MAINTAINED NODAL-DISTANCE EFFECTS IN EQUIVALENCE CLASSES

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Twelve subjects were trained to select one of two stimuli from a pair (the B pair) when presented with one of two stimuli from another pair (the A pair), thus establishing two AB relations, A1-B1 and A2-B2. In a similar fashion, additional stimuli were used to establish BC, CD, and DE relations. Trials used to train all relations occurred in each session. Once performances were established, probe trials were introduced that tested for the emergence of untrained relations (e.g., B1-D1 or A1-E1). These emergent relations were categorized according to nodal distance (i.e., the number of stimuli across which transitivity would have to hold in order for the relation to emerge). For example, a test for A2-C2 crosses one node (B2), whereas a test for A1-E1 crosses three nodes (B1, C1, and D1). Only 2 of the subjects formed equivalence classes. The evocation of class-appropriate responding by each emergent-relation probe was an inverse function of nodal distance for all 12 subjects. In addition, performance on the originally trained relations was disrupted by the introduction of probes. The 2 subjects who exhibited equivalence classes were then trained to make different numbers of key presses in the presence of each of the four A and E stimuli. In a response-transfer test, the B, C, and D stimuli evoked the responses trained to the A and E stimuli in the same equivalence class. Likelihood of class-appropriate responses was an inverse function of nodal distance, and this pattern persisted across testing. Reaction times in the transfer test were an inverted U-shaped function of nodal distance. Because training of the baseline relations occurred concurrently and the B, C, and D stimuli were presented an equal number of times before the transfer test, the test performances illustrate effects of nodal distance that were not confounded by order or amount of experience with the stimuli. The results imply that ordered, sequential exposure to individual stimulus relations may facilitate the development of equivalence classes and that the relatedness of stimuli within an equivalence class is a relatively permanent inverse function of nodal distance.

Key words: equivalence class, nodal-distance effect, relational-control kernel, stimulus substitutability, functional class, reaction time, transfer test, keyboard response, college students

A node is defined by Fields, Verhave, and Fath (1984) as a stimulus that is linked by training to at least two other stimuli. Thus, nodal distance is the number of nodes that link any two stimuli in a set of trained conditional relations. It has been proposed that the relatedness of the stimuli in an equivalence class is an inverse function of nodal distance (Fields, Adams, & Verhave, 1993; Fields & Verhave, 1987; Fields et al., 1984). This proposal has been supported by fragmentary data culled from earlier studies of equivalence class formation (Lazar, Davis-Lang, & Sanchez, 1984; McDonagh, McIlvane, & Stoddard, 1984; Saunders, Wachter, & Spradlin,

1988; Sidman, Kirk, & Willson-Morris, 1985). It has also been supported by more recent studies that systematically measured the choice performances (Dube, Green, & Serna, 1993; Fields, Adams, Newman, & Verhave, 1992; Fields, Adams, Verhave, & Newman, 1990; Kennedy, 1991; Kennedy, Ikonen, & Lindquist, 1994) and the reaction times (Bentall, Dickins, & Fox, 1993; Dickins, Bentall, & Smith, 1993; Wulfert & Hayes, 1988) occasioned by tests of emergent relations. The most recent support was provided by Fields, Adams, Verhave, and Newman (1993), who showed that nodal distance influenced transfer of responding among members of an equivalence class.

In all of these studies, however, the baseline relations were trained in a serial manner. As a result, nodal distance was confounded with the order of stimulus introduction during training and most likely with the number of times each stimulus was presented in training (Fields, Adams, & Verhave, 1993; Fields,

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Adams, Verhave, & Newman, 1993; Sidman, 1994). In addition, because different baseline relations were mastered at different rates, it is likely that each stimulus became associated with a different number of reinforcers. Therefore, the number of stimulus–reinforcer pairings could have been confounded with nodal distance, and test performances could be a function of these variables and not nodal distance. To date, there has been no demonstration of the unconfounded effects of nodal distance.

The possibility of confounding effects notwithstanding, the effects of nodality on test performance in all of the demonstrations were transient; they disappeared with the repeated presentation of trials in a given test. Having disappeared in one type of test, the effects of nodal distance reappeared with the introduction of a new type of test. This resurgence supports the view that nodal distance has a permanent effect on the relatedness of stimuli in an equivalence class, but its influence on performance in a given test is determined by the contingencies that prevail in that test (Fields, Adams, & Verhave, 1993). If the effects of nodal distance are permanent, it should be possible to devise a test in which performance correlated with nodal distance would be maintained with repeated testing.

In the current experiment, equivalence classes were established using a “simultaneous” procedure in which the variables mentioned above were not confounded with nodal distance. After class formation, different responses were trained to two stimuli in each class; thereafter, the transfer of both responses to the remaining stimuli in the class was measured. It was hypothesized that such training would increase the tendency of the remaining stimuli to evoke both responses; this procedure would increase sensitivity of responding to nodal distance and would promote maintenance of responding in the transfer test. Test performances that were correlated with nodal distance would demonstrate the permanency of the effects of nodal distance.

METHOD

Subjects

Twelve undergraduate students at Queens College City University of New York who were

not familiar with the research area were recruited from an introductory psychology class. The partial course credit earned for completing the experiment was not contingent upon performance. Students participated in four to six 1- to 2-hr sessions scheduled over a 3-week period.

