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DEVELOPMENT AND CROSSMODAL TRANSFER OF CONTEXTUAL CONTROL OF EMERGENT STIMULUS RELATIONS

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Six normally capable adults first learned three conditional relations in each of two prospective equivalence classes via match-to-sample training with figures as conditional (sample) and discriminative (comparison) stimuli. Then one trained conditional relation in each prospective class was brought under the control of contextual stimuli, two dictated nonsense syllables. Test performances indicated the emergence of untrained conditional relations, and therefore two equivalence classes, that were conditional on the contextual stimuli. These tests involved untrained combinations of contextual stimuli and stimuli in conditional relations, suggesting that the contextual stimuli functioned independently to control conditional relations rather than forming compound stimuli with samples and comparisons in training. Next, two novel figures were made equivalent to each of the original dictated contextual stimuli by match-to-sample training and testing. On subsequent tests, all subjects demonstrated transfer of conditional control of untrained conditional relations from the original auditory contextual stimuli to equivalent visual stimuli. These outcomes further supported the conclusion that the contextual stimuli exerted true conditional control over conditional relations in the equivalence classes and were not merely elements of compound stimuli.

Key words: stimulus equivalence, contextual control, conditional discrimination, second-order conditional discrimination, compound stimuli, five-term contingencies, match to sample, touchscreen response, adults

Functional analyses of complex types of behavior have been fostered in recent years by evolving models of stimulus control, in particular Sidman's stimulus equivalence analysis (Sidman, 1971; Sidman et al., 1982; Sidman & Tailby, 1982). As research on stimulus equivalence and related phenomena has proliferated, so have speculations about the usefulness of stimulus control methods for analyzing and producing types of behavior that are often labeled cognitive or linguistic. Sidman (1986) suggested that analysis of such complex behavior requires extending the unit of analysis beyond the familiar contingencies involving two terms (response and consequence), three terms (discriminative stimulus, response, and consequence), and four terms (conditional stimulus, discriminative stimulus, response, and consequence). Responding that is controlled reliably by four-term contingencies implies the development of conditional relations between conditional stimuli and discriminative stimuli (referred to as first-order conditional stimulus control). Conditional relations, including those that may give rise to stimulus equivalence, might themselves be under the conditional control of other stimuli (i.e., second-order conditional control). To examine this possibility, Sidman suggested, it may be necessary to add fifth terms—contextual stimuli—to the contingencies.

Conditional relations are often studied with match-to-sample methods in which a sample

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is the conditional stimulus and one of several comparisons is a discriminative stimulus on each trial. According to the Sidman analysis, conditional relations are equivalence relations if they are shown to have the reflexive, symmetric, and transitive properties that define a relation of equivalence in mathematics. These properties are inferred from certain match-to-sample performances that show that untrained conditional relations have emerged from trained conditional relations. When such performances are consistent with all three properties, the stimuli in a class are said to be related by equivalence (Sidman et al., 1982; Sidman & Tailby, 1982). This analysis may help explain several aspects of language acquisition. For example, the analysis specifies behavioral processes by which objects, pictures, and words can come to represent the same thing (e.g., Sidman, 1971; Sidman, Cresson, & Willson-Morris, 1974), or different words can come to have similar meanings (e.g., "funny," "humorous," "amusing"). In everyday language use, however, membership in equivalence classes is rarely fixed or static. Instead, many stimuli are members of one class in one context and participate in different classes in other contexts. That is, conditional relations within equivalence classes may be subject to conditional control by stimuli that comprise the context, which can change rapidly and frequently in a complex environment. To conduct functional analyses of stimulus equivalences in language, then, it is important to understand how second-order conditional stimulus control is acquired by contextual stimuli (Bush, Sidman, & de Rose, 1989; Sidman, 1986).

At least two general cases of contextual stimulus control seem to characterize linguistic performances. In one case, the speaker first learns verbal classes and then learns that membership in those classes can be modified by the context. For example, a speaker might learn initially that "fly" and certain other words (e.g., "bee," "ladybug," "mosquito") constitute an equivalence class. Similarly, he or she might learn that "fly" is related to a different set of words (e.g., "crawl," "swim," "run") in another equivalence class. Because the two classes have the word "fly" in common, they would probably merge into one class unless some other kind of stimulus control prevented that—for example, conditional control by the words "noun" and "verb" over conditional relations among stimuli, such as "fly" and "mosquito" versus "fly" and "run" (see Bush et al., 1989; Fucini, 1983; Green, 1987; Saunders, Saunders, Kirby, & Spradlin, 1988; Serna, 1987; Sidman, 1986; Sidman, Kirk, & Willson-Morris, 1985). Several laboratory analogues of this kind of contextual stimulus control, imposed *after* equivalence classes have developed, have been reported (e.g., Kennedy & Laitinen, 1988; Serna, 1987; Wulfert & Hayes, 1988).

