probes produced 100% and 50% selection of the nodally proximal stimulus, respectively. The 50% value reflected selections of the nodally proximal and distal stimuli once each on the right and the left, in no systematic order. These performances then did not demonstrate any form of stimulus control. Although the performances on the DCB trials suggest conditional control by nodal proximity, the 50% performances evoked by the ABC probes make it difficult to confirm that the responding evoked by the DCB probe is conditionally control by nodal proximity.

Participant ***3596***. For this participant, none of the probe pairs produced responding indicative of conditional control by nodal proximity. The DCB-ABC probe pair for Class 2, however, predominantly evoked to selection of the nodally distal stimulus. Thus, responding on this probe pair was controlled by the nodally distal stimulus. Responding on the remaining probes indicated that other stimulus control topographies were the determinants of responding.

On the ABC-ACD probe block, the ABC and the ACD probe trials for both classes always evoked the selection of the C stimulus. On the DCB-DBA probe block, the DCB and DBA probe trials for both classes evoked the selection of the B stimulus. For both the ABC-ACD and DCB-DBA probes pairs, the consistent selection of the C and B stimulus, respectively, indicated control by a particular comparison stimulus.

Finally, three probe pairs, ABD-DCA for both classes, and DCB-ABC for Class 1, resulted in comparison selections that make interpretation of the stimulus control topography difficult because at least one probe in each pair evoked selection of the nodally proximal stimulus on 50% of the trials.

On the ABD-DCA for Class 1, both the ABD and DCA trials evoked selection of the nodally proximal stimulus on 50% of the trials. On the ABD trials the participant always selected the comparison on the left, thus, demonstrating selection based on a position preference. On the DCA trials, the participant selected the nodally proximal stimulus and the nodally distal one time on the left and one time of the right, thus, demonstrating random responding. Since one trial type indicated control by position preference and the other trial type does not indicate any form of stimulus control, it is difficult to determine what controlled responding during this probe pair.

On the ABD-DCA probes for Class 2, the participant selected the nodally proximal stimulus on 50% and 75% of the trials for ABD and DCA trials, respectively. On the ABD trials the participant selected the nodally proximal stimulus and the nodally distal one time on the left and one time of the right, thus, demonstrating random responding. Thus, on these probe types the participant appeared to respond randomly. As mentioned previously, when one probe trial evokes selection of the nodally proximal stimulus on 50% of the trials, it is difficult to determine the source of control during these probe blocks.

During the DCB-ABC probe block for Class 1, the participant selected the nodally proximal stimulus on 25% and 50% of the DCB and ABC trials, respectively. On the ABC trials, the participant selected the nodally proximal stimulus and the nodally distal one time on the left and one time of the right, thus, demonstrating random responding.

Performances across probe types and participants. The combination of all test performances can be used to evaluate the views that the stimuli in an equivalence class are related to each other in terms of nodal distance or are equally related to each other. Each of these assumptions will be considered along with a third alternative.

Nodal distance. Of the seven participants who formed classes under the simultaneous protocol, conditional selection of the nodally proximal comparison stimuli was evoked by 14 of 16 probes for one participant, by 12 of 16 such probes for two participants, 3 of 16 probes for one participant, and 0 of 16 for three participants. When all probes were considered across participants, 39% of the within-class probes evoked responding reflective of conditional selection of comparisons that were nodally closer to the sample. Taken individually or collectively, these performances did not provide strong support for the view that nodal structure influenced the relatedness of stimuli in multi-nodal equivalence classes.

Equal relatedness. By definition, all of the stimuli in an equivalence class should be interchangeable with each other. Thus, all within-class preference probes should evoke the selection of each comparison with equal likelihood. In the present experiment there were 56 within-class test blocks. According to equal relatedness, 28 of the 56 test blocks should evoke selection of the nodally proximal stimulus on half of the trials for a probe type. In the present experiment, however, only 3 of 56 test blocks produced selection of the nodally proximal stimulus on half of the trials (Participant 3596 ABC-DCA for classes 1 and 2, and DCB-ACB for class 1). Thus, the results of the within-class probes do not support the view that all of the stimuli are equally related to each other.

Another outcome that would support the notion of interchangeability is based on the arbitrary assignment or the unreinforced conditional selection of comparison stimuli (Saunders, Saunders, Kirby, & Spradlin, 1988). This is demonstrated when participants systematically select a given comparison in the presence of a given sample in the absence of any training. For example, on an A1-C1-D1 probe, a participant would select C1 instead of D1 given A1. If that is the case, the presentation of A1 with B1 and C1 would uniformly result in the selection of C1. The performances evoked by the within-class probes do not appear to be in accord with such an analysis. Thus, this mode of analysis also does not provide support for the view that all of the stimuli are equally related to each other.

A third alternative: Many sources of stimulus control. Many of the probes evoked responding reflective of other sources of stimulus control. Specifically, 16% of the probes evoked conditional selection of comparisons that were nodally more distant from the prevailing samples, 16% of the probes evoked unconditional selection of a particular comparison stimulus (stimulus preference), 11% of the probes evoked unconditional rejection of a particular stimulus, 9% of the probes evoked selections that could have been controlled by either preference or rejection of a particular stimulus, and lastly, the source of control could not be determined for 9% of the probes.

Maintenance of equivalence classes. At the completion of the preference test, each participant was re-exposed to the cross-class emergent relation test blocks to evaluate the maintenance of the underlying equivalence classes. For each participant, at least 95% of the trials evoked selections of comparisons that came from the same class as the prevailing samples. These performances, then, demonstrated the maintenance of the two equivalence classes that had been established prior to the administration of the within-class preference tests. These results demonstrated that the within-class tests did not disrupt the integrity of the underlying equivalence classes even though the responses evoked by the within-class probes reflected many forms of simple discriminative or conditional discriminative control.

Summary. Ten participants began the experiment. Eight participants formed classes under the STC protocol. Seven of these participants, then, formed new classes under the simultaneous protocol. Thereafter, about 39% of the within-class probes evoked the selections of comparisons that were nodally closer to the sample on all trials. Thus, the performances evoked by the within-class preference tests did not provided a compelling demonstration of the effects of nodal structure on the differential relatedness of stimuli in multinodal equivalence classes. When the participants were subsequently re-exposed to the emergent relations test, they all responded in a class indicative manner on at least 95% of the trials per participant. Therefore, the equivalence classes remained intact after the within-class preference test.

The paucity of evidence for conditional control by nodal proximity could indicate that the nodal structure of an equivalence class does not influence strength of relations among the stimuli in equivalence classes. Such a conclusion, however, is contrary to the evidence cited in the Introduction. Thus, it is more likely that many stimulus control topographies had been induced during the training of the baseline relations that were the precursors of equivalence classes, and the ambiguity of the within-class probes prompted many of these stimulus control topographies to influence test performances. Experiment 2 was designed to increase the control of responding by nodal distance.

Experiment 2

At the end of Experiment 1, participants were given exit interviews. A large number of them reported that when they formed the classes, they learned that the stimuli in one class belonged together, and that they learned to respond to the stimuli in the other class by responding away from the stimuli in the first class. According to this description, when AB training was conducted, a hypothetical participant could have learned to select B1 instead of B2 when the sample was A1. Once learned, when the A2 stimulus was presented, the participant would not select the B1 stimulus. This outcome would occur because the B1 stimulus is already related to the A1 stimulus, thus the participant would select the B2 stimulus. Thus, the participant would respond "correctly" by rejecting the stimulus that was not from the Class 1. If an individual learned to respond to the stimuli in Class 2 by rejecting the stimuli in Class 1, he or she would be able to respond correctly to the stimuli in Class 2 without learning the relations among the stimuli.

According to Sidman (1987), to insure that participants form experimenter-defined classes, at least three comparisons should be used during the establishment of equivalence classes. When three comparisons are used, the rejection of one stimulus could not reliably produce selection of the correct stimulus. Thus, the use of three comparisons ensures the explicit formation of all specified equivalence classes. Indeed, some literature supports this notion (Sidman, 1987; Carrigan & Sidman, 1992; Johnson & Sidman, 1993; Sidman, 1994). Although, researchers have implemented this strategy by the establishment of three equivalence classes, it is also possible to establish only two classes by use of training and testing trials that contain three comparisons: one from each class and a null stimulus that was not a member of either class (Dougher, Augustson, Markham, Greenway, and Wulfert (1994).

Assuming that explicit classes can be established by use of at least three comparisons, it is also possible that control of behavior by the nodal structure of the relations in equivalence classes could be enhanced by training and testing with at least three comparisons. This design strategy was implemented in Experiment 2, which considered whether a third null comparison would increase sensitivity to the nodal structure of the stimuli in an equivalence class thereby inducing within-class test performances that were correlated with nodal structure. To stay as close to the procedures used in Experiment 1, two 4-member equivalence classes were established in Experiment 2.