Apparatus and Stimuli

The experiment was conducted on IBM®-compatible microcomputers. Each subject sat in a cubicle at a table facing a monochrome computer monitor and a keyboard. All stimuli were presented on the screen of the monitor. Responses involved pressing specific keys on the keyboard and were automatically recorded by the computer. The experiment was conducted using software developed to study equivalence classes and response transfer. Each of the two classes contained five three-letter nonsense syllables. The nonsense syllables and their letter-number designation in Class 1 were QIJ = A1, TUW = B1, COH = C1, MEP = D1, and RAB = E1; in Class 2, they were VIF = A2, KUY = B2, XOL = C2, GEZ = D2, and NAS = E2.

Procedure

Trial structure and contingencies. Each trial began when the sample stimulus (Sa) appeared on the screen. Pressing the space bar in the presence of the sample added one positive comparison stimulus (Co+) and one negative comparison stimulus (Co-) on the screen in an isosceles triangular array, with the sample at the vertex and the comparisons at the corners of the base. Subjects pressed the 1 or 2 key on the top row of the keyboard to select the comparison on the left or the right, respectively. When informative feedback was scheduled, selection of either comparison resulted in the replacement of all stimuli with a feedback message. If the Co+ was chosen, “RIGHT” appeared on the screen until the subject pressed the R key. If the Co- was chosen, “WRONG” appeared on the screen until the subject pressed the W key. When noninformative feedback was scheduled, either choice response produced the letter E on the screen; it remained until the subject pressed the E key. Pressing the R, W, or E key cleared the screen. Then, the message “Press ENTER” appeared on the screen. Pressing the enter key replaced the

message with the next sample stimulus. See Fields et al. (1990) for further details.

Training and testing were conducted in blocks of trials. The trials in each block were presented in random order without replacement. For each Sa/Co+/Co- triad, the Co+ and Co- appeared equally often in the left and right positions across trials.

Preliminary training. At the start of experiment, the subject was shown the following instructions on the computer monitor:

Thank you for volunteering to be a subject 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 contains three CUES. These will be common words, or three letter nonsense words such as ZEQ or WUV. YOUR TASK IS TO DISCOVER WHICH WORDS GO TOGETHER.

Initially there will also be INSTRUCTIONS that tell you how to respond to the cues, as well as 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 a key on the computer's keyboard. The experiment is conducted in phases. If you want to take a break at the end of a phase, please call the instructor. When you are ready to start, press the key with the word ENTER written on it.

Subjects were then trained to emit the appropriate keyboard responses needed to complete a trial. These trials contained sample and comparison stimuli that were common words, and the sample was semantically related to the positive comparison but not to the negative comparison. Three representative Sa/Co+/Co- combinations were CANARY/SPARROW/STARS, THIS/THAT/KINGS, and SOAP/THAT/WATER.

At the start of preliminary training, five instructional prompts also appeared on the computer screen with the samples and comparisons. These prompts described the specific responses that were to be emitted in the presence of each screen display. After every third consecutive correct trial, one prompt was deleted. The full complement of prompts and the sequence of screen displays that occurred at the start of preliminary training are shown in the top row of Figure 1. The sequence of deleting prompts and the screen

displays within a trial as each prompt was deleted are illustrated in successive rows of Figure 1. By the end of preliminary training, the stimuli in a trial were presented without prompts. For the remainder of the experiment, if a keyboard error was made, the instruction relevant to that error reappeared on the screen for that trial and for the next two trials; it was then eliminated unless the error recurred.

Establishment of five-member classes. Two classes were established by training AB, BC, CD, and DE on a concurrent basis. All of these relations were included in the training block, and each relation was presented the same number of times. Symbolic representations of all training trials are listed in Table 1.

The mastery criterion for training and testing was 100% class-consistent selection in a block of trials. When the training block was introduced, the selection of a comparison on each trial was followed by informative feedback, and the block was repeated until the mastery criterion was reached. As long as performance within the block remained at 100% accuracy, the percentage of trials in a block that produced informative feedback was reduced from 100%, to 75%, to 25%, and finally to 0% in successive blocks. Trials that produced feedback were randomly determined; selections on the remaining trials were followed by noninformative feedback.

Emergent-relations tests. Once training was completed, all baseline conditional relations, symmetry tests, and one-, two-, and three-node transitivity and equivalence tests were presented in a single block. Each relation was presented the same number of times. All symbolic representations of trials used for the emergent-relations tests are listed in Table 1. The test block was repeated until the mastery criterion was met or for five presentations.

Informative feedback was always presented for selections made during the baseline conditional-relation trials. Feedback was never presented for the selections made on the emergent-relations test trials.

The transfer of new stimulus-response relations. After the equivalence classes were established, discrimination training was used to teach each subject to make a different response in the presence of each of four new nonsense syllables. Stimulus fading was then used to transfer control of these responses to

Fig. 1. Sequential changes in the stimuli and the prompts that were presented during a trial are illustrated across a row. Deletion of prompts in successive blocks of trials is illustrated in successive rows. SA represents the location of the sample stimuli. CO* represents the location of the comparisons.

Table 1

Symbolic representation of stimulus triads used in the training block and in the testing block. In the training block, each Sa/Co+/Co- triad appeared four times, twice with the Co+ on the left and twice with the Co+ on the right, yielding a total of 32 trials. In the testing block, each Sa/Co+/Co- used in training and each emergent relation appeared twice, once with the Co+ on the left and once with the Co+ on the right, yielding a total of 80 trials. Arrangements in testing blocks are organized by the number of nodes.