Alternatively, the context might determine the makeup of verbal classes from the outset. This can be illustrated as follows: Given the word "noun" as a contextual stimulus, a speaker might learn that the words "fly" and "bee" are related. Separately, and in the absence of any specific contextual stimulus, he or she might learn that "ladybug" and "fly" are related as are "mosquito" and "bee." In the context of the word "verb," the speaker may learn that the words "fly" and "crawl" are related. Without a specific context, he or she might also learn to relate "swim" to "fly" and "run" to "crawl." Would the emergence of different untrained relations among these stimuli (e.g., "fly" and "mosquito" vs. "fly" and "run"), and therefore the distinct structures of two equivalence classes, be determined by the contextual stimuli "noun" and "verb"? So far, only one published experiment (Bush et al., 1989, Experiment 2) has used procedures that could provide an answer to this question. We endeavored to replicate and extend that research in the experiment described here.

Three studies (Gatch & Osborne, 1989; Kennedy & Laitinen, 1988; Serna, 1987) showed that trained conditional relations were controlled by contextual stimuli, but untrained relations were not; the outcomes on tests for untrained relations would have been the same regardless of which contextual stimulus was present (see, e.g., Gatch & Osborne, 1989, p. 376). Wulfert and Hayes (1988) also brought trained conditional relations under contextual control, but only after untrained relations documenting equivalence classes had already emerged. Bush et al. (1989) are the only investigators who have applied the Sidman (1986) five-term contingency analysis to contextual control of emergent conditional relations within equivalence classes. In their Experiment 1, 3 adults learned conditional relations labeled AB

and BC in each of three prospective equivalence classes. Each conditional relation was made conditional on the presence of one of two tones that were nominal contextual stimuli. For example, when Stimulus A1 was the sample and a high tone was present, responses to Comparison B1 and not B2 or B3 were reinforced, but when a low tone was present with Sample A1, responses to B2 were reinforced. Performances indicative of the untrained AC, CA, BA, and CB conditional relations were tested in the presence of each tone. In the context of the high tone, the equivalence classes were expected to be A1B1C1, A2B2C2, and A3B3C3. In the context of the low tone, the predicted classes were A1B2C3, A2B3C1, and A3B1C2. The behavior of 2 of 3 subjects conformed to these predictions, but the authors noted a plausible alternative explanation for the outcomes: The tones may not have acquired stimulus control functions independently of the stimuli with which they were trained, but may have become elements of compound stimuli with the visual samples and comparisons.

> . . . instead of matching the visual sample A1 to visual comparison B1 under the control of the high tone and the same visual sample to visual comparison B2 under the control of the low tone, the subjects may have been matching one compound sample (A1 + high tone) to a compound comparison (B1 + high tone) and another compound sample (A1 + low tone) to a compound comparison (B2 + low tone). If these compounds had formed, the subjects could be said to have learned only first-order and not second-order conditional discriminations. (Bush et al., 1989, p. 38).

This problem has also existed in other studies of contextual control of equivalence class membership (Gatch & Osborne, 1989; Kennedy & Laitinen, 1988; Serna, 1987; Wulfert & Hayes, 1988): All stimuli that served as samples and comparisons were presented with the contextual stimuli during training, and there were no tests to verify that the contextual stimuli functioned independently of stimuli with which they were related directly. Subjects in those studies, like subjects in the Bush et al. (1989) experiment just described, may have learned only first-order conditional discriminations in which compound sample stimuli controlled responses to compound comparisons. For the remainder of this paper, we use the term *compound stimulus* to refer to a multielement stimulus (consisting of, e.g., a tone and a figure) that controls behavior only when all elements are present; neither element functions independently to control behavior. Conversely, if stimulus elements that are presented concurrently in some conditioning operation (such as a contextual stimulus and a sample or a comparison) are shown to control behavior when presented alone, then they do not constitute a compound stimulus (cf. Bush et al., 1989; Sidman, 1986).

Bush et al. (1989) reasoned that a valid test of true second-order conditional control would require a subject to respond to untrained combinations of contextual stimuli and stimuli in conditional relations. In Experiment 2, therefore, they taught another adult subject the AB conditional relations in three prospective classes under the conditional control of two tones as contextual stimuli. Conditional relations involving two additional stimuli per class (C and D) were also taught, but without a contextual stimulus; that is, the conditional relations CB and DA were trained in the absence of tones. This permitted tests for whether untrained conditional relations among the C and D stimuli and the A and B stimuli would be controlled by the tones, even though the C and D stimuli had never been presented with the tones. The subject's test performances eventually suggested an affirmative answer, but in debriefing after the tests, he produced verbal statements suggesting that he treated the tones and the A and B stimuli as compound stimuli and then related the C and D stimuli to those compounds by chaining. The authors concluded that with this single case they had not demonstrated unequivocally that the tones exerted direct second-order conditional control over emergent relations (Bush et al.).

To date, then, there has been no convincing demonstration of true second-order conditional control of untrained conditional relations. If several subjects responded to various untrained combinations of contextual stimuli and stimuli in conditional relations in a way that was consistent with conditional control by the contextual stimuli, then a strong case could be made that the contextual stimuli functioned independently of the specific stimuli with which they were related in training, rather than as elements of compounds with those stimuli. We designed the present experiment to allow a

Table 1
Description of subjects.

