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USING THE SIMULTANEOUS PROTOCOL TO STUDY EQUIVALENCE CLASS FORMATION: THE FACILITATING EFFECTS OF NODAL NUMBER AND SIZE OF PREVIOUSLY ESTABLISHED EQUIVALENCE CLASSES

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The emergence of equivalence classes in college students is unlikely when all baseline relations are trained concurrently and all probes for emergent relations are then introduced concurrently (the simultaneous protocol). This experiment showed how the number of nodes and the size of previously established equivalence classes enhanced the emergence of new equivalence classes under the simultaneous protocol. First, one-node three-, five-, or seven-member classes or three-node five- or seven-member classes were established with college students. A sixth group received no pretraining. Then, the simultaneous protocol was used to establish new three-node five-member equivalence classes with all students. The speed and variability with which the baseline relations were established in the simultaneous protocol were inverse functions of number of nodes in the previously established classes, but not of their size. The percentage of subjects who showed the emergence of new equivalence classes under the simultaneous protocol was a direct function of number of nodes and size of pretrained classes. The additional time spent for pretraining greatly reduced the total training time needed to produce individuals who showed the emergence of classes under the simultaneous protocol. The total time saved was a direct function of number of nodes and number of stimuli in the pretrained classes.

Key words: equivalence class formation, transfer of training, nodal distance effects, class size, training protocols, computer keyboard, college students

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Studies of equivalence classes have used different sequences to present the baseline conditional relations and the probes for emergent relations. In one sequence, called the *complex-to-simple protocol* (Adams, Fields, & Verhave, 1993), the CA equivalence probes are presented immediately after the serial training of the AB and CB baseline relations. If probe performances are not class consistent, the BA and CB symmetry probes are then each presented serially. If these probes occasion class-consistent responding, the CA equivalence probes are reintroduced. Class-consistent responding by all probes indicates the emergence of equivalence classes (Sidman & Tailby, 1982). Using complex-to-simple protocols, the emergence of classes were observed in 70 to 100% of subjects across experiments (e.g., Bush, Sidman, & de Rose, 1989; Devany, Hayes, & Nelson, 1986; Fields, Adams, Newman, & Verhave, 1992; Fields, Adams, Verhave, & Newman, 1990; Lazar, Davis-Lang, & Sanchez, 1984; Saunders, Wachter, & Spradlin, 1988; Sidman, 1971; Sidman & Cresson, 1973; Sidman, Kirk, & Willson-Morris, 1985; Spradlin, Cotter, & Baxley, 1973).

Another sequence is called the *simple-to-complex protocol* (Adams et al., 1993a; Fields, Reeve, Adams, & Verhave, 1991). In this protocol, the AB baseline relations are trained, and then BA symmetry is tested. BC is then trained, followed by CB symmetry tests. Following this, AC transitivity and then CA equivalence probes are presented. As with the complex-to-simple protocol, class-consistent responding occasioned by all probes indicates the emergence of equivalence classes. Using the simple-to-complex protocol, the emergence of classes was observed in 93 to 100% of subjects across experiments. In addition, subjects typically passed emergent relations tests upon their first presentation (Adams et al., 1993a; Fields et al., 1991; Lynch & Cuvo, 1995; Schusterman & Kastak, 1993).

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Paradoxically, the reliable class formation that results from the use of these protocols has been a major impediment to the identification of historical variables that influence the emergence of new equivalence classes by typically functioning adults. Because the likelihood of class formation is very high, it is very difficult to identify variables that would raise that likelihood yet further. The identification of historical variables that influence equivalence class formation by adults, then, is best done with a protocol that can lead to the emergence of equivalence classes but is unlikely to do so. The simultaneous protocol is such a procedure (Fields, Landon-Jimenez, Buffington, & Adams, 1995). In the simultaneous protocol, first, all baseline conditional discrimination training trials are introduced in a single block of randomly presented trials that is repeated until all baseline relations are established. Then, all symmetry, transitivity, and equivalence probes are presented in a random order in a single emergent relations test block.

Fields et al. (1995) studied the formation of three-node five-member classes under the simultaneous protocol by college students. A node is a stimulus linked by training to at least two other stimuli in a potential equivalence class (Fields, Verhave, & Fath, 1984). Only 8% (1 of 12) of the subjects passed the emergent relations tests when they were first introduced, thereby showing the immediate emergence of equivalence classes. One additional subject passed the emergent relations tests with repetition. Overall, then, only 17% of the subjects showed the emergence of equivalence classes. In an experiment containing four experimental groups, Buffington, Fields, and Adams (1997) assessed the formation of one-node three-member classes by college students under the simultaneous protocol. Only 33% of the students showed the immediate emergence of equivalence classes. Some additional subjects showed the emergence of the classes with test block repetition. Overall, then, only 58% of subjects showed the emergence of the three-member equivalence classes.

Because human adults are unlikely to form equivalence classes under the simultaneous protocol, the performances occasioned by training and testing trials in the simultaneous protocol can serve as useful dependent measures for the identification of variables that enhance equivalence class formation in normally functioning adults. The first use of the simultaneous protocol to identify historical variables that influence the likelihood of equivalence class formation was reported by Buffington et al. (1997). They determined how the size of previously established equivalence classes influenced the likelihood of forming new equivalence classes under the simultaneous protocol. First, college students in three different groups showed the emergence of either three-, four-, or five-member equivalence classes using a simple-to-complex protocol (Adams et al., 1993). The percentage of subjects in each group who then subsequently showed the emergence of new three-member classes under the simultaneous protocol increased systematically from 62% to 100% as the size of the previously established classes increased from three to five members. These results demonstrated the feasibility of using the simultaneous protocol to identify an historical variable (the size of previously established equivalence classes) that influenced the emergence of new equivalence classes under the simultaneous protocol.

In the Buffington et al. (1997) study, the three-, four-, and five-member classes established in pretraining contained one, two, and three nodal stimuli, respectively. Because the size and number of nodes in the pretrained classes were confounded, however, it was not possible to determine which variable was responsible for the enhancement of class formation that was observed under the simultaneous protocol. In the present study, the transfer-of-training strategy described by Buffington et al. was used to determine how the size and the number of nodes in previously established equivalence classes independently influenced the likelihood of forming new three-node five-member equivalence classes under the simultaneous protocol. Multinodal five-member classes were studied under the simultaneous protocol because they produce lower yields than three-member classes and, thus, should increase sensitivity to the effects of pretraining variables.

METHOD

Subjects

One-hundred-eight undergraduate students from Queens College participated in this study. Each student was randomly assigned to one of six groups that differed in terms of pretraining condition. The students were volunteers from introductory psychology courses and had no prior experience with the research area. The students received partial course credit for participating in the study. The credit, however, was not contingent upon performance in the experiment. Each student participated in one to four experimental sessions over the course of 1 to 2 weeks, with each session lasting 1 to 2 hr.

Apparatus and Stimuli

The experiment was conducted with IBM®-compatible microcomputers. The stimuli were presented to the subjects on the computer screen. Each subject was required to make all responses by pressing keys on the computer keyboard. Both the recording of responses and the presentation of stimuli were controlled by software designed to study equivalence classes.

The stimuli used as members of the equivalence classes are presented in Table 1 with their corresponding symbolic representation (Fields et al., 1984). All stimuli were composed of ASCII characters, each of which was 3 mm wide and 5 mm high on the computer screen. Classes 1 and 2 were established in pretraining. The three-member classes established in pretraining contained stimuli designated A, B, and C. The five-member classes established in pretraining consisted of the stimuli designated A, B, C, D, and E. The seven-member classes established in pretraining consisted of the stimuli designated A, B, C, D, E, F, and G. The particular stimuli that corresponded to a given letter designation varied with pretraining conditions. The stimuli used as members of Classes 3 and 4 differed from those used in pretraining, and were referred to as V, W, X, Y, and Z.

Table 1

Stimuli used in pretraining (Classes 1 and 2) and in the simultaneous protocol (Classes 3 and 4). Each stimulus is represented symbolically with a letter. The number following the letter indicates class membership. *Xn-Ym* clusters designate *X* nodes in a class and *Y* stimuli in a class.

		Pretraining groups			Simultaneous
Class	Stimuli	1n-3m	1n-5m 3n-5m	1n-7m 3n-7m	3n-5m
1	LEQ	A1	A1	A1	
	HUK	B1	B1	B1	
	POV	C1	C1	C1	
	BAF		D1	D1	
	TIJ			E1	
	SEN			F1	
			E1	G1	
2	MEV	A2	A2	A2	
	GUQ	B2	B2	B2	
	ZOJ	C2	C2	C2	
	YAR		D2	D2	
	DIW			E2	
	NEF			F2	
			E2	G2	
3	QIJ				V3
	TUW				W3
	COH				X3
	MEP				Y3
	RAB				Z3
4	VIF				V4
	KUY				W4
	XOL				X4
	GEZ				Y4
	NAS				Z4

Procedure

Trial structure, contingencies, and responses within a trial. Each trial began when the words "press enter to continue the experiment" appeared on the screen. After the subject pressed the enter key, a sample stimulus was displayed in the upper portion of the screen. The subject was then required to press the space bar to display the comparison stimuli along with the sample on the screen. All stimuli were displayed in a triangular pattern, with the sample stimulus at the vertex of the triangle and each of two comparison stimuli at the corners of the base of the triangle. During each trial, the sample stimulus and the positive comparison stimulus (Co+) were from the same class, whereas the negative comparison stimulus (Co−) was from the other class. The subject selected the comparison on the left by pressing the 1 key and selected the comparison on the right by pressing the 2 key. After the subject made a response, a feedback message was displayed on the screen. If the subject selected the Co+, the word "RIGHT" appeared on the screen until the subject pressed the R key. If the subject selected the Co−, the word "WRONG" appeared on the screen until the subject pressed the W key. During noninformative feedback trials, the letter E appeared

Table 2

The stimuli used as samples and comparisons in trials for Classes 1 and 3 are represented symbolically. A parallel set of trials with samples from Classes 2 and 4 were also presented in the experiment, although they are not listed in this table. The major column headings indicate the trials used to establish the one-node or three-node classes in pretraining. Each row indicates one configuration that contains a sample (Sa), a positive comparison (Co+), and a negative comparison (Co−), all of which were presented together. The stimuli in each configuration were presented the number of times indicated in the column headed "Number of trials." The comparisons in each configuration appeared equally often on the left and the right. The trials for Classes 2 and 4 were presented in the same block as the trials for Classes 1 and 3, respectively. For example, the 3MEM block used for training AB contained (A1 B1 B2), (A1 B2 B1), (A2 B2 B1), and (A2 B1 B2) trials. BL, S, T, and E refer to baseline conditional discriminations, symmetry, transitivity, and equivalence probes, respectively. An *x*MIX test consisted of a block that contained symmetry, transitivity, and equivalence probe trials. The 3MIX and 4MIX test blocks also contained baseline review trials.