Method

Participants

Ten undergraduate students enrolled in a Psychology 101 course at Queens College served as the participants to fulfill a course requirement. All participants read and acknowledged the Informed Consent Statement given to them before the start of the experiment. The experiment lasted from 2.5 to 3.5 hours and was conducted in 1 session.

Apparatus

Hardware and software. These were the same as in Experiment 1.

Stimuli. The stimuli used during preliminary training and during equivalence class training under the simultaneous protocol were the same as in Experiment 1. The stimuli used for the third comparison were: A3 = PIB, B3 = DUR, C3 = SOF, and D3 = JEH. These stimuli were created so that the middle letter was the same for the letter designation (e.g. all stimuli with the A designation had an I as the middle letter). In addition, the first letters were different from any of the other stimuli used in the experiment.

Procedure

Phase 1: Instructions and keyboard familiarization. These were the same as in Experiment 1.

Phase 2: Preliminary Training using the simple-to-complex protocol. These were the same as in Experiment 1.

Phase 3: Training conditional discriminations with the simultaneous protocol. In this phase equivalence classes were established (with different stimuli than Phase 2) by the concurrent training of 6 conditional discriminations that formed the baselines for two

2-node 4-member equivalence classes with the structure A→B→C→D. The conditional discriminations that were trained between the Class 1 stimuli were: A1-B1, B1-C1, and C1-D1. The conditional discriminations that were trained between the Class 2 stimuli were: A2-B2, B2-C2, and C2-D2. Each trial consisted of the presentation of the sample stimulus along with a stimulus from the same class, the stimulus with the same letter designation from the other class, and a third comparison from the third stimulus set with the same letter designation as the other two comparisons. For example, a training trial for the A1-B1 conditional discrimination consisted of the presentation of the A1 stimulus as the sample along with the B1 stimulus (positive comparison), the B2 stimulus (negative comparison), and the B3 stimulus (negative comparison). During initial training blocks, during which feedback was presented on 100% of the trials, each sample stimulus was presented on six trials. A different sequence of the comparison stimuli was presented on each trial so that all possible arrangements (i.e. A1-A2-A3, A1-A3-A2, A2-A1-A3, A2-A3-A1, A3-A1-A2, A3-A2-A1) were presented one time each in a training block. For example, one trial for the A1-B1 conditional discrimination might consist of the A1 stimulus presented as the sample, the B1 stimulus presented on the left, the B2 stimulus presented in the middle, and the B3 stimulus presented on the right. All trials were presented in a block in a randomized order without replacement with feedback on all trials (100% feedback). The block was repeated until all trials in the block occasioned 100% class-consistent responding. This was followed by a maintenance phase in which the percentage of trials in a block that produce feedback was reduced from 75%, to 25%, to 0% as long as 100% accuracy was maintained. During the maintenance phase each sample stimulus was only presented 3 times and each comparison was presented one time in each position.

Phase 4: Emergent relations test 1. During this phase all of the baseline relations, symmetrical relations, 1-, and 2-node transitive and equivalence relations were presented in a test. There were six trials presented for each relation. The trials consisted of the presentation of three trials for the relation from Class 1 and three trials from Class 2, in which the position of the comparisons switched on each trial so that each stimulus was presented once in each position (i.e. left, middle, right). For example, the 2-node A-D transitive relations included A1-D1 and A2-D2. Three trials were presented in which the A1 stimulus was presented as a sample, one trial in which the positive comparison was on the left, one trial in which the positive comparison appeared in the middle, and one trial in which the positive comparison appeared on the right. The test consisted of 78 trials. All of the trials that made up the emergent relations test were spread across three test blocks, 26 trials per test block. Each block consisted of one trial for each relational type for Class 1 and Class 2. Within a block all trials were presented in a randomized order without replacement. This test (combination of three blocks) was repeated up to four times or until the participant performed with at least 92% accuracy on each of the three blocks.

Phase 5: Within-class preference tests. These were the same as in Experiment 1.

Phase 6: Emergent Relations Test. This phase consisted of the presentation of the emergent relations test described in Phase 4. This was done to evaluate the maintenance of the two equivalence classes.

Results and Discussion

Equivalence class formation under the simple-to-complex protocol. Of the 10 participants who began Experiment 2, seven formed two 3-node 5-member equivalence classes under the STC protocol. Little variation in responding was found among participants who formed the classes. Baseline relations were acquired in a minimal number of training blocks, and were maintained during feedback reduction. Most of the emergent relations probes were passed on the first test block, showing the immediate emergence of these derived relations. The remaining three participants formed 4-member classes during the STC protocol, but did not have enough time to increase class size to five members in the two hours allocated for this component of the experiment.

Equivalence class formation under the simultaneous protocol. All seven participants who formed 3-node 5-member classes under the STC protocol subsequently formed two new 2-node 4-member equivalence classes under the simultaneous protocol. Their performances during the establishment of the baseline relations and the emergent relations tests are detailed in Table 4.

Table 4. Number of blocks needed to acquire the baseline relations, maintain them during the reduction of feedback, and pass the emergent relations test.

Participant	Acquisition Blocks	Maintenance Blocks	Emergent Relations Blocks
3565	9	3	3
3599	14	4	3
3600	18	4	4
3577	4	3	5
3570	8	5	5
3576	4	3	6
3571	10	3	8
Average	9.6	3.6	4.9
Minimum	1	3	3

Acquisition of the baseline relations took place in an average of 9.6 blocks with an SEM of 1.9. Once acquired, performances were maintained during feedback reduction. Since the number of blocks actually used for feedback reduction was close to or at the minimum of 3 blocks for most participants, the baseline conditional discriminations were maintained with a few transient disruptions during this phase of the experiment.

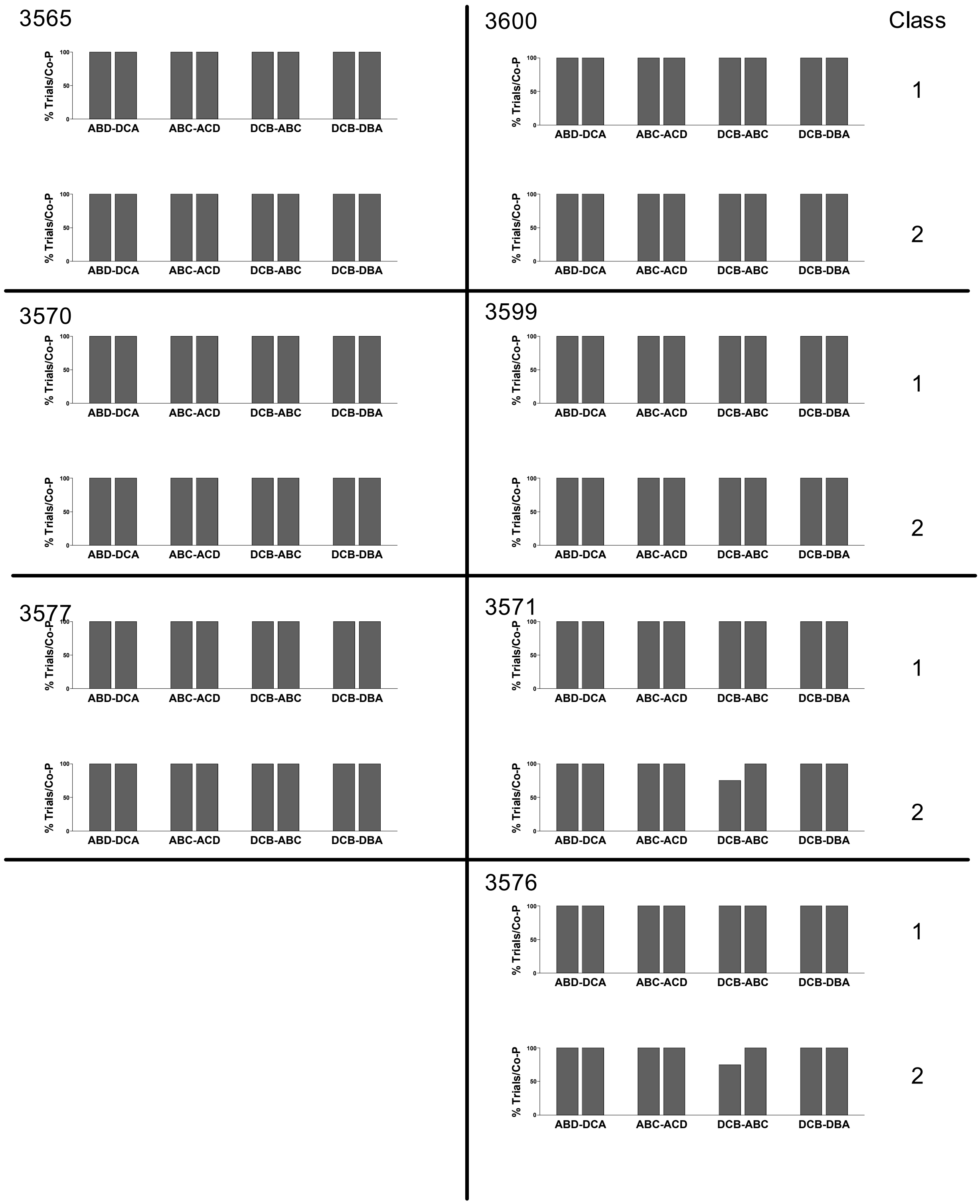
When the emergent relations tests were administered, two participants responded in a class-consistent manner to all probes and the baselines in the minimal number of test blocks, thereby documenting the immediate emergence of the 2-node 4-member equivalence classes. The five remaining participants required more than the minimum number of presentations of the emergent relations test block before responding involved the selection of comparisons from the same class as the prevalent sample, which documented the delayed emergence of the equivalence classes.