Subject	Gender	Age	Profession
1	Male	19	Physical education student (undergraduate)
2	Female	23	Computer operator
3	Female	27	Secretary
4	Female	23	Social work student (undergraduate)
5	Male	24	Linguistics student (undergraduate)
6	Female	27	Housewife

more definitive evaluation of true second-order conditional control of untrained conditional relations than previous research has provided. Similar to Experiment 2 of Bush et al. (1989), we trained 6 adults to respond to some conditional relations in two prospective equivalence classes conditionally on the presence of contextual stimuli and to respond to other conditional relations in the prospective classes without explicit contextual stimuli. This made it possible to test for contextual control of untrained conditional relations involving combinations of stimuli that had never been presented in training. Tests for transfer of contextual control of untrained conditional relations from the original contextual stimuli to equivalent stimuli (cf. Gatch & Osborne, 1989) permitted further evaluation of the extent to which the contextual stimuli functioned independently of specific samples and comparisons.

METHOD

Subjects

Six normally capable adults were recruited by public announcement and personal contact. Four females and 2 males agreed to participate for a remuneration of $20 each. The subjects are described in Table 1.

Sessions, Setting, and Apparatus

Subjects attended daily 1-hr sessions for approximately 2 weeks. Sessions were conducted in a small sound-attenuating room containing two tables, two chairs, a videocamera, an intercom, and an Apple IIe® microcomputer and monitor equipped with a Personal Touch® touchscreen, Timemaster® clock, Echo II+® speech synthesizer, disk drives, and printer.

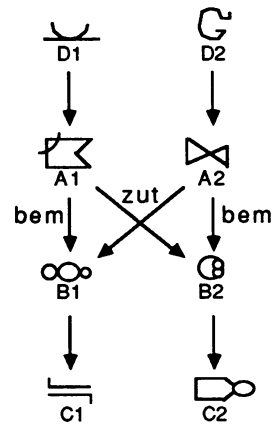
Specially designed software managed most experimental tasks, including stimulus presentations, timing, data collection, and data analysis. To start most sessions, the experimenter set up the computer system and then left the room to monitor the session from an adjacent room via videocamera. The experimenter remained in the room only when it was necessary to present contextual stimuli, because the software did not accommodate such presentations. At the end of each block of 16 trials, data were entered on a diskette and the experimenter had to reenter the room to initiate the next block of trials.

Stimulus Presentations

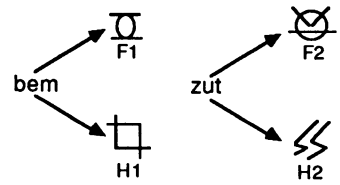
Visual stimuli were the abstract figures represented in Figure 1. Auditory stimuli were the two syllables "bem" and "zut."

Conditional relations. Samples and comparisons were presented by the computer. Each visual stimulus was drawn by the computer's high-resolution graphics and occupied an area about 2.7 cm by 3.3 cm on the computer screen. Auditory samples were presented by the computer's speech synthesizer. For convenient reference, each stimulus is designated by a letter and number (e.g., A1, B2); these codes were never seen by subjects. Conditional relations are labeled by the codes for sample and comparison stimuli that were to be related (e.g., A1B1).

When the sample was a visual stimulus, the trial began with its presentation in the center of the screen. A touch to the sample produced two visual comparisons, one on either side of the sample. The distance from the center of the sample to the center of either comparison was about 7.2 cm. The sample remained on the screen when the comparisons appeared. When the sample was auditory (Phase 4, below), touching a rectangle that appeared on the screen concurrently with sample presentation produced two comparisons, as described above. Auditory samples were presented once per trial. A response to a comparison ended a trial; the next trial began after a blank-screen intertrial interval of 2 s. There



PHASE 1:	TRAIN	A1B1, A2B2 B1C1, B2C2 D1A1, D2A2		
PHASE 2:	TRAIN	bem A1B1 A2B2	zut A1B2 A2B1	
PHASE 3:	TEST	bem	zut	No context
	EQUIV	C1D1 C2D2	C1D2 C2D1	
	SYM	B1A1 B2A2	B1A2 B2A1	
	SYM			A1D1, A2D2
	EQUIV	C1A1 C2A2	C1A2 C2A1	
	TRANS	D1C1 D2C2	D1C2 D2C1	
	TRANS	D1B1 D2B2	D1B2 D2B1	
	TRANS	A1C1 A2C2	A1C2 A2C1	
	EQUIV	B1D1 B2D2	B1D2 B2D1	
	SYM			C1B1, C2B2
	PREDICTED CLASSES:	bem A1B1C1D1 A2B2C2D2	zut A1B2C2D1 A2B1C1D2	



PHASE 4:	TRAIN	bemF1, zutF2 bemH1, zutH2	
PHASE 5:	TEST	F1H1, F2H2 H1F1, H2F2	
PHASE 6:	Test all contextually controlled relations shown in Phase 3, with F1 and H1 substituted for "bem" and F2 and H2 substituted for "zut"		

Fig. 1. Representation of experimental phases, including stimuli and relations trained and tested. The visual stimuli shown for Phases 1 and 2 were also presented in Phases 3 and 6. The visual stimuli shown for Phases 4 and 5 were also used in Phase 6. Arrows in diagrams point from samples to designated correct comparisons in trained conditional relations.

was no time limit on subjects' responses. Touches to areas of the screen where no stimuli appeared had no programmed effect.