Condition	Operation	Relation	% Feedback	1n-3m, 1n-5m, or 1n-7m			3n-7m			3n-5m			Number of trials
				Sa	Co+	Co−	Sa	Co+	Co−	Sa	Co+	Co−	
3MEM	Train AB	Baseline	100	A1	B1	B2	A1	B1	B2	A1	B1	B2	8
	Train AB	Baseline	75, 25, 0	A1	B1	B2	A1	B1	B2	A1	B1	B2	4
	Test BA	Symmetry	0	B1	A1	A2	B1	A1	A2	B1	A1	A2	8
			0	A1	B1	B2	A1	B1	B2	A1	B1	B2	8
	Train BC	Baseline	100	B1	C1	C2	B1	C1	C2	B1	C1	C2	4
			100	A1	B1	B2	A1	B1	B2	A1	B1	B2	4
	Train BC	Baseline	75, 25, 0	B1	C1	C2	B1	C1	C2	B1	C1	C2	2
			75, 25, 0	A1	B1	B2	A1	B1	B2	A1	B1	B2	2
	Test CB	Symmetry	0	C1	B1	B2	C1	B1	B2	C1	B1	B2	4
			0	A1	B1	B2	A1	B1	B2	A1	B1	B2	4
			0	B1	C1	C2	B1	C1	C2	B1	C1	C2	8
	Test BA/CB	Symmetry	0	A1	B1	B2	A1	B1	B2	A1	B1	B2	4
			0	B1	C1	C2	B1	C1	C2	B1	C1	C2	4
			0	B1	A1	A2	B1	A1	A2	B1	A1	A2	4
			0	C1	B1	B2	C1	B1	B2	C1	B1	B2	4
	Test AC	Transitivity	0	A1	B1	B2	A1	B1	B2	A1	B1	B2	4
			0	B1	C1	C2	B1	C1	C2	B1	C1	C2	4
			0	A1	C1	C2	A1	C1	C2	A1	C1	C2	8
	Test CA	Equivalence	0	A1	B1	B2	A1	B1	B2	A1	B1	B2	4
			0	B1	C1	C2	B1	C1	C2	B1	C1	C2	4
			0	C1	A1	A2	C1	A1	A2	C1	A1	A2	8
	3MIX test	BL, S, T, E	0	A1	B1	B2	A1	B1	B2	A1	B1	B2	4
			0	B1	C1	C2	B1	C1	C2	B1	C1	C2	4
			0	B1	A1	A2	B1	A1	A2	B1	A1	A2	2
			0	C1	B1	B2	C1	B1	B2	C1	B1	B2	2
			0	A1	C1	C2	A1	C1	C2	A1	C1	C2	2
			0	C1	A1	A2	C1	A1	A2	C1	A1	A2	2
4MEM	Train DB/CD	Baseline	100	D1	B1	B2	C1	D1	D2	C1	D1	D2	2
			100	B1	C1	C2	B1	C1	C2	B1	C1	C2	2
			100	A1	B1	B2	A1	B1	B2	A1	B1	B2	6
	Train DB/CD	Baseline	75, 25, 0	D1	B1	B2	C1	D1	D2	C1	D1	D2	2
			75, 25, 0	B1	C1	C2	B1	C1	C2	B1	C1	C2	2
			75, 25, 0	A1	B1	B2	A1	B1	B2	A1	B1	B2	2
	4MIX test	BL, S, T, E	0	D1	B1	B2	C1	D1	C2	C1	D1	C2	2
			0	B1	A1	A2	B1	A1	A2	B1	A1	A2	4
			0	C1	B1	B2	C1	B1	B2	C1	B1	B2	4
			0	B1	D1	D2	A1	C1	C2	A1	C1	C2	4
			0	A1	C1	C2	C1	A1	A2	C1	A1	A2	4

Table 2

(*Continued*)

Condition	Operation	Relation	% Feedback	1n-3m, 1n-5m, or 1n-7m Sa	Co+	Co−	3n-7m Sa	Co+	Co−	3n-5m Sa	Co+	Co−	Number of trials
			0	D1	C1	C2	D1	C1	C2	D1	C1	C2	4
			0	A1	D1	D2	B1	D1	D2	B1	D1	D2	4
			0	D1	A1	A2	A1	D1	D2	A1	D1	D2	4
			0	C1	D1	D2	D1	B1	B2	D1	B1	B2	4
			0	C1	A1	A2	D1	A1	A2	D1	A1	A2	4
5MEM	Train BE/EC/DE	Baseline	100	A1	B1	B2	A1	B1	B2	A1	B1	B2	2
			100	B1	C1	C2	B1	C1	C2	B1	C1	C2	2
			100	D1	B1	B2	C1	D1	D2	C1	D1	D2	2
			100	B1	E1	E2	E1	C1	C2	D1	E1	E2	6
	Train BE/EC/DE	Baseline	75, 25, 0	A1	B1	B2	A1	B1	B2	A1	B1	B2	2
			75, 25, 0	B1	C1	C2	B1	C1	C2	B1	C1	C2	2
			75, 25, 0	D1	B1	B2	C1	D1	D2	C1	D1	D2	2
			75, 25, 0	B1	E1	E2	E1	C1	C2	D1	E1	E2	2
	5MIX test	S, T, E	0	E1	B1	B2	A1	E1	E2	E1	D1	D2	2
			0	A1	E1	E2	E1	A1	A2	A1	E1	E2	2
			0	C1	E1	E2	C1	E1	E2	E1	A1	A2	2
			0	D1	E1	E2	E1	D1	D2	B1	D1	D2	2
			0	E1	A1	A2	D1	E1	E2	D1	B1	B2	2
			0	E1	C1	C2	B1	E1	E2	C1	E1	E2	2
			0	E1	D1	D2	E1	B1	B2	E1	C1	C2	2
6MEM	Train FB/CF	Baseline	100	A1	B1	B2	A1	B1	B2				2
			100	B1	C1	C2	B1	C1	C2				2
			100	D1	B1	B2	C1	D1	D2				2
			100	B1	E1	E2	E1	C1	C2				2
			100	F1	B1	B2	C1	F1	F2				8
	Train FB/CF	Baseline	75, 25, 0	A1	B1	B2	A1	B1	B2				2
			75, 25, 0	B1	C1	C2	B1	C1	C2				2
			75, 25, 0	D1	B1	B2	C1	D1	D2				2
			75, 25, 0	B1	E1	E2	E1	C1	C2				2
			75, 25, 0	F1	B1	B2	C1	F1	F2				2
	6MIX test	S, T, E	0	A1	F1	F2	A1	F1	F2				2
			0	F1	A1	A2	F1	A1	A2				2
			0	C1	F1	F2	B1	F1	F2				2
			0	F1	C1	C2	F1	B1	B2				2
			0	D1	F1	F2	D1	F1	F2				2
			0	F1	D1	D2	F1	D1	D2				2
			0	E1	F1	F2	E1	F1	F2				2
			0	F1	E1	E2	F1	E1	E2				2
			0	B1	F1	F2	F1	C1	C2				2
7MEM	Train BG/FG	Baseline	100	A1	B1	B2	A1	B1	B2				2
			100	B1	C1	C2	B1	C1	C2				2
			100	D1	B1	B2	C1	D1	D2				2
			100	B1	E1	E2	E1	C1	C2				2
			100	F1	B1	B2	C1	F1	F2				2
			100	B1	G1	G2	F1	G1	G2				10
	Train BG/FG	Baseline	75, 25, 0	A1	B1	B2	A1	B1	B2				2
			75, 25, 0	B1	C1	C2	B1	C1	C2				2
			75, 25, 0	D1	B1	B2	C1	D1	D2				2
			75, 25, 0	B1	E1	E2	E1	C1	C2				2
			75, 25, 0	F1	B1	B2	C1	F1	F2				2
			75, 25, 0	B1	G1	G2	F1	G1	G2				2

Table 2

(*Continued*)

Condition	Operation	Relation	% Feedback	1n-3m, 1n-5m, or 1n-7m			3n-7m			3n-5m			Number of trials
				Sa	Co+	Co−	Sa	Co+	Co−	Sa	Co+	Co−	
	7MIX test	S, T, E	0	A1	G1	G2	A1	G1	G2				2
			0	G1	A1	A2	G1	A1	A2				2
			0	C1	G1	G2	B1	G1	G2				2
			0	G1	C1	C2	G1	B1	B2				2
			0	D1	G1	G2	C1	G1	G2				2
			0	G1	D1	D2	G1	C1	C2				2
			0	E1	G1	G2	D1	G1	G2				2
			0	G1	E1	E2	G1	D1	D2				2
			0	F1	G1	G2	E1	G1	G2				2
			0	G1	F1	F2	G1	E1	E2				2
			0	G1	B1	B2	G1	F1	F2				2
5SIM	Train VW, WX, XY, and YZ	Baseline	100							V3	W3	W4	4
			100							W3	X3	X4	4
			100							X3	Y3	Y4	4
			100							Y3	Z3	Z4	4
	Train VW, WX, XY, and YZ	Baseline	75, 25, 0							V3	W3	W4	2
			75, 25, 0							W3	X3	X4	2
			75, 25, 0							X3	Y3	Y4	2
			75, 25, 0							Y3	Z3	Z4	2
	Mixed test	BL, S, T, E	100							V3	W3	W4	2
			100							W3	X3	X4	2
			100							X3	Y3	Y4	2
			100							Y3	Z3	Z4	2
			0							W3	V3	V4	2
			0							X3	W3	W4	2
			0							Y3	X3	X4	2
			0							Z3	Y3	Y4	2
			0							V3	X3	X4	2
			0							V3	Y3	Y4	2
			0							V3	Z3	Z4	2
			0							W3	Y3	Y4	2
			0							W3	Z3	Z4	2
			0							X3	Z3	Z4	2
			0							X3	V3	V4	2
			0							Y3	V3	V4	2
			0							Z3	V3	V4	2
			0							Y3	W3	W4	2
			0							Z3	W3	W4	2
			0							Z3	X3	X4	2

on the screen after the subject's response regardless of comparison selection. It remained on the screen until the subject pressed the E key. We selected the E key for this purpose because it indicated the end of a trial, and it is between the R and W keys on a standard keyboard.