Sa	Co+	Co-	Presented	Sa	Co+	Co-	Presented
Training							
A1	B1	B2	4	A2	B2	B1	4
B1	C1	C2	4	B2	C2	C1	4
C1	D1	D2	4	C2	D2	D1	4
D1	E1	E2	4	D2	E2	E1	4
Testing							
Baseline review							
A1	B1	B2	2	A2	B2	B1	2
B1	C1	C2	2	B2	C2	C1	2
C1	D1	D2	2	C2	D2	D1	2
D1	E1	E2	2	D2	E2	E1	2
Zero nodes							
B1	A1	A2	2	B2	A2	A1	2
C1	B1	B2	2	C2	B2	B1	2
D1	C1	C2	2	D2	C2	C1	2
E1	D1	D2	2	E2	D2	D1	2
One node							
A1	C1	C2	2	A2	C2	C1	2
B1	D1	D2	2	B2	D2	D1	2
C1	E1	E2	2	C2	E2	E1	2
C1	A1	A2	2	C2	A2	A1	2
D1	B1	B2	2	D2	B2	B1	2
E1	C1	C2	2	E2	C2	C1	2
Two nodes							
A1	D1	D2	2	A2	D2	D1	2
B1	E1	E2	2	B2	E2	E1	2
D1	A1	A2	2	D2	A2	A1	2
E1	B1	B2	2	E2	B2	B1	2
Three nodes							
A1	E1	E2	2	A2	E2	E1	2
E1	A1	A2	2	E2	A2	A1	2

the two A and two E stimuli in the equivalence classes. Finally, all of the stimuli from both classes were presented in a response-transfer test.

Within-trial contingencies. Discrimination training, stimulus fading, and response-transfer testing were conducted using blocks of trials. All trials in a block were presented in a random order without replacement. Each trial began when "GET READY!" appeared on the screen for an average of 2.5 s. A response during the presentation replaced this message with "You did not wait long enough!" The screen was then cleared for a 2.0-s intertrial interval (ITI). Key presses during the ITI

had no programmed consequence. If no key was pressed during "GET READY!" the message was replaced by a discriminative stimulus (a class member and a response-inducing prompt) that remained on the screen until a subject emitted a response (pressing at least one alphanumeric key followed by the enter key). If a response did not occur within 6 s in the discrimination training and the fading procedures or within 60 s in the response-transfer testing procedure, the discriminandum was replaced by the screen message "You took too long!"; this in turn was followed by the ITI. The trial was then repeated. If a response occurred in the presence of a

discriminative stimulus, the discriminative stimulus was replaced with a 2-s feedback message. A correct response (to be defined below) produced the feedback message "THAT'S CORRECT!" An incorrect response (to be defined below) produced the feedback message "WRONG." Both feedback messages were followed by the ITI. If no feedback message was scheduled, a response produced the ITI. Response-terminated trials were followed by the next scheduled trial.

Discrimination training. Discrimination training began with the presentation of the following instructions on the computer monitor.

In this section of the experiment you will see some nonsense words. They will be presented one at a time. While each word is on the screen, press the J key a number of times. Then press the ENTER key. PLEASE DO NOT PRESS THE J KEY MORE THAN 15 TIMES BEFORE PRESSING THE ENTER KEY. You will receive feedback after each response. YOUR GOAL IS TO RESPOND CORRECTLY TO EACH WORD.

After pressing any key to clear the instructions, subjects were trained to press the J key three times (3J) in the presence of BGT. They were then trained to press the J key five times (5J) in the presence of YHN. Thereafter, BGT and YHN were presented in a mixed block. Next, subjects were trained to press the J key nine times (9J) in the presence of TGB, after which they were trained to press the J key seven times (7J) in the presence of NHY. A mixed block followed in which TGB and NHY were presented. Finally, YHN, NHY, TGB, and BGT were presented in a mixed block. In each of these steps, the block was repeated until there was 100% accurate responding. Informative feedback was presented on all trials.

Stimulus fading. Stimulus fading was used to train the subject to make the 3J response in the presence of the A1 stimulus, the 5J response in the presence of the E1 stimulus, the 9J response in the presence of the A2 stimulus, and the 7J response in the presence of the E2 stimulus. All trials in the fading procedure contained a class member; most trials in the fading procedure also contained a prompt that was one of the stimuli used in discrimination training. The function of the prompt was to evoke the correct response in

the presence of the A or E stimulus presented on the same trial.

The procedure began with the presentation of the following instructions on the computer monitor:

CONGRATULATIONS! You are now ready to continue the experiment. In the next section, SOME familiar stimuli will be presented. YOUR TASK IS TO TYPE THE APPROPRIATE NUMBER OF Js. YOUR GOAL IS TO RESPOND CORRECTLY TO EACH STIMULUS. Please be patient and stick with the task. Thank you for your cooperation. GOOD LUCK!

After pressing any key to clear the instructions, stimulus pairs consisting of a class member and a prompt were presented on the same line of the monitor, with the class member on the left and the prompt on the right. The specific pairs were the A1 stimulus with BGT, the A2 stimulus with TGB, the E1 stimulus with YHN, and the E2 stimulus with NHY. The class member was present in all trials, and the number of letters in the prompt varied with fading level: All letters in the prompts were present in Level 4 (e.g., A1 BGT); the first letter was replaced by a period in Level 3 (e.g., A1 .GT); the last letter was replaced by a period in Level 2 (e.g., A1 BG.); the first and third letters were replaced by periods in Level 1 (e.g., A1 .G.). At Level 0, the prompt was missing; these trials contained the A1, E1, A2, and E2 stimuli only.