Preliminary training and class formation under the simultaneous protocol. Of the ten participants who began the experiment, seven formed equivalence classes under the simple-to-complex protocol. All seven subsequently formed new equivalence classes under the simultaneous protocol. Therefore, 70% of the participants, who began the experiment, formed classes under the simultaneous protocol. Of the participants who began the simultaneous protocol, 100% formed classes under the simultaneous protocol. These results are very similar to the results of Experiment 1. Further, they replicate previously reported findings of enhanced formation of equivalence classes that follow the formation of other equivalence under the simple-to-complex protocol (Fields et al., 1997; Fields, Hobbie-Reeve, Adams, & Reeve, 1999).

Effect of the third comparison. During training and testing, participants selected the comparisons that were from the same classes as the samples. Since this was accomplished in the presence of three comparisons, the participants must have learned the relations among the stimuli within a class. Because the positive comparison and the null comparison were presented on all trials, responding away from the negative comparison could not have resulted in the systematic selection of the positive comparison. Therefore, the inclusion of the third comparison during training and testing resulted in the formation of two explicit equivalence classes. The within-class tests determined whether the inclusion of the third comparison induced sensitivity to nodal structure and distance. Whether the inclusion of the third comparison increased sensitivity to nodal structure and nodal distance was assessed by the performances on the within-class preference test.

Within-class probes. Figure 2 shows the data from the within-class preference test blocks for all participants. In all cases, each within-class test trial in all of these probes predominantly evoked the selection of the nodally proximal comparison stimuli. All of these performances, then, appear to document the conditional control of responding based on the nodal proximity of the comparisons to the sample stimuli. These outcomes support the view that the strength of each relation among the stimuli in a multi-nodal equivalence class is an inverse function of the number of nodes that separate them in an equivalence class. These data hold for all participants.

Figure 2. Performances on all within-class preference probes for all participants in Experiment 2. The format is the same as that used in Figure 1.



Such a conclusion, however, can be accepted only after considering the impact of other variables that were procedurally confounded with nodal differences and thus, might also account for the performances evoked by each of the within-class probes. These are differences in relational types, and differences in functions acquired by the comparisons. Differences in relational type refer to the fact that the type of relation between the sample and each of the comparisons may be different. For example, in the ABC probes, the relation between A and B is a baseline relation, while the relation between A and C is a 1-node transitive relation. Difference in number of functions acquired by the comparisons refers to the fact that during conditional discrimination training, a stimulus can function as a sample or as a comparison. For example, when the AB conditional discrimination is trained, the A stimulus functions as a sample and the B stimulus functions as a comparison. When A is presented during training, it only functions as a sample. However, B functions as a comparison during the AB trials and as a sample during the BC trials. Therefore, B serves two functions during training. Other factors that could account for the test performance are unconditional preferences for given comparison stimuli, and rejection of given comparison stimuli. Where relevant, all of these factors will be considered for each of the probes.

Unconditional preference or rejection. It might be argued that participants had unconditional preferences for the comparisons that happened to be nodally closer to the sample. That potential source of stimulus control can be ruled out as a determinant of responding on the within-class probes by examining the content of the two probes in each within-class probe pair. For each probe pair, with the exception of ABD-DCA, at least one comparison stimulus served as a nodally proximal stimulus on one probe type and the same stimulus served as the nodally distal stimulus on other trials. During the ABC-ACD, DCB-ABC, and DCB-DBA probe blocks, the C stimulus, C and B stimuli, and the B stimulus, respectively, were nodally proximal and distal on different trials. Since both probes in a pair typically evoked the selection of the nodally proximal stimulus, the participants could not have performed in this way by the selection or rejection of particular stimuli.

Nodal proximity and number of functions. For two probes, each sample-comparison relation differed in terms of nodal number and the number of functions acquired by each comparison during training. These probes were DBA and ACD.

The DBA probe. In this probe, participants selected B instead of A. The B and A stimuli both bore equivalence relations to the sample stimulus. Thus, the selection of the nodally proximal comparison on the DBA probes could not be attributed to differences in the relations between each comparison and the sample. One factor that distinguished the relations of the comparisons to the sample was the number of nodes that separated each from the sample: 1-node for DB and 2-nodes for DA. Thus, the selection of the B comparison could be attributed to nodal proximity.

In addition, in this probe, the B stimulus served as a sample on the BC trials and as a comparison on AB trials, thus B serves two behavioral functions, i.e. served as a node. Conversely, the A stimulus only served as a sample on AB trials, thus A serves only one behavioral function, i.e. served as a single, a stimulus linked to only one other class member by training (Fields & Verhave, 1987). Therefore, the selection of the nodally proximal comparison could have been based on the selection of the comparison that had acquired two functions and not the comparison that acquired one function. To summarize, the DBA probes demonstrated conditional control based on nodal proximity, but perhaps also by a preference for a stimulus that had acquired a nodal function instead of serving as a single.

The ACD probe. In this probe, participants selected C instead of D. The C and D stimuli both bore transitive relations to the sample stimulus. Thus, selection of the nodally proximal stimulus on the ACD probes could not be attributed to differences in the relations between each comparison and the sample. One factor that distinguished the C and D comparisons was the number of nodes that separated each from the sample: 1-node for AC and 2-nodes for AD. Thus, the selection of the C comparison could be attributed to nodal proximity.

In addition, the C comparison had acquired two behavioral functions during training, and served as a nodal stimulus, while the D comparison had acquired only one behavioral function during training and served as a single. Thus, the performances could be attributed to differences in the functions acquired by each of the comparison stimuli. To summarize, the ACD probes demonstrated conditional control based on nodal proximity, but perhaps also by a preference for a stimulus that has acquired a nodal function instead of serving as a single.

DBA and ACD probes. For both of these probes, the difference in number of functions served by the comparisons during training was also correlated with nodal number. Thus, any effect attributed to difference in number of functions would be confounded with nodal number.

Nodal proximity and relational type. For two probes, each sample-comparison relation differed in terms of nodal number and relational type. These probes were ABC and DCB.

The ABC probe. In this probe, participants selected B instead of C. The B and C comparisons had both acquired two behavioral functions during training, and served as nodal stimuli. Thus, the selection of the nodally proximal stimulus on the ABC probes could not be attributed to differences in the functions acquired by each of the comparison stimuli. One factor that distinguished the B and C comparisons was the number of nodes that separated each from the sample: 0-nodes for AB and 1-node for AC. Thus, the selection of the B comparison could be attributed to nodal proximity.

In addition, both comparisons bore different types of relations to the sample stimulus, i.e. a 0-node baseline relation for AB and a 1-node transitive relation for AC. Thus, the selection of the B comparison could be attributed to a difference in relational type. To summarize, the ABC probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference.

The DCB probe. In this probe, participants selected C instead of B. The C and B stimuli both acquired two behavioral functions during training, and served as nodal stimuli. Thus, the selection of the nodally proximal stimulus on the DCB probes could not be attributed to differences in the functions acquired by each of the comparison stimuli. One factor that distinguished the C and B comparisons was the number of nodes that separated each from the sample: 0-nodes for DC and 1-node for DB. Thus, the selection of the C comparison could be attributed to nodal proximity.

In addition, both comparisons bore different types of relations to the sample stimulus, i.e. a symmetrical relation for DC and an equivalence relation for DB. Thus, the selection of the C comparison could be attributed a difference in relational type. To summarize, the DCB probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference.

ABC and DCB probes. For both of these probes, the difference in relational type was also correlated with nodal number. Thus, any effect attributed to difference in relational type would be confounded with nodal number.

Nodal proximity, functions, and relational type. For two probes, each sample-comparison relation differed in terms of nodal number, functions acquired by the comparisons, and relational type. These probes were ABD and DCA.