Trial block structure and contingencies. Each phase of training and testing consisted of a block of trials. The type and number of trials presented in each block are listed in Table 2. The trials in each block were presented in random order without replacement. Each Co+ and Co− appeared equally often on the left and right sides of the computer screen within each block. During the initial phases of training, each trial in a block was presented with informative feedback. Each block was repeated until all trials within the block occasioned selection of class-consistent comparisons; this performance was defined as the mastery criterion. After the mastery criterion was reached, the percentage of trials in a block that produced informative feedback was reduced from 100% to 75% to 25% and, finally, to 0% across blocks, provided there was no change in the accuracy of responding. If the subject did not meet the mastery criterion within 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.

During pretraining, test blocks always contained emergent relations probes and sometimes contained baseline review trials. All trials in each test block were presented without informative feedback.

During the simultaneous protocol, the test blocks (the 5SIM mixed test) contained baseline review trials and emergent relations probes. The emergent relations probe trials were always presented without informative feedback, but informative feedback was presented following comparison selection on all baseline review trials.

Start-up training. All subjects were taught the keyboard skills required to progress through each trial in the experiment. To facilitate this process, semantically related English words were used as samples and comparisons along with five instructional prompts. The prompts were deleted in a serial manner as training progressed. The prompts included in each trial and the order of deleting the prompts are indicated in Figure 1. Sequential changes in the stimuli and the prompts that were presented during a trial are illustrated across the frames in each row. The order in which prompts were deleted is indicated in successive rows. This procedure is similar to that described by Fields et al. (1990).

Experimental design. Equivalence Classes 1 and 2 were established in five different groups. Across groups, the classes differed in size and number of nodes. Spider diagrams (Fields & Verhave, 1987) indicating the nodal structures of the classes established in pretraining in each group are illustrated in Figure 2. In Group 1n-3m, one-node three-member classes were established. In Group 1n-5m, one-node five-member classes were established, and in Group 1n-7m, one-node seven-member classes were established. In Group 3n-5m, three-node five-member classes were established, and in Group 3n-7m, three-node seven-member classes were established. Thus, the five possible combinations of three-, five-, and seven-member classes were combined with either one or three nodal stimuli. In addition, no pretraining was conducted with the subjects in a sixth group called the none group. After the completion of pretraining, the simultaneous protocol was used in an attempt to establish two new three-node five-member classes (Classes 3 and 4).

The set of conditional discriminations that were used to establish the classes in pretraining were selected to maximize the similarity of behavioral function served by each node in each class (Fields & Verhave, 1987; Fields et al., 1984). That is, for all of the classes, the stimuli that were nodes functioned as sample and comparison with equal frequency in training.

Establishment of three-member equivalence classes during pretraining. The subjects in the none group were given no pretraining. All of the remaining subjects were given pretraining in which two three-member equivalence classes (Classes 1 and 2) were established by use of the simple-to-complex protocol (Adams et al., 1993; Fields et al., 1991; Lynch & Cuvo, 1995; Schusterman & Kastak, 1993). After the establishment of the AB relations, the symmetrical property of AB was assessed with BA probes. Then, BC was trained for each class, and the symmetrical property of these trained relations was assessed with CB tests. After a combined review of BA and CB symmetrical relations, transitivity was tested with AC probes. After a subject passed the AC transitivity test, equivalence was assessed with CA probes. Finally, a mixed review of all baseline, symmetrical, transitive, and equivalence relations was conducted. Class-consistent responding on all test trials indicated the establishment of two three-member classes. This ended Class 1 and 2 pretraining for the subjects in the one-node three-member (1n-3m) group.

Expansion of class size. The remaining subjects were randomly assigned to four groups for purposes of class expansion to five or seven members. This was accomplished incrementally by training one new conditional relation and then testing for expansion of class size. The number of training and testing cycles was determined by the pretraining condition to which a subject was assigned.

Expansion of class size to five members during pretraining. For the subjects in two groups

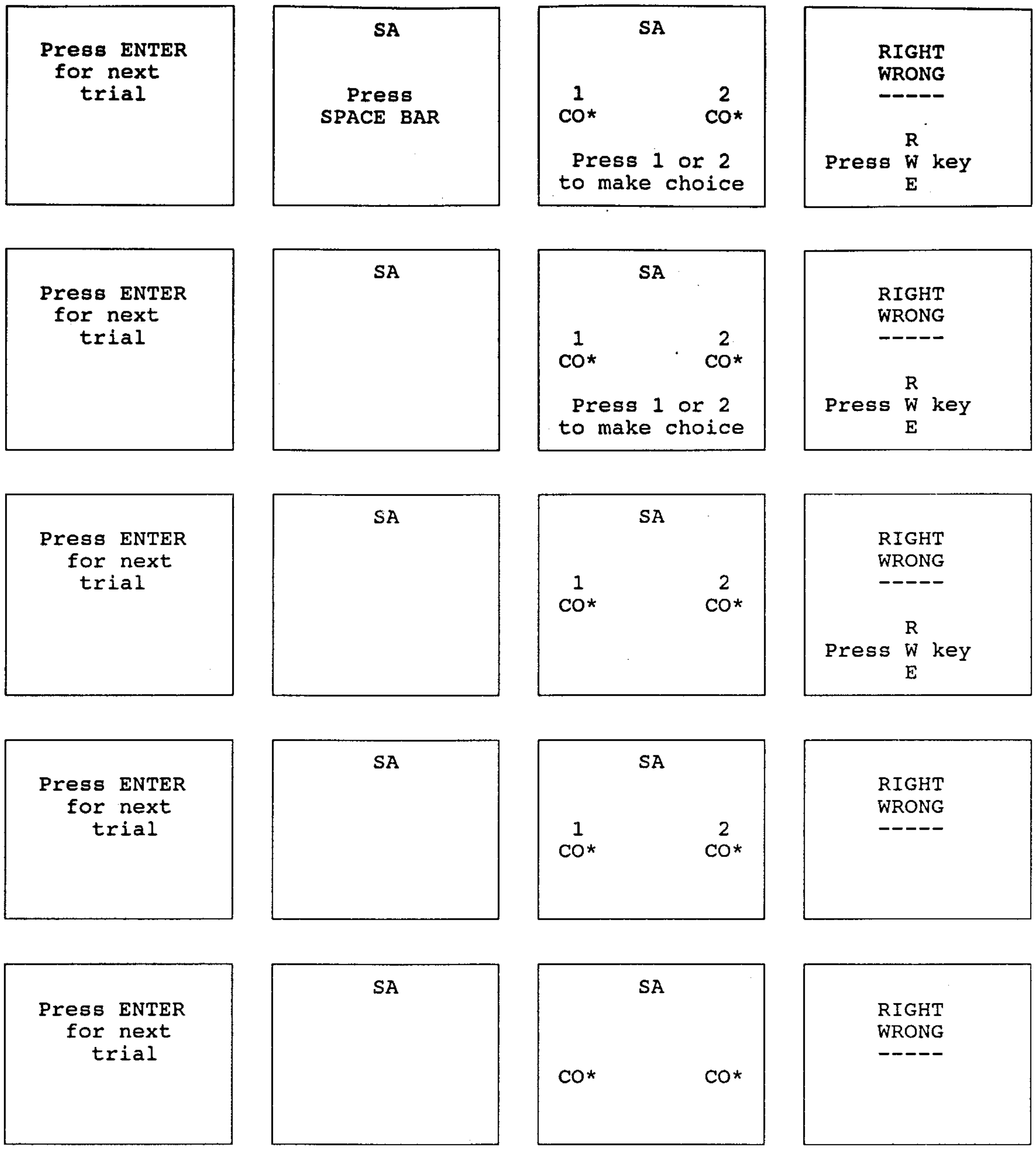

Fig. 1. Sequential changes in the stimuli and the prompts that were presented during a trial are illustrated across a row. Trial onset began with the leftmost frame. Deletion of prompts in successive blocks of trials is illustrated in successive rows. Messages are as indicated in each frame. SA represents the location of the sample stimuli. CO* represents the location of the comparisons. After a comparison was selected only one of the three feedback messages was presented on the screen, although all three possibilities are included here. The response that terminates the feedback message corresponds to presssing R for right, W for wrong, and E for enter.

(1n-5m and 1n-7m), the three-member classes were first expanded to one-node four-member classes by training DB. For the subjects in the remaining groups (3n-5m and 3n-7m), the three-member classes were first expanded to two-node four-member classes by training (CD). After the establishment of either DB or CD, expansion of class size was

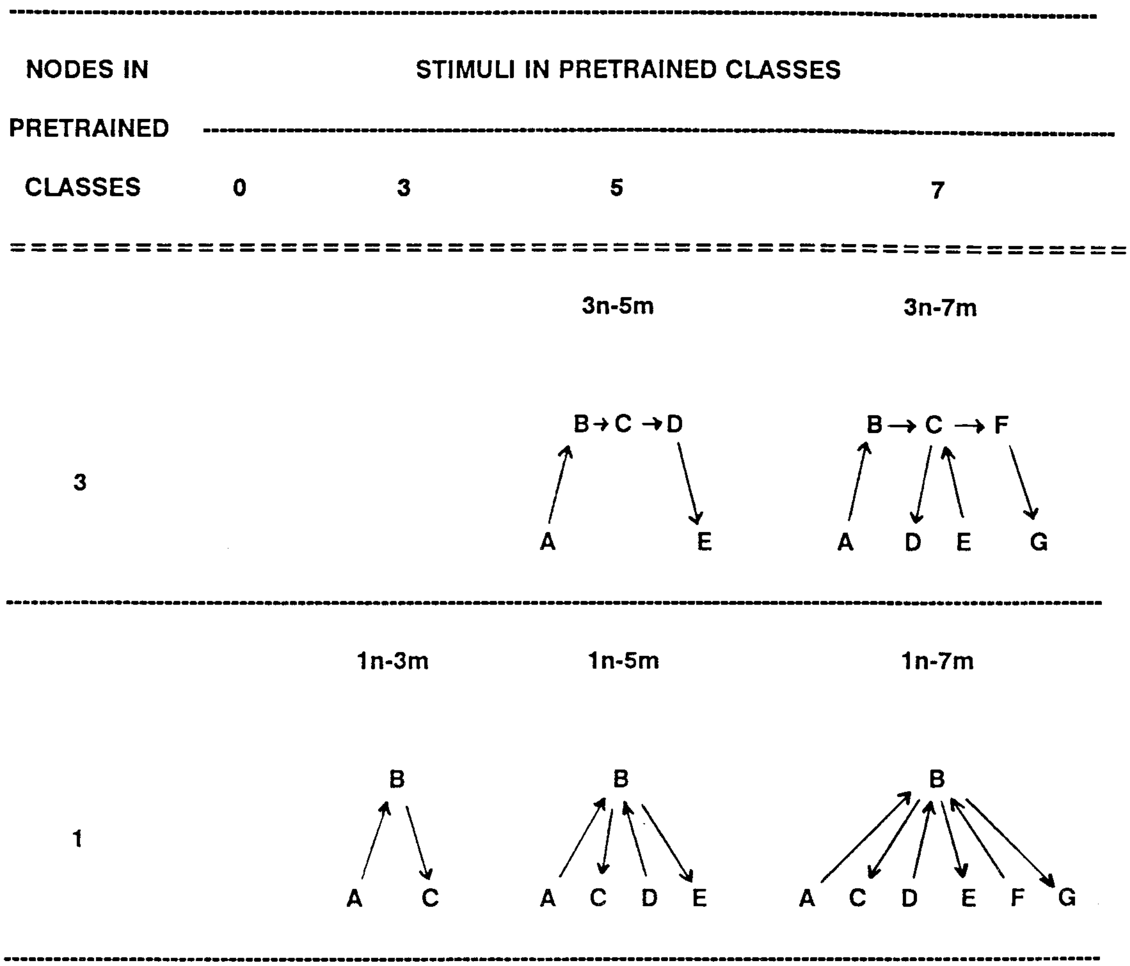

Fig. 2. Spider diagrams that illustrate the structural characteristics of the equivalence classes that were established during pretraining. *x*n = number of nodes; *x*m = class size. Lines in each diagram indicate baseline relations. The arrows connect the stimuli that were linked by conditional discrimination training, with the sample at the tail of the arrow and the comparison at the head of the arrow.