Throughout fading, the correct response for a class member was the response that had occasioned reinforcement in the presence of the prompt paired with the class member. Stimulus fading began with the presentation of a block of Level 4 trials. When response accuracy reached 100%, the procedure advanced to the next lower fading level. If response accuracy was less than 100% on the first presentation of a given block, that block was repeated. If response accuracy was less than 100% on the second presentation of the same block, the next block was presented at the prior fading level. At the start of fading (Level 4), however, the block was repeated until the criterion was met. The fading procedure ended when criterion performances occurred with the stimuli in Level 0 (the class members only). Informative feedback was presented on all trials. All blocks contained 12 trials.

After the prompts were eliminated, the following instructions were presented on the computer monitor:

In subsequent sections of the experiment you will NOT get feedback on every trial. Please be sure to pay attention to the feedback that you do receive. Thank you for your cooperation!

After pressing any key to clear the instructions, the training block containing only the A1, A2, E1, and E2 stimuli was presented repeatedly. As long as response accuracy remained at 100% within a block, the percentage of trials in a block that produced informative feedback decreased to 75%, then 25%, and finally to 0% on successive blocks. All blocks with stimuli from only one class contained 10 trials. Blocks contained 12 trials.

Response-transfer test. The response-transfer test began with the presentation of a the following instructions on the computer screen:

This section will contain MANY MORE trials than the previous section. The ONLY keyboard responses that you may type are III or IIIV or IIIIVV or IIIIVVV. Please be patient and stick with the task. Thank you for your cooperation!

A 50-trial test block was then presented in which each of the five stimuli from each equivalence class was presented five times. The test block was repeated six times, so each stimulus was presented 30 times.

RESULTS

Emergent-Relations Tests

All 12 subjects learned the baseline conditional relations; emergent-relations tests were then conducted with all subjects. Each test block contained trials used to assess maintenance of relational responding by the baselines and the emergence of relational responding occasioned by zero-, one-, two-, or three-node probes. Relational control is frequently assessed by computing the percentage of trials that occasion class-consistent responding. This measure, however, does not accurately index responding that is under the control of a stimulus-stimulus relation. To conclude that a set of stimuli exerts relational control, a given comparison must always be selected in the presence of a sample drawn

from the same potential class and must never be selected in the presence of samples that are members of other potential classes (Sidman, 1980, 1992). When a two-choice conditional discrimination format is used, relational control can be assessed fully by considering the performances occasioned by a group of four trials with the following characteristics: Two sample stimuli must be used; each must be drawn from different potential classes (e.g., A1 and B2), and each sample must be presented twice. Two other stimuli must serve as comparisons, and must be presented as a pair on all four trials (e.g., C1 and D2). For each sample, each comparison must appear once on the left and once on the right (A1/C1 D2 and A1/D2 C1). All four trials must be presented in a random order without replacement. This set of four trials is the minimal unit of measurement that can be used to assess an instance of relational responding, and it will be called a kernel. If a subject is presented with 10 kernels for assessing symmetry, and the class-consistent comparison is selected on all of the trials in seven of the kernels, for example, one would say that relational responding was evoked by 70% of the symmetry test kernels.

Figure 2 shows the percentage of baseline, symmetry, and one-, two-, and three-node kernels that produced performances indicative of relational responding during the emergent-relations test blocks for each subject. Subject 484 formed classes by the second test block; therefore, the effect of trial type on relational responding could be assessed from the data obtained in the first test block. In this block, very high levels of relational responding were produced by the baseline, symmetry, and one- and two-node kernels. A smaller percentage of the three-node kernels produced relational responding. This nodal-distance effect, seen only in the relation characterized by the largest nodal spread, is expected because the effects of nodal distance become attenuated as test performances approach the ceiling level defined by completely class-consistent responding (Fields et al., 1990).

Subject 478 formed classes by the fourth test block, so data averaged for the first three blocks were used to assess relational responding evoked by the different types of trials. Substantial disruption of relational control by

Fig. 2. Proportion of baseline, symmetry, and one-, two-, and three-node kernels that occasioned relational responding for each subject. Subjects are arrayed along the abscissa. The first 2 subjects passed the emergent-relations tests. All others did not. Data for the latter subjects are ordered in terms of the performances occasioned by the baseline kernels. Data for a given type of kernel are computed for all test blocks that produced performances not indicative of class formation. For each subject, the bars from left to right indicate performances for the baseline, symmetry, and one-, two-, and three-node kernels, respectively.

the baseline relations was observed. The baseline, symmetry (zero-node), and one-node kernels all produced similar levels of relational responding. Finally, the percentage of the one-, two-, and three-node kernels that produced relational responding was an inverse function of nodal distance.

For the 10 subjects who did not pass the tests, five test blocks were presented. Inspection of the data across test blocks for individual subjects showed no systematic trends with repeated testing (see the Appendix). Therefore, the data were averaged across blocks for each type of kernel for each subject. The data for these 10 subjects were ordered from left to right in Figure 2 in terms of the relational responding produced by the baseline kernels. Relational responding evoked by the baseline kernels was substantially disrupted for all of these subjects except 466. Relational responding evoked by the baseline kernels did not

recover with repetition of test blocks, even though all comparison selections produced feedback on baseline trials. For all 10 subjects, relational responding was produced by a smaller percentage of the symmetry or zero-node kernels than the baseline kernels. The symmetry kernels also occasioned much higher percentages of relational responding than did the one-, two-, and three-node kernels. Finally, for most subjects, relational responding occasioned by the one-, two-, and three-node kernels was an inverse function of nodal distance. A large percentage of the two- and three-node kernels for many of the subjects produced no relational responding.