The ABD probe. In this probe, participants selected B instead of D. The B and D stimuli both bore different types of relations to the sample stimulus, i.e. a baseline relation for AB and a transitive relation for AD. Thus, the selection of the nodally proximal stimulus on the ABD probes could be attributed a difference in relational type. In addition, in this probe, the B comparison had acquired two behavioral functions during training, and served as a nodal stimulus, while the D comparison had acquired only one behavioral function during training and served a single. Thus, the selection of the nodally proximal stimulus could be attributed to differences in the functions acquired by each of the comparison stimuli. Finally, one other factor that distinguished the B and D comparisons was the number of nodes that separated each from the sample: 0-nodes for AB and 2-nodes for AD. Thus, the selection of the B comparison could be attributed to nodal proximity. To summarize, the ABD probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference, or difference in the functions served by the comparisons.

The DCA probe. In this probe, participants selected C instead of A. The C and A stimuli both bore different types of relations to the sample stimulus, i.e. a symmetrical relation for DC and an equivalence relation for DA. Thus, the selection of the nodally proximal stimulus on the DCA probes could be attributed to a difference in relational type. In addition, in this probe, the C comparison had acquired two behavioral functions during training, and served as a nodal stimulus, while the A comparison had acquired only one behavioral function during training and served a single. Thus, the selection of the nodally proximal comparison could be attributed to differences in the functions acquired by each of the comparison stimuli. Finally, one other factor that distinguished the C and A comparisons was the number of nodes that separated each from the sample: 0-nodes for DC and 2-nodes for DA. Thus, the selection of the C comparison could be attributed to nodal proximity. To summarize, the DCA probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference, or difference in the functions served by the comparisons.

ABD and DCA probes. For both of these probes, the difference in number of functions served by the comparisons during training and differences in relational type were both also correlated with nodal number. Thus, any effect attributed to difference in relational type would be confounded with nodal number.

Explanatory plausibility of control by number of functions. It is possible that on the DBA, ACD, ABD, and DCA probes the participant may have selected a particular stimulus because it served two functions during training. However, if the participant was responding to all probes in the within-class preference test based on this stimulus control topography, when DCB and ABC probe trials were presented the participant should respond at random, selecting the comparisons with equal likelihood, since both stimuli serve two functions during training. The fact that the participants did not respond in this manner on these probe trials raises questions about the function of the comparisons dictating selection of the comparison.

Explanatory plausibility of control by relational type. As noted above, it is possible that on the ABD, DCA, ABC, DCB, and DBA probes, the participant may have selected a particular stimulus based on relational type. However, if the participant was responding to all probes in the within-class preference test based on this stimulus control topography, the ACD and DBA probe trials would have occasioned the selection of each comparison with equal likelihood, since both stimuli in each of these probes were of the same relational type. The fact that these probes did not produce random responding indicates that relational difference was not a critical source of stimulus control during the within-class probes.

Summary. All six probes indicate possible control by nodal proximity. The consistent selection of the nodally proximal stimulus on nearly all trials provides a robust demonstration of nodal distance effects. Since a large number of participants formed equivalence classes under the simultaneous protocol, this experiment extended the findings of nodal distance effects by the elimination of serial order confounds, and increased the generality of these effects to a large number of participants.

Although these other variables were eliminated, other confounds were present. For two of the probes, responding could have been controlled by nodal proximity in combination with the number of functions acquired by the comparisons during training. For two other probes., responding could have been controlled by nodal proximity in combination with relational type, and for two others, responding could have been controlled by nodal proximity in combination with number of functions and/or relational type.

The only source of control that was common to all of the probes presented was nodal proximity. There was, however, no probe in which there is unequivocal evidence to support the notion that nodal proximity was the sole source of control for selection of comparisons. Indeed, with a four member class, it is not possible to obtain a measure of the effects of nodal distance that is not correlated with one of these additional factors. Experiment 3 sought to resolve this matter by the establishment of a larger class with a greater range of nodal spreads.

Experiment 3

The results of Experiment 2 suggest that the inclusion of a third comparison increased control of behavior by the nodal structure of an equivalence class. These results, however, might have been restricted to 4-member classes. In addition, none of the within-class probes provided an isolated instance of the effects of nodal distance that was not also correlated with other factors that might have also influenced the test performances. Experiment 3 addressed both of these issues. A third comparison was used to establish a larger class with a greater range of nodal distances among the class members. In addition, some of the within-class probes evaluated the effects of nodal distance on comparison selection where other variables were not confounded with nodal spreads.

To be able to present within-class preference probes in which nodal distance effects would not be confounded with other variables, at minimum a 3-node 5-member class would need to be established. For example, if a 3-node 5-member class A→B→C→D→E were established, ACD or ECB probes could be conducted, where the only source of control could be nodal proximity. If an ACD probe was presented in a probe block with a probe pair such as ABC and the participant selected the nodally proximal stimulus (the C stimulus for ACD and the B stimulus for ABC) on all trials in the probe block, the only source of control can be attributed to nodal proximity. First, since the participant is selecting the C stimulus on some trials and rejecting it on other trials, he could not be responding based on stimulus preference or rejection. Second, in the ACD trials, both C and D stimuli serve two functions during training. Thus, number of functions could not be controlling responding. Lastly, in the ACD trials, the relations between the A sample and both C and D comparisons are transitive relations. Therefore, responding could not be attributed to control by relational type. The same analysis can also be applied to the ECB within-class preference probes. In Experiment 3, once two 3-node 5-member classes are established, within-class preference tests will be presented.

Method

Participants

Twelve undergraduate students enrolled in a Psychology 101 course at Queens College served as the participants to fulfill a course requirement. All participants read and acknowledged the Informed Consent Statement given to them before the start of the experiment. The experiment lasted from 2.5 to 3.5 hours and was conducted in 1 session.

Apparatus

Hardware and software. These were the same as in Experiment 1 and 2.

Stimuli. The stimuli used during preliminary training were the same as those used in Experiment 1 and 2. During equivalence class training with the simultaneous protocol, the A, B, C, and D stimuli were the same as those used in Experiments 1 and 2. However, in this experiment a fifth stimulus (the E stimulus) was added for each class. Therefore the stimuli in class 1 were A1 = QIJ, B1 = TUW, C1 = COH, D1 = MEP, and E1 = RAB; in Class 2, they were: A2 = VIF, B2 = KUY, C2 = XOL, D2 = GEZ, and E2 = NAS. These stimuli were the same as those used in Fields and Watanabe-Rose (2008). The third comparison stimuli were: A3 = PIB, B3 = DUR, C3 = SOF, D3 = JEH, and E3=LAV. These stimuli were the same as the stimuli in Experiment 2 with the addition of E3.

Procedure

Phase 1: Instructions and keyboard familiarization. This was the same as Phase 1 in Experiments 1 and 2.

Phase 2: Preliminary Training using the simple-to-complex protocol. This was the same as Phase 2 in Experiments 1 and 2.

Phase 3: Training of the Baseline Conditional Discriminations with the Simultaneous Protocol. In this phase equivalence classes were established (with different stimuli than Phase 2) by the concurrent training of 8 conditional discriminations that form the baselines for two 3-node 5-member equivalence classes with the structure A→B→C→D→E. As in Experiment 2, each trial consisted of the presentation of the sample stimulus along with a stimulus from the same class, the stimulus with the same letter designation from the other class, and a third comparison from the third stimulus set with the same letter designation as the other two comparisons. During initial training blocks, during which feedback was presented on 100% of the trials, each sample stimulus was presented on six trials for a total of 48 trials per block. A different sequence of the comparison stimuli was presented on each trial so that all possible arrangements (i.e. A1-A2-A3, A1-A3-A2, A2-A1-A3, A2-A3-A1, A3-A1-A2, A3-A2-A1) were presented one time each in a training block. All trials were presented in a block in a randomized order without replacement with feedback on all trials (100% feedback). The block was repeated until all trials in the block occasioned 100% class-consistent responding. This was followed by a maintenance phase in which the percentage of trials in a block that produce feedback was reduced from 75%, to 25%, to 0% as long as 100% accuracy was maintained. During the maintenance phase each sample stimulus was only presented 3 times and each comparison was presented one time in each position, for a total of 24 trials per block.

Phase 4: Emergent Relations Test 1. During this phase all of the baseline relations, symmetrical relations, 1-, and 2-node transitive and equivalence relations were presented in a test. There were six trials presented for each relation. The trials consisted of the presentation of three trials for the relation from Class 1 and three trials from Class 2, in which the position of the comparisons switched on each trial so that each stimulus was presented once in each position (i.e. left, middle, right). For example, the 2-node A-D transitive relations included A1-D1 and A2-D2. Three trials were presented in which the A1 stimulus was presented as a sample, one trial in which the positive comparison was on the left, one trial in which the positive comparison appeared in the middle, and one trial in which the positive comparison appeared on the right. The test consisted of 126 trials. All of the 126 trials that made up the emergent relations test were spread across three test blocks, with 42 trials per test block. Each block consisted of one trial for each relational type for Class 1 and Class 2. Within a block all trials were presented in a randomized order without replacement. This test (combination of three blocks) was repeated up to four times or until the participant performed with at least 92% accuracy on each of the three blocks.