assessed with the presentation of a mixed block of tests for emergent relations that contained all possible trials for the assessment of symmetry, transitivity, and equivalence, along with review trials containing the DB or CD baseline relations. The block was repeated until all tests for emergent relations were passed, or for a maximum of six blocks. The test blocks used to assess the emergence of the one-node or the two-node four-member classes were designated as 4MIX tests and differed in content, as listed in Table 2.

After the emergence of the four-member classes had been demonstrated, expansion to one-node five-member classes was accomplished by training BE for Groups 1n-5m and 1n-7m. Expansion to three-node five-member classes was accomplished by training DE for Group 3n-5m and by training EC for Group 3n-7m. After the establishment of the BE, DE, and EC relations, the expansion of class size was assessed with the presentation of a test block (5MIX) that contained probes that assessed symmetry, transitivity, and equivalence. The block was repeated until all such tests for emergent relations were passed, or for a maximum of six blocks. The content of the 5MIX test block differed for the assessment of the one-node or the three-node classes, as listed in Table 2. This ended pretraining for the one-node five-member (1n-5m) and three-node five-member (3n-5m) groups. For the remaining subjects, the five-member classes were then expanded to seven members.

Expansion of class size to seven members during pretraining. The one-node five-member classes were expanded to one-node six-member classes by training the FB conditional relations for Group 1n-7m. The three-node five-member classes were expanded to three-node six-member classes by training the CF conditional discrimination for Group 3n-7m. After the establishment of FB or CF, expansion of class size was assessed with the presentation of a mixed block (6MIX) of tests for emergent relations that contained trials that assessed symmetry, transitivity, and equivalence. The block was repeated until all such tests for emergent relations were passed, or for a maximum of six blocks. The content of the 6MIX test block differed for the assessment of the one-node or the three-node classes, as listed in Table 2.

After the emergence of the six-member classes had been demonstrated, expansion to one-node seven-member classes was accomplished by training BG; expansion to three-node seven-member classes was accomplished by training FG. After the establishment of BG or FG, expansion of class size was assessed with the presentation of a mixed block of tests for emergent relations that contained trials for the assessment of symmetry, transitivity, and equivalence. The block was repeated until all tests for emergent relations were passed, or for a maximum of six blocks. The content of the 7MIX test block differed for the assessment of the one-node or the three-node classes, as listed in Table 2. This completed pretraining for all subjects.

Establishment of new equivalence classes using the simultaneous protocol: 5SIM. Once pretraining was completed, the simultaneous protocol was used in an attempt to establish two new three-node five-member classes. These new classes, Classes 3 and 4, were also established for subjects who received no pretraining (the none group). First, the conditional relations VW, WX, XY, and YZ were introduced in a single training block, as indicated in Table 2. Each trial type was presented an equal number of times within the block. Trials were presented in random order without replacement. During the initial phases of training, each trial in a block was presented with informative feedback. The training block was repeated until all trials within the block occasioned class-consistent comparison selections. After this mastery criterion was reached, the percentage of trials in a block that produced informative feedback was reduced from 100% to 75% to 25% and, finally, to 0%. Following this training, the baseline conditional relations, as well as all of the symmetry, transitivity, and equivalence probes, were presented in a single test block. Trials were presented in random order without replacement. The 5SIM mixed test block was repeated until criterion was met, or for a maximum of five blocks. During this test block, informative feedback was provided only for selections made on each baseline trial. Noninformative feedback was presented for selections made on each emergent relations test trial.

RESULTS

Class formation in pretraining. As seen in the Appendix, in all phases of pretraining, the baseline relations were established within a few blocks of the minimum scheduled for presentation. In addition, the majority of subjects passed the serially presented tests for emergent relations and the mixed tests in one or two blocks. There was also a low level of intersubject variability in performances within and across groups for a given type of relation or test block.

Acquisition of baseline conditional relations under the simultaneous protocol. As seen in Table 3, baseline conditional relations were established by all subjects in each group. This consistency indicated that pretraining did not influence the likelihood of establishing the baseline conditional relations under simultaneous training conditions. In contrast, the pretraining conditions influenced the speed with which the conditional discriminations were established under the simultaneous protocol. Speed was indexed by taking the reciprocal of the number of blocks needed to establish the baseline relations under the simultaneous protocol. This effect was statistically significant as measured by a 1 × 6 ANOVA, $F(5) = 2.73$; $p = .0236$.

Figure 3 (left) shows that the baseline relations were established most slowly under

Table 3

Number of training blocks used by each subject for the establishment of the baseline conditional discriminations during the simultaneous protocol. The column heading is the type of pretraining the group received; *x*n represents the number of nodes in the pretraining group, and *x*m represents the class size of the pretraining group. The number of blocks in each group have been ranked to ease analysis.

Pretraining groups											
None		1n-3m		1n-5m		1n-7m		3n-5m		3n-7m	
Subject	Block	Subject	Block	Subject	Block	Subject	Block	Subject	Block	Subject	Block
MC00	10	HS13	8	SL15	7	PA17	8	RG35	7	IG37	7
MG00	10	TBA13	9	KR15	8	BM17	9	AL35	8	OR37	8
SK00	11	VY13	9	MR15	8	EV17	9	CM35	8	OA37	8
ME00	12	RS13	9	LM15	9	RF17	9	DBA35	9	WT37	9
KK00	12	BF13	10	MS15	10	MKA17	9	PS35	9	KL37	9
JM00	13	TBB13	11	MM15	10	MP17	9	MJ35	10	DGA37	9
ND00	14	RM13	14	AD15	11	JP17	10	DBB35	10	MA37	10
RFA00	14	RP13	15	EC15	12	MKB17	10	JG35	11	AK37	11
DP00	14	EZ13	16	JL15	13	EA17	11	CG35	11	AE37	12
RFB00	15	ED13	17	DK15	14	DT17	11	MG35	11	DA37	12
AS00	15	SH13	17	SS15	15	BS17	12	DG35	11	NF37	12
AF00	16	MN13	21	LL15	20	AV17	13	DI35	11	JS37	12
NY00	18	AA13	23	SV15	20	NE17	14	KW35	12	DGB37	13
MI00	20	RP13	27	FJ15	20	RS17	16	SG35	13	IP37	14
PC00	28	GT13	30	LB15	21	NM17	16	MV35	14	CI37	15
JQ00	31	WK13	32	GM15	23	AA17	24	DI35	15	TO37	17
BM00	39	IA13	37	GS15	26	EP17	45	MR35	19	CG37	19
RL00	71	DT13	42	AL15	41	PB17	46	KG35	35	JD37	19

the simultaneous protocol after no pretraining or after the establishment of one-node three-member classes during pretraining. When the size of the one-node classes in pretraining was increased from three to seven members, the speed with which the baseline relations were established under the simultaneous protocol increased by 20%. The trend was systematic, but it was not statistically significant, 1 × 3 ANOVA, $F(2) = 1.13$, $p = .33$.

Under the simultaneous protocol, the baseline relations were established fastest after the

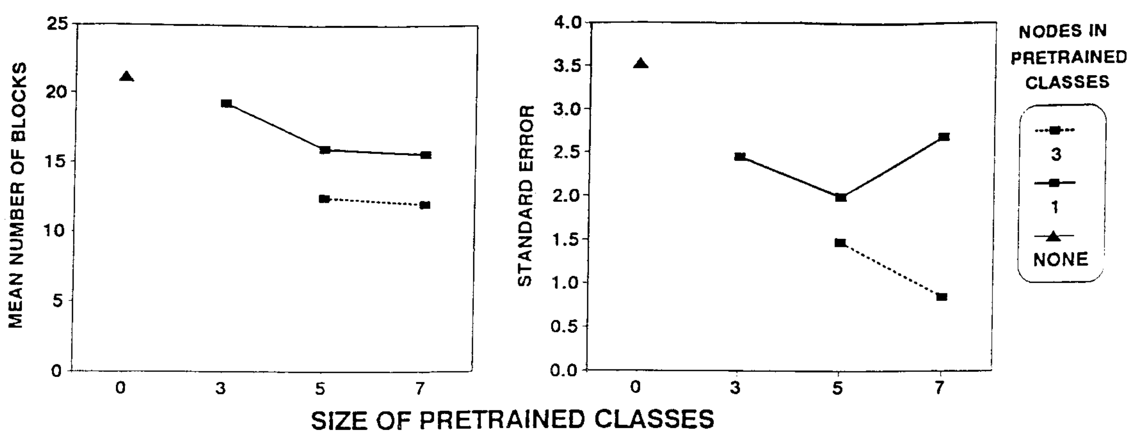

Fig. 3. The mean number of blocks required for the establishment of the baseline conditional discriminations under the simultaneous protocol is plotted as a function of the number of nodes and the size of the pretrained classes on the left. The intersubject standard error in number of blocks required to establish the baseline conditional discriminations under the simultaneous protocol is plotted as a function of the size and the number of nodes in pretrained classes on the right.

Table 4

Pair-wise comparisons of variances between pretraining conditions. The analyses are based on the data in Table 3.

	None	1n-3m	1n-5m	1n-7m	3n-5m	3n-7m
None	—	2.05	3.07*	1.67	5.59*	16.74*
1n-3m		—	1.50	1.22	2.73*	8.19*
1n-5m			—	1.84	1.82	5.45*
1n-7m				—	3.34*	10.01*
3n-5m					—	2.99*
3n-7m						—

* Critical $F = 2.26$ for $p < .05$.