Two-Option Response-Transfer Test

After Subjects 484 and 478 demonstrated the formation of equivalence classes, discrimination training with A1, E1, A2, and E2 was conducted and response transfer to all class members was measured. Response transfer was assessed by measuring the relative frequency with which the responses trained to the A and E stimuli were evoked by all of the stimuli in both classes. In the transfer test blocks, 96% of the responses evoked by the B, C, and D stimuli in a given class were those trained to the A or E stimuli from the same class, as seen in Table 2. Such between-class differential responding demonstrates that the stimuli in the equivalence classes also acted as members of separate functional classes. The other 4% of responses were of two types. Most of these responses had been trained to

Table 2
Number of each type of response occasioned by stimuli in transfer tests.

Subject	Class	Correct	Error types	
		Within-class	Across-class	4, 6, 8, or 10 Js
478	1	286	12	2
	2	298	2	0
484	1	293	1	6
	2	274	19	7
Total		1,151	34	15

the stimuli that were members of the other class (across-class errors). The remaining responses always involved pressing the J key one time more or one time less than the J sequences that were trained to the A and E stimuli in the same class. These were probably typing errors. For three classes, across-class errors occurred more frequently than typing errors. The reverse was true for the remaining class.

Figure 3 illustrates the relative frequency ($\times 100$) with which the responses trained to the A and E stimuli were evoked by each of the stimuli in each class. In general, response-transfer performance was an inverse function of nodal distance. Presentation of the A and E stimuli in each class almost always resulted in the responses that had been trained to them, so discriminative control by the A and E stimuli was maintained in the absence of explicit reinforcement. The relative frequency with which the B, C, D, and E stimuli in a class occasioned the response trained to the A stimulus in the same class was an inverse function of nodal distance. Similarly, the likelihood of the D, C, B, and A stimuli occasioning the response trained to the E stimulus was an inverse function of nodal distance. Finally, the responses trained to the E stimuli transferred to B, C, and D with a greater likelihood than did the responses trained to the A stimuli.

In some cases, the sum of responses trained to the B, C, or D stimuli in a class did not equal 100%. This occurred because subjects also emitted some responses other than those trained to the A and E stimuli (see Table 2).

Table 3 lists the relative frequency with which each stimulus occasioned the responses trained to the A and E stimuli in each half of the transfer test. Responding was an inverse function of the nodal distance that separated the stimuli within a class during each half of the transfer test. There was no systematic variation in test performance between the two halves of the response-transfer test.

Figure 4 shows the reaction times occasioned by all 10 stimuli during the transfer tests. Reaction times were measured from the onset of a stimulus to the pressing of the first key in the response sequence, regardless of the response that followed. Averages were

computed for all 30 presentations of each stimulus.

For Subject 484, the reaction times were shortest for the A and E stimuli, longest for the C stimuli, and intermediate for the B and D stimuli. Across the stimuli, the minimum and maximum reaction times varied fivefold in Class 1 and threefold in Class 2. For Subject 478, reaction times lengthened systematically from E to B and then shortened at A. Across the stimuli, the minimum and maximum reaction times varied by 18% in Class 1 and 22% in Class 2.

The reaction times to the A and E stimuli when they became discriminanda for the *xj* responses during stimulus fading averaged less than 0.75 s for Subject 478. For Subject 484 they were longer than 1.0 s for three of the four stimuli. A comparison of these reaction times with the functions presented in Figure 4 shows that when the reaction times for the A and E stimuli were relatively short (about 0.75 s), small differences in reaction times were observed in B, C, and D (Subject 478). When the reaction times for the A and E stimuli were relatively long (about 1.0 s), large differences in reaction times were observed in B, C, and D (Subject 484). Thus, the magnitude of the effect of nodal distance on the reaction time occasioned by the transfer stimuli was inversely correlated with reaction times occasioned by the A and E stimuli during pretest discrimination training.

The transfer performances could have been correlated with the number of reinforcers linked with each class member during the establishment of the baseline relations, AB, BC, CD, and DE. This was determined by counting the number of times the B, C, and D stimuli were presented as positive comparisons and were followed with reinforcers. No data were collected for the A stimuli because they were never presented as comparisons. Data for the E stimuli were not tabulated because they were used as discriminanda for the J responses and thus did not provide a measure of response transfer.

The 2 subjects who formed equivalence classes mastered the baseline relations at different rates. When used as positive comparisons, the B, C, and D stimuli were each paired with different numbers of reinforcers, as indicated in Table 4. For Subject 478, the D stimuli were paired with more reinforcers

Fig. 3. The relative frequency ($\times 100$) with which each stimulus in a class occasioned the response trained to the A or E stimulus in the same class. Data for Subject 478 are presented in the top half of the figure; data for Subject 484 are shown in the bottom half. Data for Class 1 are shown on the left; data for Class 2 are shown on the right. Within each quadrant, transfer of responding from the A stimulus is shown on the upper graph, and transfer of responding from the E stimulus is shown below. The training stimulus in each graph is indicated by the asterisk.

Table 3

Response transfer in Trials 1–30 and 31–60 for each stimulus in each class. Different functions are presented for each type of J response. For each function, a gradient is listed for the data collected in Test Blocks 1–3 and 4–6. Each entry is based on 30 presentations of a stimulus. The asterisk designates the stimulus that was used as the S^d for the response that heads the column.