Every block of 16 trials presented balanced conditional discriminations. For example, a block of trials designed to teach the AB conditional relations included eight of each of the following trial types, in which the sample is listed first and is followed by the correct and incorrect comparisons in parentheses: A1 (B1, B2), A2 (B2, B1). No other stimuli ever appeared in a block of AB trials. The order of trial types within each block of trials was unsystematic, with the restrictions that (a) the same sample was not presented on more than three consecutive trials, and (b) the correct comparison did not appear in the same position (left or right of the sample) on more than three consecutive trials. These rules were used to construct all blocks of trials for this experiment.

Contextually controlled conditional relations. In previous studies of contextual control of equivalence classes, nominal contextual stimuli were presented simultaneously with all conditional and discriminative stimuli throughout training trials. This may have promoted the development of control by compound stimuli rather than independent conditional control by the contextual stimuli (cf. Thomas & Schmidt, 1989). Therefore, we presented contextual stimuli only once briefly to start each trial, concurrently with sample onset but never with comparisons. In other studies, contextual stimulus control was not always established easily, perhaps in part because the nominal contextual stimuli were abstract figures (Gatch & Osborne, 1989; Kennedy & Laitinen, 1988; Serna, 1987), colors (Wulfert & Hayes, 1988), or tones (Bush et al., 1989). We speculated that, for our language-capable adult subjects, contextual control might be achieved more readily with word-like stimuli (dictated nonsense syllables).

Contextual stimuli were presented by the experimenter because of software limitations. For these conditions, the experimenter sat adjacent to the subject, facing the computer monitor and making no eye contact with the subject. Auditory contextual stimuli were dictated once by the experimenter concurrently with presentation of a visual sample and were not repeated within a trial. Visual contextual stimuli were presented on cards (7.7 cm by 7.7 cm) held at the top center of the computer monitor for 1 s while the sample was visible, and then removed. Subjects were not required to touch the contextual stimuli. Procedures for the remainder of the trial were the same as for conditional relations, described above.

Blocks of trials to train or test contextual control comprised balanced second-order conditional discrimination trials. For example, the block of 16 trials to establish contextual control of the AB conditional relations included four of each of the following trial types, denoted contextual stimulus–sample (correct comparison, incorrect comparison): "bem"–A1 (B1, B2); "zut"–A1 (B2, B1); "bem"–A2 (B2, B1); and "zut"–A2 (B1, B2). No other stimuli ever appeared in a block of trials to train contextually controlled AB conditional relations. All trial blocks involving contextual stimuli were constructed similarly.

Instructions

In most other studies of contextual control, subjects were given verbal or written instructions (Gatch & Osborne, 1989; Kennedy & Laitinen, 1988; Serna, 1987; Wulfert & Hayes, 1988). The extent to which instructions affect equivalence class development is not well understood, but it appears that the influence can be substantial (Green, Sigurdardottir, & Saunders, 1991; Sigurdardottir, Green, & Saunders, 1990). Our subjects, therefore, received only the minimal instructions necessary to initiate responding. To start the first session, a figure (the sample for the first trial) appeared on the computer screen. The subject was instructed to "touch it." When the comparisons appeared, subjects were instructed to "touch again." Further responses to the sample had no effect. When the subject touched a comparison, the experimenter left the room. No other instructions were provided to subjects. The experimenter responded to all questions from subjects with, "Sorry, I cannot tell you now but it will be explained to you when you have completed the sessions."

Training and Testing Contingencies

During initial training, subjects heard a computer-generated jingle when they touched the designated correct comparison. A buzzer sound followed responses to incorrect com-

parisons. The screen went blank when a subject touched two comparisons simultaneously, and an error was recorded. No instructions were provided about these consequences. We assumed that the jingle would function as a reinforcer and the buzzer as a punisher. No programmed consequences followed any responses on test trials, but all sessions in which testing was scheduled began with a reinforced review of previous training.

In all training conditions, subjects were required to achieve a standard criterion of 97% correct over two trial blocks (31/32 trials), at per-trial consequence probabilities of 1.0, then .20. They proceeded to the next phase only when they maintained criterion responding with .20 consequence probability. A similar criterion (at least 97% consistent with predicted relations over 48 trials) was applied to unreinforced test performances to determine whether untrained relations were demonstrated reliably.

Procedural Reliability

Because the experimenter (rather than the computer) presented the contextual stimuli, an observer recorded contextual stimulus presentations in Phases 2, 3, and 6 (described below). When the contextual stimuli were the dictated syllables, the observer simply wrote "bem" or "zut" on a data sheet next to a number representing each trial. For this purpose each visual contextual stimulus was assigned a single number, and the observer recorded the corresponding number on the data sheet after observing the contextual stimulus presented on each trial. Prior to each session, the first author prepared a list of the contextual stimuli to be presented on each trial. The observer did not see the list before or during a session. After the session, the observer's recordings were compared with the trial list to determine the reliability with which the experimenter carried out the procedures. A correct presentation was scored when the observer recorded that the experimenter presented the predesignated contextual stimulus for a particular trial; any discrepancy was recorded as incorrect. Procedural reliability was estimated by dividing the number of correct presentations by the total number of trials in a session and multiplying by 100%. Mean reliability throughout the experiment was 99.68% (range, 98.47% to 100%).