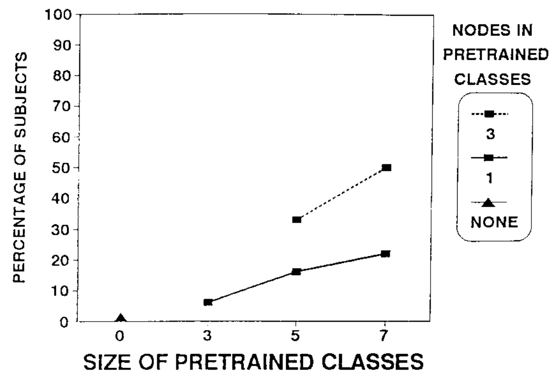

Fig. 4. The percentage of subjects who passed the emergent relations test under the simultaneous protocol on the first presentation of the test block (immediate emergence). Each function shows the effect of class size, holding number of nodes constant. The two functions differ in terms of the number of nodes contained in each pretrained class.

prior establishment of three-node five- or seven-member classes: about 20% faster than after the prior establishment of one-node five- or seven-member classes and about 40% faster than after no pretraining or after the establishment of one-node three-member classes. The size of three-node pretrained classes, however, did not influence the speed with which the conditional relations were established under the simultaneous protocol. These trends were systematic, but only some were statistically significant. Specifically, the baseline relations under the simultaneous protocol were established significantly faster after pretraining with three-node five- or seven-member classes than after pretraining one-node three-member classes, as confirmed by protected t tests, 1n-3m versus 3n-5m, $t = -2.46$, $p < .05$; 1n-3m versus 3n-7m, $t = -2.35$, $p < .05$, or after no pretraining, none versus 3n-5m, $t = -2.75$, $p < .01$; none versus 3n-7m, $t = -2.65$, $p < .01$.

The right side of Figure 3 shows that intersubject variability in the blocks needed to establish baseline relations was greatest after no pretraining, and was an inverse function of number of nodes in the pretrained classes. Variability was unrelated to the size of the pretrained classes that contained one nodal stimulus. When the pretrained classes contained three nodes, however, variability was a decreasing function of the size of the pretrained classes. These trends were confirmed by the statistical analysis of all pairwise comparisons of variability for all of the pretraining conditions, as shown in Table 4.

To summarize, the number of nodes in previously established equivalence classes influenced both the average speed and the intersubject variability with which the new conditional discriminations were established under the simultaneous protocol. The size of previously established equivalence classes influenced the speed with which the new conditional discriminations were established under the simultaneous protocol to a small degree, and reduced variability when the pretrained classes contained three nodes.

Pretraining effects on immediate emergence of new equivalence classes. The immediate emergence of equivalence classes has been demonstrated when performances that are consistent with the experimenter-defined sets are occasioned by the first presentation of all emergent relations probes. This is the strongest index of equivalence class formation, because it reflects the effects of prior training only and is not influenced by potential effects of test block repetition (Lazar et al., 1984; Saunders & Green, 1992; Saunders et al., 1988; Sidman, 1992a, 1994; Spradlin et al., 1973).

Figure 4 shows how the immediate emergence of equivalence classes under the simultaneous protocol was influenced by the size and the number of nodes in the pretrained classes. Differences in immediate emergence across all conditions were statistically significant ($\chi^2 = 18.17$, $p = .003$). None of the subjects who received no pretraining (the none group) showed the emergence of classes during the first test block presented in the simultaneous protocol. All pretraining conditions, however, produced some percent-

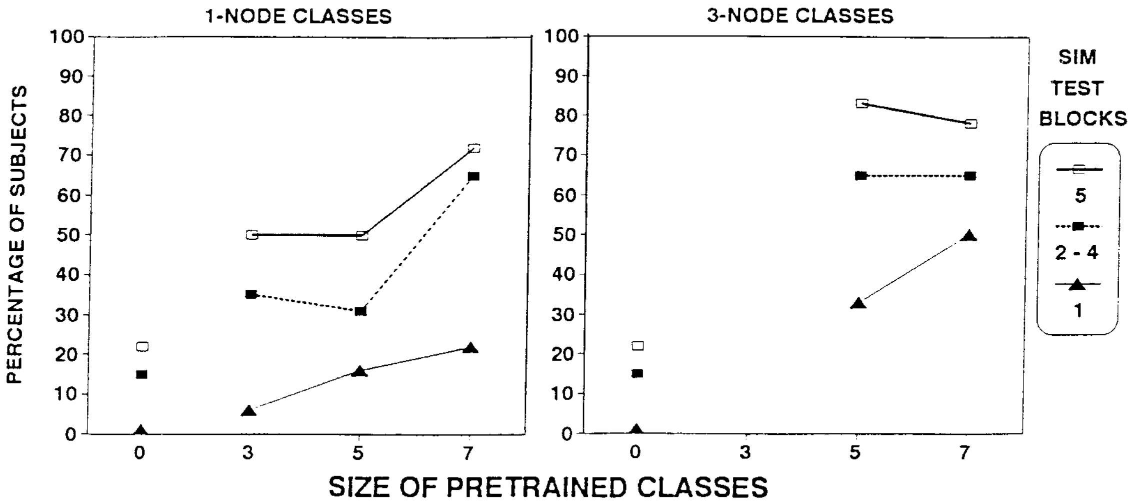

Fig. 5. The percentage of subjects who passed the emergent relations test under the simultaneous protocol with repeated presentations of the test blocks. Data are plotted as functions of the size and the number of nodes in the classes established during pretraining. Data on the left side were obtained after the pretraining of classes that contained one node. Data on the right side were obtained after the pretraining of classes that contained three nodes. The functions on each side illustrate the percentage of subjects who showed the emergence of Classes 3 and 4 in the first, the average of the second through fourth, and the fifth presentation of the test blocks presented under the simultaneous protocol.

age of subjects who showed immediate emergence of equivalence classes under the simultaneous protocol. Some pretraining, then, enhanced immediate emergence when compared to no pretraining ($\chi^2 = 5.85$, $p = .016$). When pretrained classes contained only one node, the percentage of subjects who showed immediate emergence was a gradual increasing function of the size of the pretrained classes. When the pretrained classes contained three nodes, immediate emergence was also a direct function of the size of the pretrained classes, but was not statistically significant ($\chi^2 = 5.898$, $p = .052$).

The effect of number of nodes in the classes established in pretraining on the immediate emergence of equivalence classes under the simultaneous protocol can be discerned by comparing data points across functions for the same class size. Increasing the number of nodes in the pretrained classes produced substantial increases in the percentage of subjects who showed the immediate emergence of classes under the simultaneous protocol when class size was held constant. The difference in the percentage of subjects who showed immediate emergence after the prior establishment of one-node five- and seven-member classes or three-node five- and seven-member classes was statistically significant ($\chi^2 = 4.19$, $p < .05$). To summarize, the percentage of subjects who showed the immediate emergence of new equivalence classes under the simultaneous protocol, which typically does not support class formation, was a direct function of two structural parameters of previously established classes: nodal number and possibly class size. The visual inspection of Figure 4 and the statistical analyses both support the view that nodal number exerted more influence than class size on the immediate emergence of new classes under the simultaneous protocol.

When the five- and seven-member data were compared, increasing the size of the one-node pretrained classes produced a 6% increase in the percentage of subjects who showed immediate emergence. In contrast, increasing the size of the three-node pretrained classes produced a 17% increase in the percentage of subjects who showed immediate emergence. The fact that the increment in yield produced by number of nodes was greater with larger class sizes demonstrated an interaction between these two parameters of the pretrained classes.

Pretraining effects on delayed emergence of new equivalence classes. If class-consistent respond-

Table 5

Average number of blocks needed for subjects to pass the tests for emergent relations under the simultaneous protocol for those subjects who required more than one block to pass the tests. Data are listed as a joint function of the size and the number of nodes that characterized the classes established during pretraining. *X*n-*Y*m clusters designate *X* nodes in a class and *Y* stimuli in a class.

Group	Average number of blocks
None	3.0
1n-3m	3.0
1n-5m	3.7
1n-7m	2.4
3n-5m	3.1
3n-7m	3.4
All	3.05

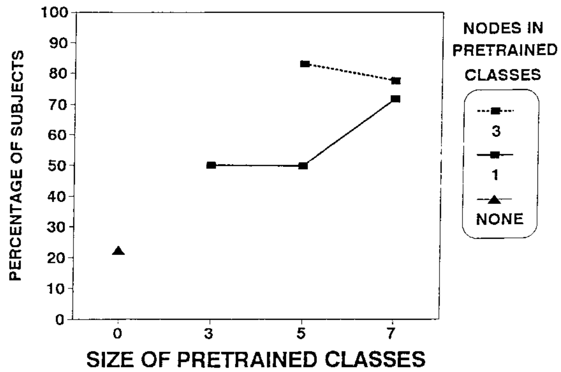

Fig. 6. The percentage of subjects who passed the emergent relations test under the simultaneous protocol regardless of test block. Data are plotted as a function of the size and number of nodes in the pretrained classes.

ing does not occur on the first presentation of emergent relations probes, such a performance may emerge with the repeated presentation of the probes. This demonstrates the delayed emergence of equivalence classes. The effects of the size and the number of nodes in the pretrained classes on the percentage of subjects who showed the delayed emergence of equivalence classes under the simultaneous protocol are illustrated in Figure 5.

When the pretrained classes contained one node, the percentage of subjects who showed the immediate emergence of classes during the initial test block was a gradual increasing function of the size of the pretrained classes. During the second to fourth test blocks, although an increasing percentage of subjects showed the emergence of classes under the simultaneous protocol, the effect of class size was not linear. Although three- and five-member pretrained classes produced the same effect, the seven-member pretrained classes produced much larger increases in delayed emergence. This functional relation was maintained and shifted upward by the fifth test block. Therefore, delayed emergence was influenced by the size of the pretrained classes that contained one nodal stimulus.

When the pretrained classes contained three nodes, the percentage of subjects who showed the immediate emergence of the new classes was a direct function of the size of the pretrained class. Repeated testing resulted in a large increase for subjects who were pretrained with the five-member class and a smaller increase for subjects who were pretrained with seven-member classes.

The percentage of subjects who showed the delayed emergence of Classes 3 and 4 was shown in Figure 5. Table 5 shows how pretraining influenced the speed of delayed emergence. For subjects who showed the delayed emergence of new classes in the simultaneous protocol, an average of 3.05 blocks was required to pass the tests for emergent relations. Surprisingly, the speed of delayed emergence remained constant across all pretraining conditions, ANOVA, $F(5) = 1.16$, $p < .40$. This constancy showed that the rate of delayed emergence was not influenced by the prior establishment of other equivalence classes or by the size or number of nodes in the previously trained classes.