Phase 5: Within-Class Preference Tests. Once the participant passed the emergent relations test they were given within-class preference tests to assess the effects of nodal distance. In the preference tests each trial contained a sample and two comparisons, all three of which were in the same class. The comparisons differed in terms of the nodal distance that separated each from the sample.

Table 5 lists the within-class probes used to assess the effects of nodal distance on preference among the members of each of the 3-node 5-member classes. All of the possible within-class probes were not presented. The probes administered in the experiment evaluated many comparisons of various nodal spreads. As in Experiments 1 and 2, the first block consisted of probes that contain the largest nodal spread between the two comparisons. These probes are presented first, since, according to accounts of nodal distance, these stimuli should be are most discriminable from each other. The order in which the other blocks were presented is similar to the order in which they were presented in Experiments 1 and 2. Test blocks that consisted of probe pairs in which the sample differed for each of the probes, but the comparison stimuli remained the same were presented first. Then blocks that consisted of probe pairs in which the sample remained the same and one comparison was the nodally proximal stimulus on half the trials and the nodally distal stimulus on the other half were presented. Although some probes are different than those used in Experiments 1 and 2, the manner in which they were presented was the same.

Table 5. Within-class preference probes for Experiment 3. See description for Table 2.

Sa	CoP	CoD	--TYPES—	
A	B	E	0-BL	3-T
E	D	A	S-0	3-E
A	C	D	1-T	2-T
E	D	C	0-S	1-E
E	C	B	0-S	2-E
A	B	C	0-BL	1-T
A	C	E	1-T	3-T
A	B	C	0-BL	1-T
D	B	A	1-E	2-E
D	C	B	0-S	1-E

The first test block consisted of ABE and EDA probes. The ABE probe consisted of a 0-node baseline relation pitted against a 3-node transitive relation. The EDA probe consisted of a 0-node symmetrical relation pitted against a 3-node equivalence, respectively. These trials consisted of relations in which the maximal nodal spread separates the two comparisons.

Test block two consisted of the ACD and EDC probes. The ACD probes consisted of a 1-node transitive relation pitted against a 2-node transitive relation. The EDC probes consisted of a 0-node symmetrical relation pitted against a 1-node equivalence relation.

Test block three consisted of the ECB and ABC probes. The ACB probes consisted of a 1-node equivalence relation pitted against a 2-node equivalence relation. The ABC probes consisted of a 0-node baseline pitted against a 1-node transitive relation.

The fourth test block consisted of the ACE and ABC probes. The ACE probes consisted of a 1-node transitive relation pitted against a 3-node transitive relation. The ABC probe consisted of a baseline relation pitted against a 1-node transitive relation.

The fifth test block of the DBA and DCB probes. The DBA probes pitted a 1-node equivalence relation against a 2-node equivalence relation. The DCB probe consisted of a symmetry relation versus a 1-node equivalence relation.

With the exception of the first probe blocks, all probe blocks consist of trials in which one comparison acted as a nodally proximal stimulus on one probe type and a nodally distal stimulus on the other probe type. The consistent selection of the nodally proximal comparison on both probe types in the block would demonstrate that selections were not based on an unconditional preference for one stimulus.

Phase 5: Emergent Relations Test 2. This phase consisted of the presentation of the emergent relations test described in Phase 3. This was done to evaluate the maintenance of the two equivalence classes.

Results and Discussion

Equivalence class formation under the simple to complex protocol. Ten of the 12 participants who began Experiment 3 formed two 3-node 5-member equivalence classes using the STC protocol. Little variation was found among the performances produced by the participants in this phase of the experiment. Baseline relations were acquired in a minimal number of training blocks, and were maintained during feedback reduction. Most of the emergent relations probes were passed on the first test block which documented the immediate emergence of these derived relations and formation of 3-node 5-member equivalence classes. The remaining two participants formed 4-member classes during the STC protocol but did not have enough time to increase class size to five members in the two hours allocated for this component of the experiment.

Equivalence class formation under the simultaneous protocol. The 10 participants who formed the two 5-member classes under the simple-to-complex protocol, were presented with training and testing to establish two new 3-node 5-member equivalence classes under the simultaneous protocol. Seven of these participants formed the 3-node 5-member classes. Of the remaining participants, one did not acquire the baselines during the allotted time, and two acquired the baselines but ran out of time before the administration of the emergent relations test blocks.

Table 6 presents the performances during the establishment of the baseline relations and the emergent relations tests for the seven subjects who formed classes under the simultaneous protocol. The baseline relations were acquired in an average of 6 blocks with a SEM of 0.95. Once acquired, performances were maintained during feedback reduction. Since the number of blocks actually used for feedback reduction was close to or at the minimum of 3 blocks for most participants, the baseline conditional discriminations were maintained with a few transient disruptions during this phase of the experiment.

Table 6. Number of blocks needed to acquire the baseline relations, maintain them during the reduction of feedback, and pass the emergent relations test for participants who formed classes in Experiment 3. The latter measures include the number of blocks to complete the criterion run of 3 consecutive blocks each of which evoked the criterion level of class-indicative responding. An asterisk indicates that the participant was exposed to the within-class preference test following equivalence class formation.

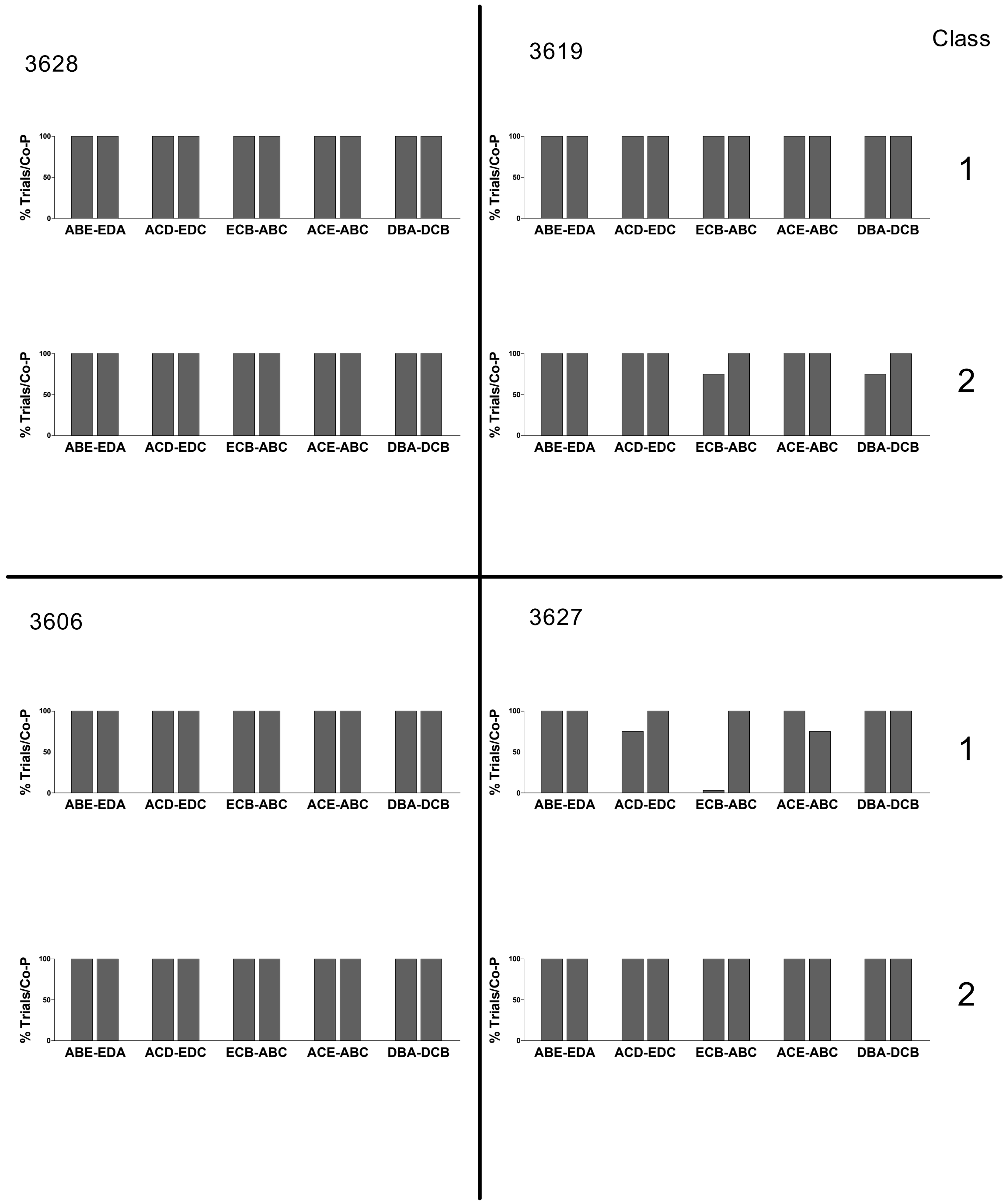
Participant	Number of Blocks To 100% Accuracy	Maintenance Blocks	Emergence Blocks
3606*	4	3	3
3627*	4	3	3
3619*	6	3	3
3628*	4	3	5
3618	7	7	5
3620	6	3	6
3629	11	4	6
Average	6	3.8	4.4
Minimum	1	3	3

When the emergent relations tests were administered, three participants (3606, 3627, and 3619) responded in a class-consistent manner to all probes and the baselines in the minimal number of test blocks, thereby documenting the immediate emergence of the 3-node 5-member equivalence classes. The four remaining participants (3628, 3618, 3620, and 3629) required more than the minimum number of presentations of the emergent relations test block before responding involved the selection of comparisons from the same class as the prevalent sample, which documented the delayed emergence of the equivalence classes.