Experimental Plan

The experiment was conducted in six phases, summarized in Figure 1. In Phase 1, subjects were taught conditional relations labeled AB, BC, and DA among visual stimuli in two prospective equivalence classes, but no equivalence class tests were conducted. In Phase 2, the AB conditional relations were brought under the conditional control of two dictated contextual stimuli, "bem" and "zut." Phase 3 tested for untrained conditional relations (CD, BA, CA, DC, DB, AC, and BD) that would show the development of four equivalence classes, two under the control of each of the contextual stimuli. We expected performances on tests for these relations to be determined by the contextual stimuli because each of these relations could be derived only via the AB relations, which had been modified by the contextual stimuli in Phase 2 training (see diagram in Figure 1). Other Phase 3 tests assessed symmetry of the trained relations that were never brought under contextual control (DA and BC). The AD and CB relations were tested without contextual stimuli because they did not logically require the contextually controlled AB relations for their emergence. The equivalence classes that were expected to develop under the conditional control of the contextual stimuli were: "bem," A1B1C1D1 and A2B2C2D2; and "zut," A1B2C2D1 and A2B1C1D2. In Phase 4, conditional relations were established between new visual stimuli and the original dictated contextual stimuli. Tests for the development of equivalence classes including the dictated stimuli and the new visual stimuli were conducted during Phase 5. Phase 6 tested for transfer of contextual control from the dictated stimuli to the new visual stimuli. Details about each phase are presented in conjunction with the results, below.

RESULTS

All relations trained and tested in each phase are shown in Figure 1, in the order in which subjects were exposed to them.

Phase 1: Train Conditional Relations

The conditional relations A1B1, A2B2, B1C1, B2C2, D1A1, and D2A2 were taught in this phase. Two conditional relations—one

in each prospective class, such as A1B1 and A2B2—were presented in each 16-trial block, and each block was presented a minimum of twice in succession with per-trial consequence probabilities of 1.0, then .20. No testing followed this phase.

All subjects demonstrated criterion performance (97% correct over 32 consecutive trials with .20 consequence probability) on the first pair of relations (A1B1, A2B2) within a total of 5 to 10 blocks of trials. The other two pairs of relations (B1C1, B2C2 and D1A1, D2A2) were both mastered in an average of four training blocks per subject.

Phase 2: Train Contextual Control of AB Relations

In this phase, AB conditional relations in each class were brought under conditional control of auditory contextual stimuli. Subjects learned to respond to the A1B1 and A2B2 relations only when they were preceded by the dictated contextual stimulus "bem" and to the conditional relations A1B2 and A2B1 only in the presence of "zut" (see Figure 1). A block of 16 trials presented every possible combination of contextual stimulus, sample, and comparisons four times each. The trial block was presented at least twice with per-trial consequence probabilities of 1.0, then .20.

Criterion levels of responding (97% correct over 32 consecutive trials with .20 consequence probability) were demonstrated within a total of seven to eight blocks of trials by Subjects 1, 3, 4, and 6. Subject 2 required 77 blocks of trials before attaining criterion. Subject 5 was responding consistently by the 26th block, but most often responded to the comparison stimulus that was followed by the buzzer. His performance therefore did not exceed 6% correct, according to the experimenter-designated relations, but on 94% of trials he demonstrated these relations reliably: A1B1 and A2B2 in the presence of "zut" and A1B2 and A2B1 in the presence of "bem."

Phase 3: Test Untrained Relations

Fourteen conditional relations (CD, BA, CA, DC, DB, AC, and BD in both classes) were tested in the presence of both contextual stimuli. Separate 16-trial blocks each tested four relations (e.g., C1D1, C2D2, C1D2, C2D1; see Figure 1). Relations that involved the same pairs of stimuli as samples and comparisons (e.g., CD and DC) were tested in separate blocks to minimize the possibility that subjects might discriminate, even without reinforcement, that certain pairs of stimuli appeared together consistently while the third stimulus appearing with them changed across trials. For instance, on a trial with C1 as the sample the comparisons were D1 and D2, and a trial with D1 as the sample had C1 and C2 as comparisons. Repeated exposure to such trials, in which C1 and D1 were constant while the other comparison appearing with them varied, could produce comparison selections that seemed to be consistent with stimulus equivalence but were in fact false positives (Harrison & Green, 1990). The tests for contextual control of the CD relations were the most stringent, because those relations could emerge only if all of the originally trained relations (BC, DA, and contextually controlled AB) were both symmetric and transitive, and because the CD tests presented entirely untrained combinations of contextual stimuli, samples, and comparisons. The CA and BD tests also evaluated contextual control of equivalence, but required symmetry and transitivity in only two sets of trained relations each (BC and contextually controlled AB, DA and contextually controlled AB, respectively). The AC, DB, and DC relations could emerge under contextual control if the trained relations just mentioned were transitive. The BA tests evaluated contextual control of symmetry in the AB relations as modified by Phase 2 training. All of these untrained relations could emerge from combinations of trained relations that included the contextually controlled AB relations. Tests for AD and CB were merely tests for symmetry in the conditional relations DA and BC that were trained without contextual stimuli.