Overall effects of pretraining on equivalence class formation under the simultaneous protocol. Figure 5 illustrated the effects of repeated testing on the delayed emergence of one-node classes alone or three-node classes alone. Figure 6 summarizes the cumulative effects of the number of nodes and size of pretrained classes on the emergence of new classes established using the simultaneous protocol. A higher percentage of subjects showed the emergence of classes after as many as five presentations of the test blocks used in the simultaneous protocol after some pretraining than after no pretraining ($\chi^2 = 15.10$, $p < .0002$). For the one-node pretrained classes, increasing the size of the pretrained classes from three to five members did not influence the percentage of subjects who showed the emergence of classes under the simultaneous protocol. As the size of the pretrained classes increased from five to seven members, an increasing percentage of subjects showed the emergence of classes under the simultaneous protocol. This trend, however, was not statistically significant ($\chi^2 = 1.87$, $p = .17$). For three-node classes, regardless of the size of the pretrained classes, the same percentage of subjects showed the emergence of classes under the simultaneous protocol. The effects of nodal number in the pretrained classes was also compared. For five-member pretrained classes, increasing the number of nodes in the pretrained classes significantly increased the percentage of subjects who showed the emergence of classes under the simultaneous protocol ($\chi^2 = 6.42$, $p < .02$). When seven-member classes were established during pretraining, essentially the same high yields were obtained under the simultaneous protocol, regardless of the number of nodes in the pretrained classes.

To summarize, the likelihood of forming new equivalence classes under conditions that typically do not support class formation was a direct function of the size and the number of nodes that characterized previously established equivalence classes. Maximal yields under the simultaneous protocol were produced by pretraining with smaller classes that contained a maximal number of nodal stimuli and by larger classes regardless of number of nodal stimuli. Therefore, the enhancement of class formation under the simultaneous protocol resulted from an interaction between the size and the number of nodes in previously established classes.

Cost-benefit analysis of pretraining. Although the prior establishment of two equivalence classes increased the percentage of subjects who showed the emergence of two new equivalence classes under the simultaneous protocol, the establishment of the pretrained classes took additional time. Was there some value to be gained by the expenditure of the additional time needed to conduct pretraining? To answer that question, we calculated the total time spent by all subjects in a group from the start of pretraining to the completion of the last test block presented in the simultaneous protocol, as seen in the third column of Table 6. These measures were obtained regardless of the ultimate success or failure of a subject in the formation of equivalence classes under the simultaneous protocol. The total time spent by the subjects in a group was then divided by the number of subjects in that group who showed the emergence of equivalence classes under the simultaneous protocol ("successful" subjects), as seen in the fourth column of Table 6. The result was the aggregate amount of time spent in training all of the subjects in a group that was needed to produce 1 subject who showed the emergence of new equivalence classes under the simultaneous protocol, as listed in the fifth column of Table 6. Separate computations were made for subjects who showed the emergence of classes in the first test block (presented in the upper portion of Table 6) and in the first to fifth test block (presented in the lower portion of Table 6).

Table 6

Average time required to train a subject who showed the emergence of classes under the simultaneous protocol. Total time is the sum of the time needed to conduct all pretraining and all training and testing under the simultaneous protocol. Each group is indicated by nodes and class size in Column 2. *x*n-*y*m clusters designate *x* nodes in a class and *y* stimuli in a class. The number of subjects who showed the emergence of new classes under the simultaneous protocol in the first test block and in all test blocks is listed in the "Number to pass" column. The average aggregate time for 1 successful subject was obtained by dividing the data in Column 3 by the data in Column 4. Pretraining conditions are listed in descending order of aggregate time needed to produce 1 subject who showed the emergence of classes under the simultaneous protocol.

Emergence in	Nodes/ size in pretraining	Total time (min)	Number to pass	Aggregate time for 1 successful subject (hr)
Block 1	None	1,885	0	—
	1n-3m	2,794	1	46.6
	1n-5m	3,517	3	19.5
	1n-7m	4,210	4	17.5
	3n-5m	2,926	6	8.1
	3n-7m	4,054	9	7.5
Blocks 1–5	None	2,712	4	11.3
	1n-5m	4,013	9	7.4
	1n-3m	3,402	9	6.3
	1n-7m	4,490	13	5.8
	3n-7m	4,352	14	5.2
	3n-5m	3,273	15	3.6

Figure 7 illustrates the time needed to train 1 subject in a group who showed immediate emergence of classes under the simultaneous

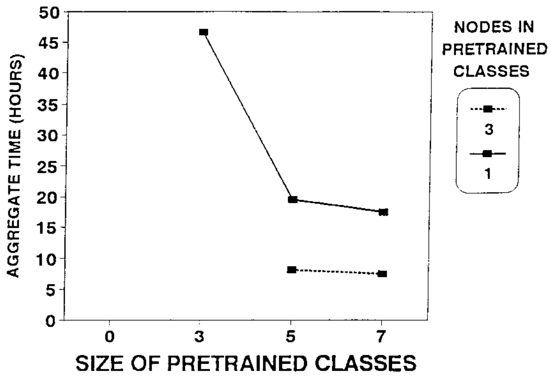

Fig. 7. Aggregate group training time needed to produce 1 subject who showed the immediate emergence of equivalence classes under the simultaneous protocol. Data are plotted as a function of the size and number of nodes in the pretrained classes.

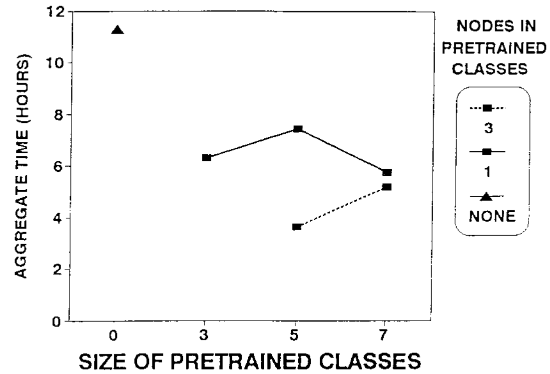

Fig. 8. Aggregate group training time needed to produce 1 subject who showed the delayed emergence of equivalence classes under the simultaneous protocol. Data are plotted as a function of the size and number of nodes in the pretrained classes.

protocol. When no pretraining was used, none of the subjects in the group showed immediate emergence. Thus, a measure of efficiency could not be obtained, nor could efficiency be compared to the subjects in groups that received pretraining. After pretraining of one-node three-member classes, 46.7 aggregate training hours were needed to produce 1 subject who showed the immediate emergence of new equivalence classes under the simultaneous protocol. The aggregate time decreased by a factor of 2.5 when one-node five- or seven-member classes were established in pretraining. The aggregate time decreased by a factor of 6.0 when three-node five- or seven-member classes were established in pretraining.

There was a major increase in the training efficiency when the size of the pretrained classes increased from three to five members. Increases beyond five members, however, did not result in further improvements in efficiency. In contrast, for pretrained classes that contained at least five members, an increase in the number of nodes in those classes more than doubled training efficiency.

Figure 8 illustrates the time needed to train 1 subject in a group who showed emergence of classes under the simultaneous protocol in one to five test blocks. An aggregated time of 11.3 hr was required to produce 1 successful subject when they did not receive any pretraining (the none group). All levels of pretraining reduced the time needed to produce one individual who could form equivalence classes under the simultaneous protocol. This time decreased by a factor of 1.6 when one-node three- or five-member or one-node seven-member classes were established in pretraining. This time decreased by a factor of 3.14 when three-node five-member classes were established in pretraining. Thus, the maximal savings was achieved by the prior establishment of intermediate size classes that contained many nodal stimuli.

DISCUSSION

Equivalence classes that varied in size and nodal number across groups were established with college students through the use of a simple-to-complex protocol and the incremental expansion of class size. Regardless of size or nodal number, all classes emerged rapidly during pretraining. Students were then exposed to the simultaneous protocol in an attempt to form new equivalence classes. The size and number of nodes in the previously established classes influenced many aspects of equivalence class formation under the simultaneous protocol.

Equivalence class formation during pretraining. During pretraining, the simple-to-complex protocol was used to establish three-member classes. Subsequent expansions of class size were implemented on an incremental basis. Most of the probes used to assess the emergence of classes and the expansion of class size occasioned class-consistent performances as soon as they were introduced. Therefore, the expansion of class size in pretraining was not influenced by the size or the number of nodes in the classes that had already been established in pretraining. These results replicate the findings reported by other researchers who also used simple-to-complex training and testing protocols to establish equivalence classes (Adams et al., 1993; Fields et al., 1991; Lynch & Cuvo, 1995; Schusterman & Kastak, 1993).

Acquisition of baseline relations under the simultaneous protocol. All subjects learned the baseline conditional relations under the simultaneous protocol. The average speed with which the baseline conditional relations were established was a direct function of the number of nodes in previously trained classes; acquisition speed was also influenced, but to a lesser degree, by the size of the previously trained classes. This is the first demonstration that the number of nodal stimuli in previously established classes influences the acquisition of new conditional discriminations.

Buffington et al. (1997) reported that the speed with which the baseline relations were established under the simultaneous protocol was an inverse function of the size of the pretrained classes. In that study, however, class size was confounded with the number of nodes in the pretrained classes. The results of the current experiment suggest that the effects reported by Buffington et al. were determined by the number of nodes in the pretrained classes rather than by their size.

Immediate emergence. The percentage of subjects who showed the immediate emergence of new equivalence classes under the simultaneous protocol was a direct function of both the number of nodal stimuli in the pretrained classes and the size of the pretrained classes. The effect of nodal number, however, was greater than the effect of class size. This is the first demonstration that the number of nodes in a previously established class and the size of those classes are both independent variables that influence the formation of new equivalence classes by college students.

Buffington et al. (1997) showed that concurrent increases in the size and the number of nodes in previously established equivalence classes increased the percentage of college students who then showed the emergence of new one-node three-member classes under the simultaneous protocol. The results of the present experiment suggest that the enhancement reported by Buffington et al. could well represent the combination of the independent effects of the size and the number of nodes in the pretrained classes used in that experiment.

Delayed emergence. The delayed emergence of equivalence classes has been observed in many experiments (e.g., Devany et al., 1986; Fields et al., 1990; Lazar et al., 1984; Sidman et al., 1985; Sidman, Willson-Morris, & Kirk, 1986; Sigurdardottir, Green, & Saunders, 1990; Spradlin et al., 1973). The results of the current experiment showed that both the size and the number of nodes in previously established equivalence classes influenced the percentage of subjects who then showed the delayed emergence of new equivalence classes. Although a number of theories have been presented to account for delayed emergence (Saunders & Green, 1992; Sidman, 1992a, 1994), both the nodal structure and the size of previously established equivalence classes are the first independent variables that have been shown to influence the delayed emergence of new equivalence classes.