		Class 1 responses				Class 2 responses			
		3J		5J		7J		9J	
		Test blocks							
Subject	Stimulus	1–3	4–6	1–3	4–6	1–3	4–6	1–3	4–6
478	A	100*	100*	0	0	0	0	100*	100*
	B	0	40	80	20	27	40	67	60
	C	7	0	87	93	13	67	87	33
	D	0	0	87	93	97	97	0	0
	E	0	0	100*	100*	100*	100*	0	0
484	A	100*	97*	0	0	0	0	97*	100*
	B	80	100	13	0	0	0	20	53
	C	7	0	87	87	87	80	13	0
	D	7	0	87	93	87	93	0	0
	E	0	0	100*	93*	100*	100*	0	7

Fig. 4. Average reaction times, in milliseconds, plotted as a function of stimuli used in the response-transfer test. Reaction time was measured from the presentation of a stimulus to the first press of a key on the keyboard, and was averaged over all presentations of a given stimulus. Data for Subject 478 are presented in the top half, and data for Subject 484 are shown in the bottom half. Data for Class 1 are shown on the left, and data for Class 2 are shown on the right. Note that the reaction-time range differs in three of the four graphs.

Table 4

The number of reinforcers occasioned by each stimulus when used as a positive comparison during conditional discrimination training.

Subject	Class	Stimuli		
		B	C	D
478	1	72	76	103
	2	64	55	103
484	1	49	57	51
	2	50	80	50

than the B or C stimuli. For Subject 484, the C stimuli were paired with more reinforcers than the B or D stimuli. These data were not correlated with the response-transfer performances.

DISCUSSION

Equivalence Class Formation

Yields. Only 2 of 12 subjects formed equivalence classes in this experiment. This proportion is low compared to those reported in other experiments on equivalence class formation. For example, in other studies in which five-member three-node equivalence classes were established using a highly programmed method of serial training and testing (the simple-to-complex protocol), more than 95% of subjects formed these classes. When similar classes were established using a less programmed method of serial training and testing (the traditional complex-to-simple serial protocol), 70% of subjects formed five-member equivalence classes with the same nodal structure (Adams, Fields, & Verhave, 1993).

Unlike both the abovementioned serial protocols, the procedure used in the current experiment involved the concurrent training of all baseline relations, followed by the concurrent introduction and assessment of all emergent-relations probes. This was done to hold constant the variables that are confounded with nodal distance in serial protocols. The low yield, then, is correlated with the concurrency of training and/or testing of emergent relations. Additional research will be needed to determine the parameters of the simultaneous training and testing protocol that result in lower class-formation yields than serial protocols.

Baseline disruption during emergent-relations test blocks. Prior to the emergent-relations tests, the baseline trials had been presented in the absence of feedback, and completely class-consistent responding was maintained. When the emergent-relations tests were introduced, the baseline performance was substantially disrupted for most subjects. This disruption occurred on a transient basis for 1 subject who eventually formed the classes. For the subjects who did not form classes, however, the baseline performances remained disrupted throughout testing. It seems that the disruption of baseline performances was driven by the concurrent introduction of many new emergent-relations probes. The lack of relational control by the emergent-relations probes generalized to the baseline trials, and the effect was not overridden even by the direct reinforcement of responding on all baseline trials. This provides a measure of the strength of the disruptive effects of the concurrent introduction of the emergent-relations probes. Additional research will be needed to identify the parameters that control this effect.

Nodal-distance effects during emergent-relations test blocks. For most of the subjects, the performance occasioned by the emergent-relations probes was an inverse function of nodal distance. Because these data were not correlated with order of introduction of stimuli or stimulus relations, they provide an unfounded measure of the effects of nodal distance during emergent-relations tests.

The nodal-distance effect on emergent-relations test performances was transient for the subjects who formed classes, replicating findings reported by Dube et al. (1993), Fields et al. (1990, 1992), Kennedy (1991), Kennedy et al. (1994), Lazar et al. (1984), McDonagh et al. (1984), Saunders et al. (1988), and Sidman et al. (1985). An effect of nodal distance was also observed even when equivalence classes did not form, suggesting that the effect of nodal distance on the relations that emerge between stimuli may be independent of the formation of equivalence classes.

Response-Transfer Tests

Nodal-distance effects on response transfer. Transfer of control of responding was an inverse function of the nodal distance separat-

ing the stimuli in an equivalence class. This effect was observed within the same class for two different responses, and in both classes. In addition, the response-transfer functions were maintained with repeated testing under extinction conditions; thus, the effects of nodal distance continued in a steady state after the formation of equivalence classes.

Three of the four transfer functions were asymmetrical. More transfer occurred from E to D than from A to B, even though no nodes separated E from D and B from A. The asymmetry could reflect sampling error, could be unique to the individual subjects studied, or could be due to the particular nonsense syllables assigned as the A, B, D, and E stimuli. Additional research is needed to identify the factors that determine the form of the functions produced by two-option response-transfer tests.

Variables confounded with nodal distance. In previous studies, nodal distance was confounded with three variables: (a) the order of introducing the class members during training, (b) the number of times each class member was presented in training, and (c) the number of reinforcers paired with each stimulus. Any of these variables could have accounted for test results attributed to nodal distance.

In the current experiment, nodal distance was not confounded with the order of introduction because all stimuli were introduced at the same time. Nodal distance was also not confounded with the number of presentations of the B, C, and D stimuli because each was presented an equal number of times during training. Thus, these two variables could not have accounted for the response transfer data obtained in the present experiment.

When the baseline relations were trained, the B, C, and D stimuli were paired with different numbers of reinforcers. The reinforcer frequencies occasioned by these stimuli, however, were not correlated with the transfer performances produced by these stimuli, so reinforcer frequency could not account for the test performances.