Every session in which testing was scheduled began with a review of Phase 1 and Phase 2 training in which the per-trial consequence probability was 1.0. Each test included 48 trials (one 16-trial block repeated three times) that evaluated two or four untrained relations on equal numbers of trials (see Figure 1). There were no programmed consequences following any comparison selections on tests. The test for the untrained CD relations (the most stringent test for equivalence) was administered first, followed by the other tests in the order listed in Figure 1. If criterion was not met on the CD test, it was readministered following

subsequent tests to see whether the emergence of other underlying relations facilitated CD performances. Other tests on which criterion was not attained were readministered in subsequent sessions. If criterion performance was still not demonstrated, relevant training reviews (Phases 1 and/or 2) were provided and tests for relations that could have supported the emergence of the below-criterion performances were readministered. Then the tests on which criterion had not been attained were repeated.

Results for this phase are shown in Figure 2. All subjects demonstrated the emergence of untrained relations, with varying amounts of review and testing. Subjects 3, 4, and 6 all had test performances that were consistent with second-order conditional control of all untrained relations from the outset, and maintained criterion performance on training reviews. Subject 1 showed clear conditional responding on all tests in the first test session but, on all except the BA test, the contextual stimuli controlled selection of the comparison that was not consistent with our predictions. The AD tests, which did not involve contextual stimuli, produced similar results. After the predicted CA relations emerged (Test 7), all remaining relations emerged except AC, which emerged after a third review. Trained relations were maintained at criterion levels during reviews. For Subject 2, the CD and DC relations also appeared to emerge reliably after a near-criterion performance on the CA test (Test 6; see Figure 2). The AC and CA relations seemed to emerge under contextual control the first time they were tested, as did the AD and CB relations that were not under contextual control, but BD and DB relations were not shown consistently despite repeated reviews and retesting. On Tests 9 through 33 (with reviews interspersed, and baseline performances maintained at criterion), most of Subject 2's performances suggested strong conditional control, but on many tests the control was opposite that predicted. Finally, beginning with Test 34, all remaining untrained relations were demonstrated reliably (see Figure 2).

During training, Subject 5 responded consistently to comparisons that were most likely to be followed by the buzzer instead of the jingle. Therefore, he learned the conditional relations A1B1 and A2B2 in the presence of "zut" and A1B2 and A2B1 in the presence of "bem" (i.e., the opposite of the other subjects). We predicted that he would respond to the experimenter-designated incorrect comparison stimuli during tests. Results confirmed this and therefore are presented in terms of what was predicted from his earlier learning. A near-criterion initial performance on the test for CD relations under contextual control was followed by below-criterion performances on tests for BA and AD (Tests 2 through 4; see Figure 2). The CA relations were demonstrated on only 11 of the first 16 test trials, but Subject 5 made only two more errors on all the remaining CA test trials (Test 5). Thereafter, all remaining untrained relations were demonstrated to criterion. Responses on baseline trials remained accurate (in that they produced the buzzer) on 96% of all review trials.

Phase 4: Train Conditional Relations with Contextual Stimuli

The purpose of this phase was to train conditional relations between the auditory stimulus "bem" as a sample and novel visual stimuli F1 and H1 as comparisons, and between the auditory sample "zut" and novel visual comparisons F2 and H2 (see Figure 1). A block of 16 trials presented four of each of the following trial types: "bem" (F1, F2), "zut" (F2, F1), "bem" (H1, H2), and "zut" (H2, H1). All subjects attained criterion within six to eight blocks of trials.

Phase 5: Test Equivalence

Tests for the emergence of two equivalence classes with "bem," F1, and H1 in one class and "zut," F2, and H2 in the other class were conducted. A 16-trial test block evaluated emergence of the conditional relations F1H1, F2H2, H1F1, and H2F2 (see Figure 1). All of those relations were demonstrated to criterion within two test blocks by all subjects.

Symmetry of auditory-visual conditional relations is difficult to test directly; instead, we asked subjects to name the F and H stimuli. On naming tests, the experimenter presented the visual stimuli (F1, H1, F2, H2) on cards (7.7 cm by 7.7 cm), one at a time, and asked "What is it?" Subjects were expected to produce the oral names "bem" and "zut" for the visual stimuli that had been related to those auditory stimuli in training. Each stimulus was presented eight times in unsystematic order in a test block that was presented twice. Subjects