Preliminary training and class formation under the simultaneous protocol. Of the twelve participants who began the experiment, ten formed equivalence classes under the simple-to-complex protocol. Of the ten, seven formed the new 2-node 4-member equivalence classes under the simultaneous protocol. Of the participants who began the experiment, 57% formed classes under the simultaneous protocol (7 of 12). Of those who began the simultaneous protocol, 70% formed classes under that condition (7 of 10). Three participants, however, ran out of time before they were exposed to the emergent relations tests used to document the formation of equivalence classes. It is possible that these individuals would have demonstrated the emergence of the equivalence classes if given more time. Therefore, if only the individuals that were exposed to the emergent relations test under the simultaneous protocol are considered 100% formed classes (7 out of 7). Prior research has shown that only about 20% of participants form these classes under the simultaneous protocol with no prior training. Thus, the results of the present experiment are consistent with the previous findings: prior establishment of equivalence classes under the STC protocol enhances the subsequent formation of new equivalence classes under the simultaneous protocol.

Within-class preference tests. Due to time constraints, only four participants who formed classes under the simultaneous protocol were exposed to the within-class preference tests. Figure 3 depicts the data obtained from them. With one exception (the ACB-ABC probes for 3627 for class 1), the trials in each within-class probe predominantly evoked the selection of the nodally proximal comparison stimuli. Notwithstanding the one exception, all of the remaining performances, then, appear to document the conditional control of responding based on the nodal proximity of the comparisons to the sample stimuli. By implication, these outcomes support the view that the strength of each relation among the stimuli in a multi-nodal equivalence class is an inverse function of the number of nodes that separate them in an equivalence class.

Figure 3. Performances on all within-class preference probes for all participants in Experiment 3. The format is the same as that used in Figure 1, however, the data for two participants are presented on the left side of the page and the data for two other participants are presented on the right side of the page.



Before giving further consideration to this general finding, the exception was produced by the ECB and ABC probes for Class 1 for participant 3627 evoked selection of the nodally proximal stimulus on 0% and 100% of the trials, respectively. For this probe pair, the ECB and the ABC trials both evoked selection of the B stimulus. Therefore, responding on these probes may demonstrate control by preference for B or by rejection of the C stimulus.

As mentioned above, the general outcomes support the view that the strength of each relation among the stimuli in a multi-nodal equivalence class is an inverse function of the number of nodes that separate them in an equivalence class. As in Experiment 2, such a conclusion, however, can be accepted only after considering the impact of other variables that were confounded with nodal differences and thus, could also have accounted for the performances evoked by each of the within-class probes. These include differences in the types of relations that exist between each comparison and the sample, and differences in the behavioral functions acquired by the comparisons during training. Other factors that could account for the test performance are unconditional preferences for given comparison stimuli and rejection of given comparison stimuli. Where relevant, all of these factors will be considered for each of the probes.

Unconditional preference or rejection. As in Experiment 2, the probe pairs in Experiment 3 were arranged so that consistent selection of the nodally proximal stimulus on a given probe block would rule out unconditional control by stimulus preference or rejection.

Nodal proximity alone. For two of the probes, the only factor that differentiated each comparison from the sample was nodal number. These were the ACD and the ECB probes.

The ACD probe. In this probe, participants selected C instead of D. The C and D stimuli both bore transitive relations to the sample stimulus. Thus, the selection of the nodally proximal comparison on the ACD probes could not be attributed to differences in the relations between each comparison and the sample. Also, both comparisons had acquired two behavioral functions during training. Thus, the performances could not be attributed to differences in the functions acquired by each of the comparison stimuli. Finally, the only factor that distinguished the C and D comparisons was the number of nodes that separate each from the sample: 1-node for AC and 2-node for AD. Thus, the selection of the C comparison could be attributed to nodal proximity. These considerations then support the view that the ACD probes demonstrated conditional control based on nodal proximity, unconfounded by other variables.

The ECB probe. In this probe, participants selected C instead of B. The C and B stimuli both bore equivalence relations to the sample stimulus. Thus, the selection of the nodally proximal comparison on the ECB probes could not be attributed to differences in the relations between each comparison and the sample. Also, both comparisons had acquired two behavioral functions during training, both comparison stimuli serve as nodes. Thus, the performances could not be attributed to differences in the functions acquired by each of the comparison stimuli. Finally, the only factor that distinguished the C and B comparisons was the number of nodes that separate each from the sample: 1-node for EC and 2-node for EB. Thus, the selection of the C comparison could be attributed to nodal proximity. These considerations then support the view that the ECB probes demonstrated conditional control based on nodal proximity, unconfounded by other variables.

Nodal proximity and number of functions. For two probes, each sample-comparison relation differed in terms of nodal number and the number of functions acquired by each comparison during training. These probes were ACE and DBA.

The ACE probe. In this probe, participants selected C instead of E. The C and E stimuli both bore transitive relations to the sample stimulus. Thus, the selection of the nodally proximal comparison on the ACE probes could not be attributed to differences in the relations between each comparison and the sample. One factor that distinguished the C and E comparisons was the number of nodes that separate each from the sample: 1-node for AC and 3-nodes for AE. Thus, the selection of the C comparison could be attributed to nodal proximity. In addition, one comparison had acquired two behavioral functions during training, and served as a nodal stimulus, while the other comparison had acquired only one behavioral function during training and served as a single. Thus, the performances could be attributed to differences in the functions acquired by each of the comparison stimuli. To summarize, the ACE probes demonstrated conditional control based on nodal proximity, but perhaps also by a preference for a stimulus that had acquired a nodal function instead of serving as a single.

The DBA probe. In this probe, participants selected B instead of A. The B and A stimuli both bore equivalence relations to the sample stimulus. Thus, selection of the nodally proximal comparison on the DBA probes could not be attributed to differences in the relations between each comparison and the sample. One factor that distinguished the

B and A comparisons was the number of nodes that separate each from the sample: 1-node for DB and 2-nodes for DA. Thus, the selection of the B comparison could be attributed to nodal proximity. In addition, one comparison had acquired two behavioral functions during training, and served as a nodal stimulus, while the other comparison had acquired only one behavioral function during training and served as a single. Thus, the performances could be attributed to differences in the functions acquired by each of the comparison stimuli. To summarize, the DBA probes demonstrated conditional control based on nodal proximity, but perhaps also by a preference for a stimulus that had acquired a nodal function instead of serving as a single.

ACE and DBA probes. For both of these probes, the difference in number of functions served by the comparisons during training was also correlated with nodal number. Thus, any effect attributed to difference in number of functions served by the comparisons would be confounded with nodal number.

Nodal proximity and relational type. For three probes, each sample-comparison relation differed in terms of nodal number and relational type. These probes were EDC, DCB, and ABC.

The EDC probe. In this probe, participants selected D instead of C. The D and C stimuli had both acquired two behavioral functions during training, and served as nodal stimuli. Thus, the selection of the nodally proximal comparison could not be attributed to differences in the functions acquired by each of the comparison stimuli. One factor that distinguished the D and C comparisons was the number of nodes that separated each from the sample: 0-nodes for ED and 1-node for EC. Thus, the selection of the D comparison could be attributed to nodal proximity. In addition both comparisons bore different types of relations to the sample stimulus, i.e. a symmetrical relation for ED and an equivalence relation for EC. Thus, the selection of the D comparison could be attributed to a difference in relational type. To summarize, the EDC probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference.

The DCB probe. In this probe, participants selected C instead of B. The C and B comparisons both had acquired two behavioral functions during training, and served as nodal stimuli. Thus, the selection of the nodally proximal comparison could not be attributed to differences in the functions acquired by each of the comparison stimuli. In this probe, one factor that distinguished the C and B comparisons was the number of nodes that separated each from the sample: 0-nodes for DC and 1-node for DB. Thus, the selection of the C comparison could be attributed to nodal proximity. In addition, both comparisons bore different types of relations to the sample stimulus, i.e. a symmetrical relation for DC and an equivalence relation for DB. Thus, the selection of the C comparison could also be attributed to a difference in relational type. To summarize, the DCB probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference.