Because all three variables were not confounded with nodal distance, the results of the current experiment provide an unambiguous demonstration of the effects of nodal distance. These results also support the view that nodal distance was the primary deter-

minant of test performances observed in prior studies of equivalence class formation.

Nodal-Distance Effects in Equivalence Classes and Functional Classes

Measurement of sustained nodal-distance effects. In a previous study, Fields, Adams, Verhave, and Newman (1993) established two three-node five-member equivalence classes consisting of nonsense syllables, and then one new response was trained to one stimulus in each class. When the remaining stimuli were presented, the effects of nodal distance were observed in some classes with some subjects. When present, however, the effects of nodal distance were transient. With repeated testing, performance became completely class consistent for all of the stimuli, and in an order that was a direct function of nodal distance.

In the current experiment, we also established two three-node five-member equivalence classes consisting of nonsense syllables. The current experiment differed from that conducted by Fields, Adams, Verhave, and Newman (1993) in only one significant way: A different response was trained to each of two stimuli in each class prior to conducting response-transfer tests. Under these conditions, the transfer test produced a sustained pattern of responding that was an inverse function of nodal distance.

The transient or sustained effect of nodal distance was correlated with the number of stimuli in an equivalence class that were used as discriminanda for different responses. The training of a different response to at least two different stimuli in the equivalence class, then, appears to be the critical variable that permitted the measurement of the effects of nodal distance on test performance on a sustained basis (Fields, Adams, & Verhave, 1993).

Permanence of nodal-distance effects. In the current experiment, for both subjects who formed equivalence classes, nodal distance influenced the emergent-relations test performance on a transient basis. By the end of emergent-relations testing, however, performance had reached a ceiling and was no longer correlated with nodal distance. In the post-class-formation transfer tests, the frequency of responding for both subjects and the reaction-time data for 1 subject were

correlated with nodal distance. These data support the view that nodal distance exerts a long-term and perhaps a permanent effect on the relatedness of stimuli in an equivalence class.

Nodal distance is built into an equivalence class by the training of the specific set of baseline relations that are the prerequisites of a prospective equivalence class (Fields & Verhave, 1987). The effects of nodal distance may be transient or maintained depending on the number of responses that could be made to the stimuli within a class for a given test. When only one response can be made, all of the stimuli in a class immediately or eventually come to evoke the same response, so the availability of one response option per class produces a transient effect of nodal distance. This occurred during the emergent-relations tests used in the current experiment. When at least two different responses can be evoked by the stimuli within a class, performances show the effects of nodal distance on a sustained basis. This occurred during the response-transfer test described in this experiment (Fields, Adams, & Verhave, 1993).

Equivalence classes and functional classes. A functional class consists of a set of perceptually disparate stimuli all of which control the same response, after that response has been trained to occur in the presence of one of the stimuli in the set. With rare exception, in the response-transfer test, the B, C, and D stimuli that were members of a given equivalence class occasioned only those responses that had been trained to the A and E stimuli from the same class. Such differential responding with regard to stimulus sets appears to demonstrate that the stimuli that were members of an equivalence class also acted as members of the same functional class (Sidman, Wynne, Maguire, & Barnes, 1989). All of the stimuli within a functional class, however, did not evoke the same response with the same likelihood. Because different stimuli within the equivalence class evoked different responses with different likelihoods, stimuli in the same equivalence class did not act as members of the same functional class. The stimuli in a single equivalence class can act as members of different functional classes. It follows, then, that the stimuli in an equivalence class are not always interchangeable or substitutable. When a response-transfer test of the sort used

here is conducted, a knowledge of nodal distance on the part of the experimenter helps to predict which stimuli in an equivalence class will act as members of a given functional class. The transfer-test data, then, do not support the position that equivalence classes are sets of stimuli that are universally interchangeable or substitutable for each other (Devaney, Hayes, & Nelson, 1986; Dixon & Spradlin, 1976; Saunders & Green, 1992; Sidman, 1990, 1994; Sidman & Tailby, 1982; Spradlin & Dixon, 1976; Spradlin & Saunders, 1986).

Reaction-Time Data and Implications

Reaction time in response-transfer tests. In the current experiment, reaction time in the response-transfer tests was an inverted U-shaped function of nodal distance. The shape of the function can be understood by considering how nodal distance influences reaction times during baseline and emergent-relations probes. According to Bentall *et al.* (1993), Dickins *et al.* (1993), and Wulfert and Hayes (1988), reaction time is a direct function of the nodal distance that separates the stimuli in baseline relations and emergent relations. When transfer of responding is measured, the reaction times for response transfer should be a direct function of the nodal distance that separates the training stimulus from the transfer stimulus in an equivalence class. In our transfer procedure, however, two such functions are active: one that specifies the transfer of response function from the A stimulus, and one that specifies the transfer of response function from the E stimulus. The combined effects of these two functions produce the inverted U-shaped chronometric functions obtained in the two-option transfer test.

When the A and E stimuli occasioned relatively long reaction times at the end of discrimination training (Subject 484), the reaction times in the transfer tests showed rather large effects of nodal distance. When the A and E stimuli occasioned relatively short reaction times at the end of discrimination training (Subject 478), the reaction times in the transfer tests showed rather small effects of nodal distance. These results are not unlike those reported by Bentall *et al.* (1993). In their study, reaction times became shorter

and nodal-distance effects became greatly attenuated with repeated emergent-relations tests. In a replication of the current experiment, perhaps the training of long and short reaction times to the A and E stimuli, respectively, would yield maintained chronometric effects of nodal distance.