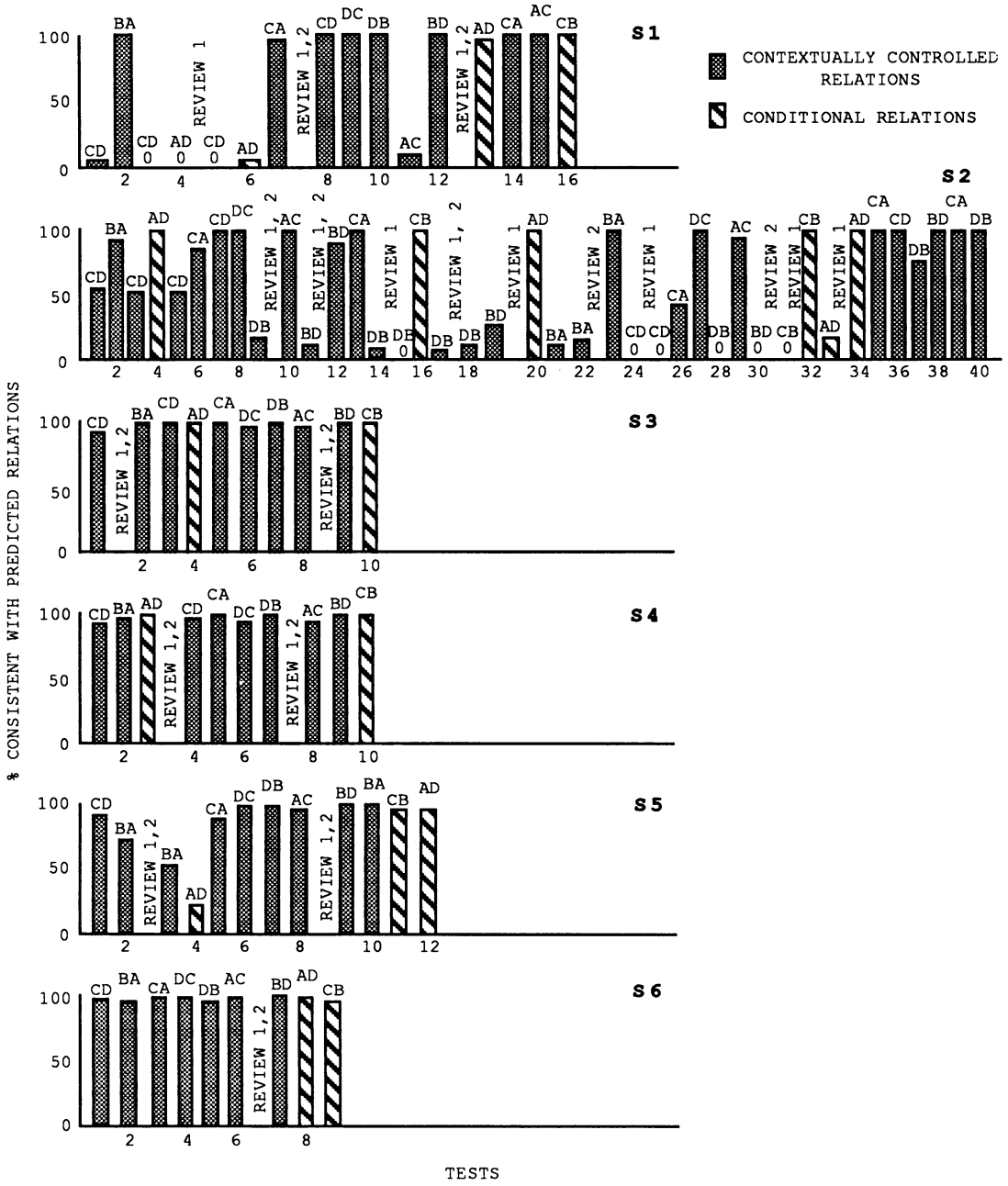


Fig. 2. Results of Phase 3 tests for untrained conditional relations with all subjects. Each bar represents performance on 48 test trials. Labels above the bars indicate the relations tested. Numbers on the *x* axes indicate consecutive tests. Reviews refer to preceding phases that were reviewed between tests (see Figure 1).

1, 2, and 4 called the visual stimuli F1 and H1 "bem" and F2 and H2 "zut" on oral naming test trials. Subject 3 described the physical features of each stimulus when first asked, "What is it?" She then gave the predicted responses when the question was changed to, "What is it called?" Subject 5 named F1 and H1 "zut" and F2 and H2 "bem," consistent with the relations he had demonstrated during Phase 4 training. Subject 6 assigned various

names to these visual stimuli; for example, she called F1 "hole," F2 "tiger," H1 "seesaw," and H2 "road."

Identity-matching tests with card and computer versions of stimuli F1, H1, F2, and H2 were conducted next to determine whether subjects would discriminate that the stimuli on cards were the same as the ones they had seen on the computer screen, because in the next phase these stimuli were presented on cards. These tests also evaluated whether the trained conditional relations among these stimuli were reflexive. On each trial, as soon as the sample appeared on the computer screen the card with the corresponding stimulus was placed over it and the subject was instructed once to "touch it." When he or she did so, the comparison stimuli appeared on the computer screen. The card sample remained in place. Responses to the comparison that was identical to the sample were scored correct. No programmed consequences followed any responses. Two 16-trial test blocks were administered. Performances on these identity matching tests were, for Subjects 1, 2, and 4, 100%; for Subject 3, 94%; for Subject 5, 69%; and for Subject 6, 88%. No remediation was provided following below-criterion performances on naming or identity-matching tests.

Phase 6: Test Transfer of Contextual Control

Tests in this phase evaluated whether the visual stimuli F1, F2, H1, and H2 controlled the conditional relations that had emerged originally under the control of "bem" and "zut": CD, BA, CA, DC, DB, AC, and BD (Phase 3; refer to Figure 1). Each block of 16 test trials presented equal numbers of four different contextual stimulus/sample/comparison combinations, in unsystematic order. For example, the CD test block included four of each of the following trial types, denoted contextual stimulus–sample (correct comparison, incorrect comparison): F1–C1 (D1, D2); F2–C1 (D2, D1); F1–C2 (D2, D1); F2–C2 (D1, D2). Tests for control of all untrained conditional relations by F1 and F2 were conducted first, followed by tests for control by H1 and H2. Each test session began with a review of Phase 4 training trials, with 1.0 consequence probability. Training Phases 1 and 2 were also reviewed when criterion was not met on any test, and the test was repeated. The following equivalence classes were expected to be conditional on the visual stimuli that were equivalent to "bem" and "zut," respectively: A1B1C1D1 and A2B2C2D2 in the presence of F1 and H1 and A1B2C2D1 and A2B1C1D2 in the presence of F2 and H2. In other words, this phase evaluated transfer of second-order conditional control from the original auditory contextual stimuli to each of the visual stimuli that were related to them by equivalence.