The ABC probe. In this probe, participants selected B instead of C. Both the B and C stimuli had acquired two behavioral functions during training, and served as nodal stimuli. Thus, the selection of the nodally proximal comparison could not be attributed to differences in the functions acquired by each of the comparison stimuli. One factor that distinguished the B and C comparisons was the number of nodes that separated each from the sample: 0-nodes for AB and 1-node for AC. Thus, the selection of the B comparison could be attributed to nodal proximity. In addition, both comparisons bore different types of relations to the sample stimulus, i.e. a baseline relation for AB and a transitive relation for AC. Thus, the selection of the B comparison could be attributed a difference in relational type. To summarize, the ABC probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference.

EDC, DCB, and ABC. For all of these probes, the difference in relational type was also correlated with nodal number. Thus, any effect attributed to difference in relational type would be confounded with nodal number.

Nodal proximity, functions, and relational type. For two probes, each sample-comparison relation differed in terms of nodal number, functions acquired by the comparisons, and relational type. These probes were EDA, ABE.

The EDA probe. In this probe, participants selected D instead of A. The D and A stimuli both bore different types of relations to the sample stimulus, i.e. a symmetrical relation for ED and an equivalence relation for EA. Thus, the selection of the nodally proximal comparison could be attributed a difference in relational type. In addition, in this probe, the D comparison had acquired two behavioral functions during training, and served as a nodal stimulus, while the A comparison had acquired only one behavioral function during training and served a single. Thus, the performances could be attributed to differences in the functions acquired by each of the comparison stimuli. Finally, one other factor that distinguished the D and A comparisons was the number of nodes that separated each from the sample: 0-nodes for ED and 3-nodes for EA. Thus, the selection of the D comparison could be attributed to nodal proximity. To summarize, the EDA probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference, or difference in the functions served by the comparisons.

The ABE probe. In this probe, participants selected B instead of E. The B and E stimuli both bore different types of relations to the sample stimulus, i.e. a baseline relation for AB and a transitive relation for AE. Thus, the selection of the B comparison could be attributed a difference in relational type. In addition, in this probe, the B comparison had acquired two behavioral functions during training, and served as a nodal stimulus, while the E comparison had acquired only one behavioral function during training and served a single. Thus, the performances could be attributed to differences in the functions acquired by each of the comparison stimuli. Finally, one other factor that distinguished the B and E comparisons was the number of nodes that separated each from the sample: 0-nodes for AB and 3-nodes for AE. Thus, the selection of the B comparison could be attributed to nodal proximity. To summarize, the ABE probes could have demonstrated conditional control based on nodal proximity, but perhaps also by a relational difference, or difference in the functions served by the comparisons.

EDA and ABE probes. For both of these probes, the difference in number of functions served by the comparisons during training and difference in relational type were also correlated with nodal number. Thus, any effect attributed to difference in number of functions served by the comparisons relational type of relational type would be confounded with nodal number.

Plausibility of control by number of functions. As noted above, it is possible that on the DBA, ACE, EDA, and ABE probes, the participant may have selected a particular stimulus because it served two functions during training. However, if the participant was responding to all probes in the within-class preference test based on this stimulus control topography exclusively, the DCB, ABC, ACD, ECB, EDC probe trials would have occasioned the selection of each comparison with equal likelihood, since both stimuli in each of these probes served two functions during training. The fact that the participants did not respond in this manner on these probe trials questions the plausibility of arguing that the performances evoked by the entire constellation of the within-class probes could be accounted for by number of functions acquired by the comparisons during training. Granting this inference, the only alternative is that conditional selection of the comparisons was determined by the nodal proximity of each to the samples in the probes.

Plausibility of control by relational type. As noted above, it is possible that on the ABE, EDA, EDC, ABC, and DCB probes, the participant may have selected a particular stimulus based on relational type. However, if the participant was responding to all probes in the within-class preference test based on this stimulus control topography exclusively, the ACD, ECB, DBA, and ACE probe trials would have occasioned the selection of each comparison with equal likelihood, since both stimuli in each of these probes were of the same relational type. That fact that these probes did not produce random responding questions the plausibility of arguing that the performances evoked by the entire constellation of the within-class probes could be accounted for by differences in relational type. Granting this inference, the only alternative is that conditional selection of the comparisons was determined by the nodal proximity of each to the samples in the probes.

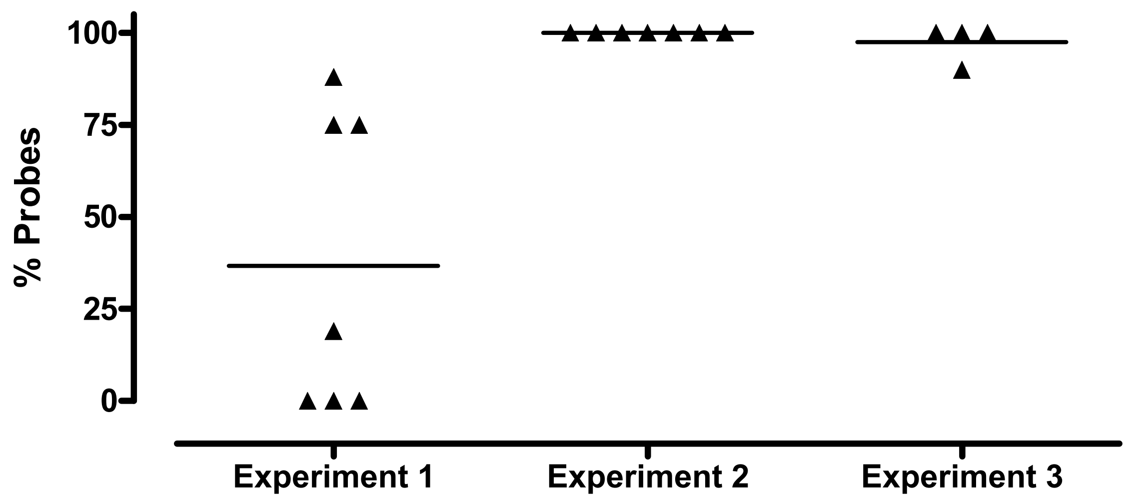
Summary. Virtually all of the within-class probes evoked the conditional selection of the comparison that was nodally closer to the sample than the more nodally distal comparison. Nodal distance was the only variable that distinguished the comparisons from the samples for two probes (ACD and ECB). In total, these probes were presented on 16 occasions (4 per participant and four participants). The performances evoked by 14 of these 16 probes, then, provided an unconfounded measure of the effects of nodal distance on the relatedness of stimuli in multinodal equivalence classes. In addition, these tests were not confounded by serial order. Thus, they extend the findings reported by Alligood and Chase (2007).

For other probes, the comparisons could be distinguished from the sample based on nodal proximity but also by one of two other factors: the functions acquired by the comparisons and/or the relational types that characterize the sample-comparison pairs in the probes. Although these factors were present in some of the probes and absent in others, all of the probes evoked the selection of the nodally proximal comparisons. The selections of the comparisons in the entire set of within-class probes cannot be reasonably accounted for by these factors that were confounded with nodal proximity. Therefore, the most parsimonious account of the performances evoked by the within-class preference probes is that they reflect control by the nodal proximity of each comparison to the sample. This interpretation supports the notion that the strength of relations among the stimuli in a multi-nodal equivalence class is an inverse function of the number of nodes that separate the stimuli in the class based on the training structure.

General Discussion

Summary. Three experiments were conducted to assess the strength of relations among the stimuli in equivalence classes. The assessment was based on the performances evoked by the stimuli presented in within-class preference tests. Figure 4 presents a summary of the outcomes across the three experiments. This figure is in column scatter format. Each data point is for one participant and indicates the percentage of probe pairs in both classes that produced the selection of the nodally proximal stimulus on at least seven of the eight trials in a pair. The horizontal line indicates the mean of the data points for each experiment.

Figure 4. This figure is a column scatterplot that summarizes the outcomes of Experiments 1, 2, and 3. The values on the ordinate indicate the percentage of probe pairs in both classes that produced the selection of the nodally proximal stimulus on at least seven of the eight trials in a pair. Each data point indicates this percentage for one participant. The horizontal bar indicates the average for each Experiment. The data for the participants are grouped by Experiment, Experiment 1 is presented on the left, Experiment 2 in the middle, and Experiment 3 is presented on the right.