Extending the range of nodal effects on equivalence class formation. Many studies have shown that a variety of test performances occasioned by the stimuli in an equivalence class are systematically related to the nodal distance that separates the stimuli within that class (Fields, Adams, & Verhave, 1993). For example, the likelihood of selecting class-consistent comparisons in emergent relations probes is an inverse function of nodal distance (Bentall, Dickins, & Fox, 1993; Dickins, Bentall, & Smith, 1993; Dube, Green, & Serna, 1993; Fields et al., 1990, 1992, 1993, 1995; Kennedy, 1991; Kennedy, Itkonen, & Lindquist, 1994; Kennedy & Laitinen, 1988; Lazar et al., 1984; McDonagh, McIlvane, & Stoddard, 1984; Meehan & Fields, 1995; Saunders et al., 1988; Sidman et al., 1985; Wulfert & Hayes, 1988). In addition, the initial transfer of responding among the stimuli in the same class is an inverse function of nodal distance (Barnes & Keenan, 1993; Fields et al., 1993, 1995). The order in which new responses transfer among class members is a direct function of nodal distance (Fields et al., 1993). Reaction time is a direct function of nodal distance in tests for emergent relations (Bentall et al., 1993; Wulfert & Hayes, 1988), and in post-class-formation response-transfer tests (Fields et al., 1995). Finally, response speed is an inverse function of nodal distance in tests for emergent relations conducted after class formation (Spencer & Chase, 1996). The results of the current study extend these findings in a new direction. Enhancing the establishment of new equivalence classes is a direct function of the number of nodes in previously established equivalence classes.

Cost effectiveness of pretraining and instructional implications. Establishing one set of equivalence classes during pretraining reduced by three- to sixfold the aggregate instructional time required to train 1 subject who showed the emergence of equivalence classes under the simultaneous protocol. In addition to increasing yield, pretraining also reduced the amount of time needed to train an individual who showed the emergence of classes under the simultaneous protocol. The maximization of yield and minimization of instructional resources have obvious implications for enhancement of the cost effectiveness of instructional systems.

To illustrate, in natural settings some equivalence classes emerge under training and testing conditions that are essentially unstructured and unprogrammed. The simultaneous protocol is one reasonable emulation of such a condition. Maximizing the percentage of individuals who form equivalences under unstructured conditions of training and testing while minimizing the expenditure of instructional resources could be accomplished in the following manner. First, a set of initial equivalence classes could be established using the simple-to-complex protocol. Then, new equivalence classes could be established under the simultaneous protocol. After such a training history, a student should be more likely to form new equivalence classes in an unstructured setting.

Enhancing reliability of equivalence class formation. Many experiments have identified procedures that can be used to reliably induce equivalence classes. Although varied, all of these procedures typically involve the sequential introduction of baseline conditional relations and emergent relations probes. In contrast, equivalence classes are less likely to emerge under the simultaneous protocol. The results of the current experiment, however, show that the prior establishment of equivalence classes under the simple-to-complex protocol increases the reliability of equivalence class formation under the simultaneous protocol. With appropriate prior training, then, the reliability of equivalence class formation need not always depend on the use of highly programmed sequential training and testing protocols.

Summary and implications. In the current experiment, a transfer-of-training design was used to identify historical variables that influenced equivalence class formation. The effectiveness of this strategy depended on the use of the simultaneous protocol as the test component of the transfer design. Because a small percentage of subjects form classes under the simultaneous protocol without benefit of prior training, it is easy to measure increases in yield that are correlated with exposure to historical variables. By using this strategy, we found that the emergence of new equivalence classes under the simultaneous protocol was substantially enhanced by the number of nodes and the number of stimuli that characterized previously established equivalence classes. Both of these structural parameters of equivalence classes, then, functioned as independent variables that influenced the emergence of new equivalence classes. Similar group-based transfer-of-training designs (e.g., Wulfert, Dougher, & Greenway, 1991) could be used to identify other historical variables that enhance the likelihood of equivalence class formation. Additional research will be needed to determine whether the variables identified in the current experiment would have similar effects on a within-subject basis. Indeed, the data obtained in the current study could be used to guide the selection of parameters to be used in analogous within-subject experiments.

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APPENDIX

The number of blocks needed to establish the baseline relations and to pass the tests for emergent relations for subjects in each phase of pretraining.

		3 member (% feedback)														4 member (% feedback)				
Group	Subject	AB 100	75	25	0	BA 0	BC 100	75	25	0	CB 0	BA, CB 0	AC 0	CA 0	3 MIX 0	CD 100	75	25	0	4 MIX 0
1n-3m	TBA13	2	1	1	1	1	1	1	1	1	1	1	1	1	1					
	RM13	3	1	1	1	1	1	1	1	1	1	1	1	1	1					
	EZ13	1	1	1	1	2	1	1	1	1	1	1	1	1	2					
	ED13	3	1	1	1	2	2	1	1	1	1	1	2	1	1					
	SH13	3	1	1	1	1	2	1	1	1	1	2	1	1	3					
	TBB13	3	1	1	1	1	4	1	1	1	1	1	1	1	1					
	AA13	2	2	1	1	1	1	1	1	1	1	1	1	1	1					
	RP13	2	2	1	1	2	4	1	1	2	2	1	5	1	2					
	VY13	4	2	1	1	1	1	1	1	1	1	1	2	1	2					
	RS13	2	1	1	2	2	2	1	1	1	1	1	2	1	4					
	DT13	4	1	2	1	1	3	1	1	1	2	1	*12*	1	1					
	HS13	2	1	1	1	1	1	1	1	1	2	1	1	1	1					
	IA13	2	1	1	1	1	3	5	2	2	5	2	3	1	1					
	MN13	3	1	1	1	1	1	1	1	1	1	2	4	1	1					
	GT13	2	1	1	1	1	1	1	1	1	1	1	1	1	2					
	WK13	2	1	1	1	1	3	1	1	1	1	3	1	1	3					
	BF13	5	2	1	2	1	3	1	1	1	1	1	1	*12*	*9*					
	PT13	6	1	1	1	1	2	2	1	1	1	1	1	2	1					
1n-5m	LM15	3	1	1	1	*18*	2	2	1	1	2	1	*9*	*7*	2	7	4	1	1	*8*
	GS15	2	3	4	1	1	2	2	3	3	5	3	*9*	1	1	2	1	1	1	2
	JL15	2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1
	LB15	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	2	1	1	2
	SL15	2	1	2	1	2	1	1	1	1	1	1	1	2	1	1	1	1	1	3
	LL15	5	1	1	1	1	1	1	1	1	1	2	1	3	1	3	1	1	1	1
	AD15	3	1	1	1	1	2	1	1	2	1	3	2	1	1	3	1	1	2	3
	MS15	2	1	1	1	1	2	1	1	1	2	1	1	3	1	2	1	1	2	2
	KR15	2	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	1	2
	DK15	6	1	1	1	2	5	1	1	1	3	2	1	1	1	3	1	2	1	6
	EC15	2	1	1	1	1	2	1	1	1	1	1	1	2	2	1	1	1	1	2
	AL15	4	1	1	2	5	3	2	1	1	4	2	6	4	1	2	1	1	1	3
	MR15	2	1	1	1	1	2	1	1	1	1	2	1	3	1	3	1	1	1	2
	SV15	2	1	1	1	2	2	1	1	1	1	1	1	2	2	5	1	1	2	5
	SS15	2	1	1	1	1	2	1	1	1	2	1	2	1	1	2	1	1	1	1
	GM15	2	1	1	1	1	3	1	1	1	2	1	3	1	2	2	1	1	2	5
	FJ15	1	2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1
	MM15	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	6
3n-5m	DBA35	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2
	KG35	11	1	1	1	1	5	2	1	1	2	1	3	2	4	3	2	1	1	5
	PS35	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
	JG35	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
	KW35	2	1	1	2	2	2	1	2	2	2	2	2	2	1	4	1	2	1	4
	CG35	1	1	2	1	1	4	1	1	1	3	1	4	1	1	2	1	1	1	1
	MJ35	3	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
	AL35	2	1	1	1	2	2	1	1	1	1	1	1	3	2	2	1	1	1	1
	MG35	4	1	1	1	1	1	1	1	1	1	1	1	1	2	4	1	1	1	4
	CM35	2	1	1	1	2	2	1	1	1	1	1	2	3	2	2	2	1	2	1
	DG35	3	1	1	1	1	3	1	1	1	1	1	1	1	1	2	1	2	1	2
	DIA35	2	1	1	1	1	1	1	2	1	1	1	1	2	1	1	2	1	1	4
	SG35	3	1	1	1	1	1	1	1	3	1	2	2	1	2	3	1	1	1	3
	RG35	2	1	1	1	1	3	1	1	1	1	1	1	1	1	2	1	1	1	1
	MR35	2	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1	1	1	3
	MV35	3	2	1	1	1	3	1	1	1	2	4	4	1	3	2	1	1	1	2
	DBB35	2	1	1	1	1	4	4	1	1	1	1	2	1	1	2	1	1	1	2
	DIB35	2	1	1	1	1	2	1	1	1	2	1	2	1	1	2	2	1	1	6

APPENDIX

(Extended)

5 member (% feedback)					6 member (% feedback)					7 member (% feedback)				
DE 100	75	25	0	5MIX 0	EF 100	75	25	0	6MIX 0	FG 100	75	25	0	7MIX 0
1	1	1	1	2										
2	1	1	2	1										
1	1	1	1	1										
2	1	1	1	1										
2	1	1	1	1										
1	1	1	1	2										
2	1	1	1	1										
4	1	1	2	1										
2	1	1	1	2										
4	1	1	1	3										
2	1	1	1	2										
6	1	1	1	3										
2	1	1	2	3										
2	1	1	1	2										
2	1	1	1	2										
3	1	2	1	6										
2	1	2	1	3										
4	1	2	2	2										
1	1	1	1	1										
3	1	1	1	1										
1	1	1	1	1										
1	1	1	1	1										
2	1	1	1	1										
1	1	1	1	2										
1	1	1	1	1										
1	1	1	1	1										
2	1	1	1	2										
2	1	1	1	1										
1	1	1	1	2										
3	1	1	1	1										
4	1	1	1	3										
3	1	1	1	2										
1	2	1	1	2										
2	1	1	1	1										
2	1	1	1	1										
1	1	1	1	1										

APPENDIX

(*Continued*)