Bentall et al. (1993), Dickins et al. (1993), and Wulfert and Hayes (1988) found that reaction time was a direct function of the nodal distance separating the stimuli in the baseline and emergent-relations tests for zero- and one-node relations. These reaction times were averaged across relations and subjects. The reaction-time data obtained in the current experiment confirmed and extended those previous findings by showing consonant reaction-time effects with a different type of test (response transfer) over a greater range of nodal distances (zero, one, two, and three nodes) for a single subject.

Reaction-time links to semantic memory and serial list learning. The chronometric data obtained in the response-transfer test can be used to link the study of equivalence classes to serially learned lists in humans (Ebbinghaus, 1913; Fields, Adams, & Verhave, 1993; Fields et al., 1990; Slamecka, 1964, 1965, 1985) and in nonhumans (Terrace, 1986). Chronometric data can also be used to link equivalence classes to semantic memory networks (Balota & Lorch, 1986; Chiavello, Senehi, & Nuding, 1987; Collins & Loftus, 1975; Collins & Quillian, 1969; Fields, Adams, & Verhave, 1993; Fields et al., 1990; McNamara & Altarriba, 1988; McNamara, Hardy, & Hirtle, 1989; McNamara, & Healy, 1988). Reaction time is a direct function of the "associative distance" that separates the stimuli in a serial list or a semantic memory network. In the current experiment, nodal distance was found to have a direct effect on reaction time in the response-transfer tests. Thus, the effects of nodal distance on reaction time occasioned by the stimuli in an equivalence class are similar to the effects of associative distance on the reaction times occasioned by the stimuli in semantic memory networks and serial lists. Associative distance and nodal distance are both operationally defined in similar ways; that is, by the number of nodes that separate stimuli in a group of interconnected stimuli. It appears that the nodal structures of equivalence classes, serial lists, and seman-

tic memory networks exert similar influences on the relatedness of the stimuli in each domain.

The analysis of nodal distance in equivalence classes, then, may inform our understanding of serial lists and semantic memory networks. This can be illustrated with the following examples. In a serially learned list, the relatedness of stimuli can be viewed as an inverse function of associative distance. In a serial list, however, associative distance is inevitably correlated with temporal separation of stimuli, so a perennial problem is to determine whether relatedness is influenced by nodal distance, temporal separation, or both. In the current experiment, nodality alone influenced relatedness; thus, these results support the view that the relatedness of remotely associated stimuli in a serial list is a function of nodality. In addition, temporal separation may also influence relatedness in serial lists.

The relatedness of the stimuli in a semantic memory network is inferred from reaction-time data. Relatedness is not established by the manipulation of independent variables. The data in the current experiment show that a class of stimuli can be established in which the relatedness of the stimuli in the class is specified a priori by the conditional relations that are trained as the prerequisites of the class. By extension, the training of a particular set of conditional relations that produced a given nodal structure could be used to create a semantic memory network with an experimentally determined relational structure.

Summary. Nodal distance influenced emergent-relations test performances on a transient basis for subjects who formed equivalence classes and on a sustained basis for subjects who did not form equivalence classes. For the subjects who formed classes, nodal distance also influenced response topography and reaction time in a post-class-formation response-transfer test. These effects were maintained with repeated measures. All results support the view that nodal distance permanently influenced the relatedness of stimuli in an equivalence class. The transient or permanent effects of nodal distance on test performance, then, depended on the contingencies occasioned by the particular test. A comprehensive understanding of the relatedness of stimuli in an equivalence class requires a specification of the nodal structure

of the class and the number of responses that can be evoked by the stimuli in a class during a given type of test (Fields, Adams, & Verhave, 1993). The response-transfer test data support the position that the stimuli in an equivalence class are not universally substitutable for each other. Finally, the chronometric data obtained during the response-transfer tests provide a basis for linking the study of equivalence classes to the study of semantic memory networks.

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APPENDIX

The percentage of baseline (TRN), symmetry (SYM), one-node (1-N), two-node (2-N), and three-node (3-N) kernels that produced relational responding during each emergent-relations test block for each subject. Subjects 484 and 478 formed equivalence classes. The remaining subjects did not and are listed in descending order of averaged baseline performances during the emergent-relations test blocks.

Type of kernel/opportunities							Type of kernel/opportunities						
Sub- ject	Block	TRN 4	SYM 4	1-N 6	2-N 4	3-N 2	Sub- ject	Block	TRN 4	SYM 4	1-N 6	2-N 4	3-N 2
484	1	100	100	83	100	50	476	1	50	25	17	0	0
	2	100	100	100	100	100		2	75	25	17	0	0
	3	—	—	—	—	—		3	75	25	0	0	0
	4	—	—	—	—	—		4	75	25	0	0	0
	5	—	—	—	—	—		5	75	25	17	0	0
	Average	100	100	92	100	75		Average	67	25	6	0	0
478	1	75	75	50	50	0	535	1	75	50	17	0	0
	2	50	100	50	50	0		2	50	0	17	0	0
	3	50	75	83	50	0		3	50	25	0	0	0
	4	100	100	100	100	100		4	75	25	17	0	0
	5	—	—	—	—	—		5	50	50	0	0	0
	Average	67	68	71	63	25		Average	63	25	12	0	0
466	1	100	50	0	0	0	482	1	75	50	33	0	0
	2	100	100	0	0	0		2	0	0	17	0	0
	3	100	100	0	0	0		3	75	25	17	0	0
	4	100	75	17	0	0		4	75	25	0	0	0
	5	75	100	0	0	0		5	50	50	33	0	0
	Average	95	85	3	0	0		Average	56	25	17	0	0