In Experiment 1, two 2-node 4-member classes were formed using trials that contained two comparisons. Very few within-class preference probes evoked data that reflected control by the nodal separation of stimuli in the classes. Experiment 2 replicated Experiment 1 but training and testing trials included a third null comparison stimulus. Most of the within-class preference tests evoked data that reflected control by the nodal separation of stimuli in the classes. Experiment 3 used the same training and testing procedures as in Experiment 1 but participants formed 3-node 5-member classes. Once again, most of the within-class preference tests evoked data that reflected control by the nodal separation of stimuli in the classes.

Nodal Distance Effects. In Experiments 2 and 3, nodal distance effects were demonstrated in 2-node 4-member and 3-node 5-member equivalence classes. In the latter classes, for two probes, the effects of nodal distance were unconfounded with any other variable. For the remaining probes in Experiments 2 and 3, nodal distance was confounded with relational type and/or the number of functions served by the comparisons. Notwithstanding this situation, the only variable that was correlated with every probe was nodal distance; thus, nodal distance appears to influence the relatedness of stimuli in these classes.

The results of the within-class preference tests, then, extended the findings that have shown the effects of nodal structure on the differential relatedness of stimuli in equivalence classes. These include the influence of nodal structure on delayed emergence ((Fields, Adams, Verhave, & Newman, 1990; Sidman, Kirk, & Willson-Morris, 1985; Kennedy, 1991; Kennedy, Itkonen, and Lindquist, 1994; Bentall, Jones, & Dickins, 1998; Spencer & Chase, 1996), on response latency (Bentall, Jones, & Dickins,1998; Kennedy, 1991; Spencer & Chase, 1996; Wulfert & Hayes, 1988; Tomanari, Sidman, Rubio, & Dube, 2006), the transfer of responding to the members of an equivalence class (Fields, Adams, Verhave, & Newman, 1993), the post class formation bifurcation of a multinodal equivalence class (Fields et al., 1995; Fields & Watanabe-Rose, 2008), and preferences for nodally proximal stimuli during within-class preference tests ((Fields, et al., 1989, May; as cited in Fields, Adams, Verhave, & Newman, 1993; Alligood & Chase, 2007).

Effect of the third null comparison. In Experiment 1, when two comparisons were used during equivalence class training and testing, participants could have formed one class and responded to the stimuli in the other class by rejection of the stimuli from the former class. The inclusion of a third comparison for training and testing, as in Experiments 2 and 3, resulted in the formation of two explicit equivalence classes. In addition, the performances evoked by the within-class probes in Experiments 2 and 3 demonstrated control of behavior by nodal structure. Notwithstanding the fact that these three Experiments were run sequentially, a comparison of the results of Experiment 1 with those obtained from Experiments 2 and 3 suggest that the inclusion of a third null comparison during equivalence class formation also increased sensitivity to nodal structure and nodal distance among the stimuli in the classes.

Generality of nodal distance effects across many participants. Prior studies have demonstrated the post-class formation effects of nodal distance after classes after the formation of equivalence classes under the simultaneous protocol. In these studies, however, about 20% of participants formed equivalence classes. Therefore, the effects of nodal distance might have been restricted to individuals with the ability to form classes under this protocol without prior training.

In Experiments 2 and 3, participants formed one set of equivalence classes under the STC protocol, and then attempted to form new equivalence classes under the simultaneous protocol. Under these conditions, a much larger percentage of participants formed equivalence classes with the simultaneous protocol. Thereafter, the results for all participants in Experiments 2 and 3 showed that the relatedness of stimuli in equivalence classes was an inverse function of nodal distance. Because the effects of nodal distance were documented for a large number of participants, this effect can be viewed as being a general phenomenon that is not restricted to individuals who could form equivalence classes without prior training. In addition, since the equivalence classes were formed under the simultaneous protocol, nodal distance effects were not confounded with number of training trials or serial order of presentation.

Influence of preliminary training on sensitivity to nodal structure. The use of preliminary training resulted in the subsequent formation of 4 or 5 member classes by many participants. These results are consistent with the results of prior research (Fields et al., 1997; Buffington, et al., 1997). It could be argued that the preliminary training used in these experiments also increased sensitivity to nodal distance. This, however, could not be the case because most of the participants in Experiment 1 did not respond in accordance with nodal distance during the within-class preference tests. Rather, a comparison of the procedures used in Experiment 1 relative to those used in Experiments 2 and 3 suggest that sensitivity to nodal distance was governed by the inclusion of a null third comparison during the formation of equivalence classes under the simultaneous protocol.

Maintenance of equivalence classes. In Experiments 1, 2, and 3, after the presentation of the within-class preference tests, the participants were re-exposed to the emergent relations test used to document the presence of equivalence classes. In all experiments, the equivalence classes remained intact regardless of performances on the within-class preference test. Thus, the underlying equivalence classes were not disrupted by exposure to within-class preference probes or by any type of performances evoked by the within-class probes.

Future Research. Two of the within-class probes in Experiment 3 measured the effects of nodal spread for relations of the same type (i.e. transitivity and equivalence) that were not confounded with any other variables. Other probes measured the effects of nodal spread that were confounded with relational type and/or the number of functions served by the comparisons during training. None of the probes, however, measured the effects of different relational types where the nodal spread was held constant. Theoretically, that latter issue could have been measured with a 3-node 5-member class using within-class CAE probes. In this probe type, the A and E comparison stimuli are both separated from the sample by one node, where CE is a 1-node transitive relation and CA is a 1-node equivalence relation. This probe, however, is problematic because the two comparison stimuli served different functions during training: A served as a sample and E served as a comparison. Therefore, the functions served each comparison would be confounded with relational type. As such, it would not be possible to obtain an unambiguous measure of the relative strengths of transitive and equivalence relations. This, then, is an inherent limitation in the use of 5-member classes for measuring differences in the strength of relational type.

It is possible, however, to evaluate potential differences in the strength of different types of relations where nodal spread is held constant with equivalence classes that are more than five members. For example a 7-member class could be established by training AB, BC, CD, DE, EF, FG and would have the following nodal structure: A→B→C→D→E→F→G. A within-class probe, such as a DBF probe could be used to evaluate the differential strengths of a 1-node equivalence relation (DB) relative to a 1-node transitive relation relative (DF). In addition, both comparisons had acquired two behavioral functions. Thus, nodal number and acquired functions would not be confounded with relational type. The outcomes of such a test would provide a comparison of any differential effects of transitive and equivalence relations.

Finally, in Experiment 3, there were only two probes where nodal distance was not confounded with relational type or number of functions served by the comparisons during training. When larger classes are established, more of these types of probes can be conducted. For example, if a 5-node 7-member class were established 20 probes could be presented in which nodal distance was not confounded with any other variable.

Theoretical Implications. In early studies, the differential strength of relations between stimuli in an equivalence class was measured by accuracy of responding during delayed emergence of equivalence classes, and by differences in latency to respond during initial emergent relations tests: i.e., nodal distance effects. These studies, however, only demonstrated nodal distance effects on a transient basis. More recently, nodal distance effects have been demonstrated after equivalence classes have formed, with the use of dual-option response transfer tests and within-class preference tests. All of these experiments, however, had some shortcomings that limited the conclusions regarding the generality of the effects of nodal distance. These shortcomings involved potential confounds of nodal distance with serial order of presentation of stimuli and/or number of presentations of trials, and low yields.

The current experiments overcame all of these shortcomings and demonstrated the effects of nodal distance. In addition, the generality of the findings was increased by demonstrating nodal distance effects with a large number of participants who formed classes under the simultaneous protocol. Therefore, the results of these experiments demonstrate the unconfounded effects of nodal distance as a general phenomenon and document the fact that nodal distance influences the relatedness of stimuli within an equivalence class.

When the baselines for an equivalence class are established, behavior comes under the control of two stimulus control topographies: one based on class and the other based on nodal structure. The expression of each of these topographies of selection based responding depends on the format of the test trial, the opportunity to respond on a between class basis, and the contingencies of reinforcement that were available during training trials that had the same format as the test trial. The emergent relations tests presented before and after the within-class preference tests evoked class-consistent responding to all relations during traditional match-to-sample trials that documented the presence of equivalence classes. Thus, under conditions that signal between-class contingencies, the stimuli in a class produce responding indicative of stimulus interchangeability or equal stimulus relatedness. These contingencies overshadow the effects of nodality. During the within-class preference test, participants were given an opportunity to respond to a situation in which two response options from the same class were pitted against each other. In these situations, participants responded in accordance with nodal distance. Thus, under conditions that signal the absence of between-class contingencies, the nodal structure of the class is expressed by the evocation of performances that are in accordance with the nodal structure of the underlying equivalence class. To summarize, the presence of between-class contingencies results in the non-expression of nodality; conversely, the absence of between-class contingencies results in the expression of nodal structure. The results of these studies indicate that the stimulus substitutability and the associative distance account of nodal distance can both be used to describe responding to stimuli in equivalence class, each in a different context that is defined by the content of the test trials.

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