		3 member (% feedback)														4 member (% feedback)				
Group	Subject	AB 100	75	25	0	BA 0	BC 100	75	25	0	CB 0	BA, CB 0	AC 0	CA 0	3 MIX 0	CD 100	75	25	0	4 MIX 0
1n-7m	BM17	2	1	1	1	1	1	1	1	1	1	1	3	1	1	3	1	1	1	2
	RS17	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	3
	JP17	2	1	1	1	1	3	1	1	1	1	1	2	4	1	2	1	1	1	2
	MKA17	2	1	1	1	2	2	1	1	1	1	1	1	1	1	3	1	1	1	1
	EV17	2	2	1	1	1	2	1	1	1	4	4	3	1	1	8	1	1	1	3
	BS17	2	1	1	2	4	3	1	1	1	1	1	1	2	2	2	1	2	1	1
	PA17	2	1	1	1	1	1	1	1	1	2	1	1	6	1	1	1	1	1	1
	EA17	3	1	1	1	1	2	1	1	1	1	2	2	1	1	2	1	1	1	2
	NE17	3	1	1	1	1	4	1	1	2	4	1	2	1	2	1	1	2	1	1
	AV17	4	1	1	1	2	2	1	1	1	2	1	1	1	1	2	1	1	1	2
	RF17	2	1	1	1	3	1	1	1	1	1	1	1	1	1	2	1	1	2	4
	MKB17	2	1	1	1	1	2	1	3	3	2	1	1	2	2	3	3	2	1	1
	DT17	2	1	1	1	1	3	1	1	1	1	1	1	3	1	2	1	1	1	1
	EP17	1	1	2	1	1	2	1	1	1	4	2	2	1	1	1	1	1	1	2
	NM17	2	1	1	1	1	2	1	1	1	1	1	2	6	1	2	1	1	1	3
	PB17	3	1	1	1	1	1	2	1	2	5	2	2	2	2	6	4	1	1	3
	AA17	2	6	4	1	2	4	3	1	1	3	4	4	2	4	1	1	1	1	3
	MP17	1	1	2	1	1	2	1	1	1	2	1	1	1	1	3	2	1	3	6
3n-7m	JS37	2	1	1	1	1	3	1	1	1	1	1	1	1	1	2	1	1	1	1
	WT37	2	1	1	2	1	3	1	1	1	1	1	1	3	1	2	1	1	1	2
	CI37	3	1	1	1	1	3	1	1	1	1	1	4	1	1	2	2	3	1	1
	AE37	2	1	1	1	1	3	1	1	1	4	2	*8*	*15*	1	1	1	1	1	1
	MA37	2	1	1	1	1	2	1	1	1	1	1	3	1	1	2	1	1	1	1
	IG37	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
	AK37	2	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1	1	1	1
	OR37	2	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1	1	1	2
	DA37	3	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1
	KL37	2	1	1	1	1	1	1	1	1	1	1	2	3	2	2	1	1	2	3
	DGA37	2	2	1	1	2	2	1	1	1	1	1	1	1	1	2	1	1	1	1
	OA37	2	1	1	1	3	1	1	1	1	2	1	2	2	1	2	1	2	4	2
	CG37	4	1	1	1	1	1	1	2	3	1	1	2	1	1	2	1	1	1	1
	DGB37	4	1	1	1	1	3	1	1	1	1	1	1	1	2	2	1	1	1	1
	IP37	5	1	1	1	1	2	1	1	1	2	1	4	1	1	4	1	1	1	3
	JD37	1	1	1	1	1	2	1	1	1	1	1	1	1	1	3	2	4	1	3
	TO37	3	1	1	1	1	3	1	1	1	1	2	4	2	2	5	1	2	1	1
	NF37	2	1	1	1	1	2	1	1	1	1	1	1	2	1	2	1	1	1	1
1n-3m	*M*	2.83	1.22	1.06	1.11	1.22	2.00	1.28	1.06	1.11	1.39	1.28	2.28	1.67	2.06					
1n-5m	*M*	2.50	1.22	1.22	1.11	2.33	1.94	1.17	1.22	1.17	1.72	1.44	2.39	2.00	1.28	2.44	1.22	1.06	1.28	3.06
3n-5m	*M*	2.72	1.06	1.06	1.06	1.22	2.33	1.22	1.11	1.17	1.33	1.28	1.72	1.39	1.50	2.06	1.22	1.11	1.06	2.44
1n-7m	*M*	2.11	1.33	1.28	1.06	1.44	2.11	1.17	1.11	1.22	2.06	1.50	1.72	2.06	1.44	2.56	1.33	1.17	1.17	2.28
3n-7m	*M*	2.50	1.06	1.00	1.06	1.17	2.11	1.00	1.06	1.11	1.28	1.11	2.17	2.22	1.17	2.17	1.11	1.39	1.22	1.50
1n-3m	*SE*	0.29	0.10	0.06	0.08	0.10	0.26	0.23	0.06	0.08	0.23	0.14	0.64	0.61	0.46					
1n-5m	*SE*	0.31	0.13	0.17	0.08	0.95	0.24	0.09	0.15	0.12	0.28	0.17	0.64	0.37	0.11	0.36	0.17	0.06	0.11	0.49
3n-5m	*SE*	0.52	0.06	0.06	0.06	0.10	0.27	0.17	0.08	0.12	0.14	0.18	0.24	0.16	0.20	0.22	0.10	0.08	0.06	0.37
1n-7m	*SE*	0.18	0.28	0.18	0.06	0.20	0.23	0.12	0.11	0.13	0.32	0.23	0.21	0.39	0.18	0.42	0.20	0.09	0.12	0.31
3n-7m	*SE*	0.24	0.06	0.00	0.06	0.12	0.18	0.00	0.06	0.11	0.18	0.08	0.45	0.79	0.09	0.24	0.08	0.21	0.18	0.19
All	*M*	2.53	1.18	1.12	1.08	1.48	2.10	1.17	1.11	1.16	1.56	1.32	2.06	1.87	1.49	2.31	1.22	1.18	1.18	2.32
All	*SE*	0.14	0.07	0.05	0.03	0.20	0.10	0.06	0.04	0.05	0.11	0.07	0.21	0.22	0.11	0.14	0.06	0.05	0.05	0.17

Note. Data for subjects in each pretraining condition are shown in the successive horizontal segments. Group averages and standard errors are listed at the bottom. *x*MEMBER refers to the number of stimuli in each class established during pretraining. AB, BC, and XY refer to baseline relations that were directly trained in various portions of pretraining. BA, CB, AC, and CA were single emergent relations probes presented during the formation of the three-member classes during pretraining. 3MIX, 4MIX, and 5MIX were the mixed test blocks presented to confirm the

APPENDIX

(*Extended, Continued*)

5 member (% feedback)					6 member (% feedback)					7 member (% feedback)				
DE 100	75	25	0	5MIX 0	EF 100	75	25	0	6MIX 0	FG 100	75	25	0	7MIX 0
1	1	1	1	1	2	1	1	1	1	2	1	1	1	1
2	2	1	1	1	1	1	1	1	1	2	1	1	1	1
2	1	1	1	2	2	1	1	1	2	2	1	1	1	1
1	1	1	1	1	2	2	1	1	1	2	1	1	1	1
2	1	3	1	2	1	1	1	1	1	2	1	1	1	1
1	1	1	1	1	2	1	1	1	1	2	1	1	1	1
5	1	2	1	6	2	1	1	1	1	1	1	1	1	1
1	1	1	1	1	2	1	1	1	2	3	2	1	1	3
2	1	1	1	3	1	1	1	2	1	1	1	1	1	3
2	1	1	1	1	2	2	2	1	1	2	1	1	1	1
2	1	1	1	2	3	4	5	5	1	1	2	1	1	2
4	1	2	2	1	3	2	2	1	1	2	1	2	1	1
2	1	1	1	1	2	1	1	1	2	2	1	1	1	1
2	1	1	3	6	2	3	3	1	1	6	5	4	1	3
3	1	1	1	3	1	1	1	1	1	1	1	2	1	3
5	1	2	1	2	2	1	1	1	1	1	2	1	1	1
4	1	1	1	3	2	1	1	1	1	2	1	1	1	2
3	1	1	1	1	3	2	1	1	2	4	3	1	1	1
2	1	1	1	2	2	1	1	2	1	2	3	2	1	2
3	1	1	1	2	3	1	2	1	3	3	2	1	2	1
2	1	1	1	1	3	2	1	1	1	1	2	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	2
1	1	1	1	1	2	1	1	1	2	2	1	1	1	2
1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	3	1	1	1	2	1	1	1	2
1	1	1	1	1	3	1	1	1	1	1	1	1	1	3
3	1	1	1	2	2	1	1	2	4	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	2	1	2	1	2
2	1	1	2	2	2	2	1	1	1	2	1	1	2	1
3	1	1	2	1	1	1	1	1	2	1	1	1	1	1
1	1	1	1	1	2	1	1	1	4	1	1	1	2	1
4	1	1	1	4	1	1	2	1	2	11	2	1	3	*8*
7	7	4	2	5	3	1	1	1	1	1	1	1	1	
3	1	1	1	2	2	1	1	1	3	2	2	1	2	1
2	1	1	1	2	3	1	1	1	1	1	1	1	1	1
2.44	1.00	1.17	1.22	2.11										
1.78	1.06	1.00	1.00	1.39										
2.44	1.06	1.28	1.17	2.11	1.94	1.50	1.44	1.28	1.22	2.11	1.50	1.28	1.00	1.56
2.28	1.39	1.17	1.17	1.72	1.89	1.22	1.11	1.11	1.78	2.00	1.33	1.11	1.33	1.78
0.30	0.00	0.09	0.10	0.29										
0.22	0.06	0.00	0.00	0.14										
0.30	0.06	0.14	0.12	0.38	0.15	0.20	0.25	0.23	0.10	0.29	0.25	0.18	0.00	0.20
0.36	0.34	0.17	0.09	0.27	0.19	0.08	0.08	0.08	0.25	0.57	0.14	0.08	0.14	0.40
2.24	1.13	1.15	1.14	1.83	1.92	1.36	1.28	1.19	1.50	2.06	1.42	1.19	1.17	1.67
0.13	0.08	0.05	0.04	0.13	0.08	0.08	0.08	0.07	0.09	0.19	0.09	0.06	0.05	0.14

emergence of the three-member classes or to assess the expansion of class size to four members and five members, respectively. Each phase required a minimum presentation of one block. Subjects are identified by initials and two numbers. The numbers represent the number of nodes and size of the classes established in pretraining. The italic data points in the table indicate test block sequences that were longer than usual. Additional test blocks were presented because test performances at the end of the first set of test blocks were near criterion.