Results of these tests for Subjects 1, 4, and 5 are shown in Figure 3. These 3 subjects demonstrated virtually immediate and complete transfer of contextual control of the untrained conditional relations. Recall that Subject 5's responses were maintained by the buzzer rather than the jingle during training; as they were in previous test phases, his results here were consistent with predictions based on this earlier performance rather than on our original predictions.

Results for Subject 2 are shown in the upper portion of Figure 4. It appeared that the contextual stimuli F1 and F2 did not control the untrained CD relations on the first test but did so on the second test. After a training review, tests for control of the BA and CA relations by F1 and F2 yielded strong evidence of conditional control, but opposite to what was predicted (Tests 4 and 5, upper portion of Figure 4). After another review, F1 and F2 appeared to control the DC and DB relations as predicted (Tests 6 and 7, upper portion of Figure 4), but outcomes of Tests 8 through 16 were as predicted for only the AC, BA, and CA relations. After a review of Phases 1, 2, and 4 following Test 16, results of tests for control of the CD, DB, and BD relations by F1 and F2 were consistent with predictions. Next, tests for control by H1 and H2 confirmed transfer from the original contextual stimuli for all relations except BD and DB (Tests 26 and 28 through 31, upper portion of Figure 4). After three additional reviews, results of DB and BD tests with H1 and H2 were consistent with predictions.

Results for Subject 6 are presented in the lower portion of Figure 4. This subject responded to the predicted comparisons about 50% of the time on the first test for control of DC relations by F1 and F2. A series of potential remedial procedures with tests interspersed failed to produce predicted performances on tests for contextual control by F1 and F2. They included a retest for identity

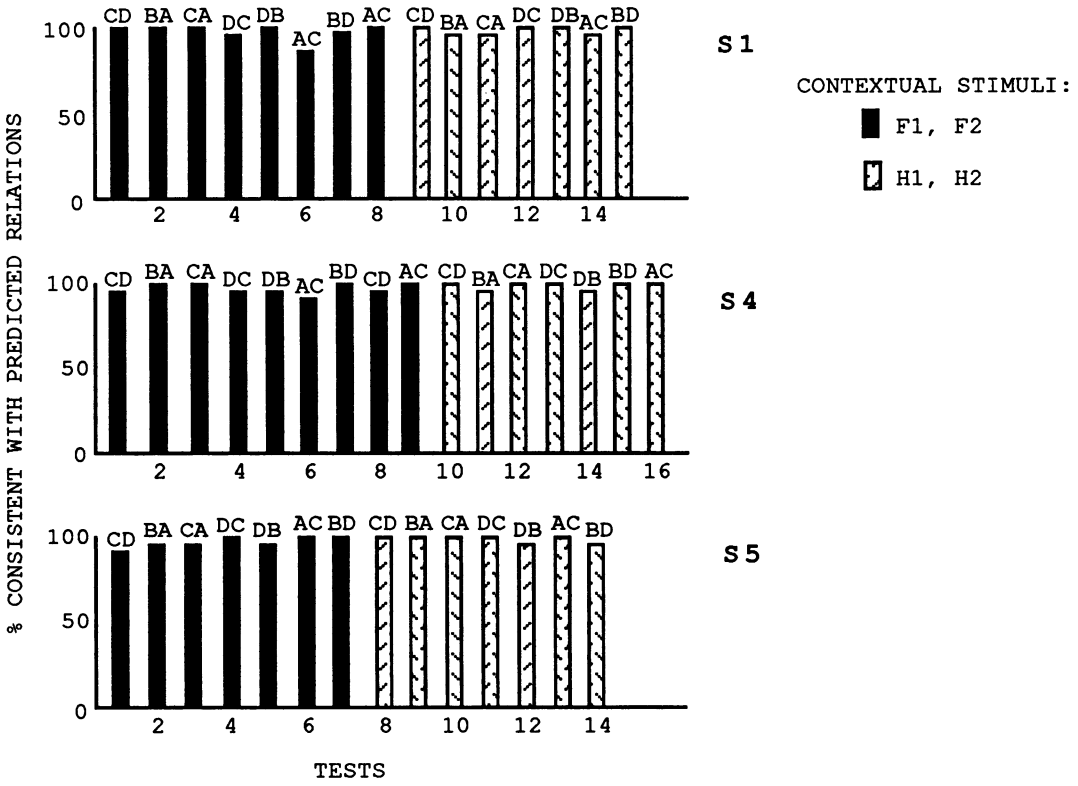


Fig. 3. Results of Phase 6 tests for transfer of control from auditory contextual stimuli to equivalent visual stimuli F1, F2 (solid bars) and H1, H2 (stippled bars) for Subjects 1, 4, and 5. Each bar represents performance on 48 test trials.

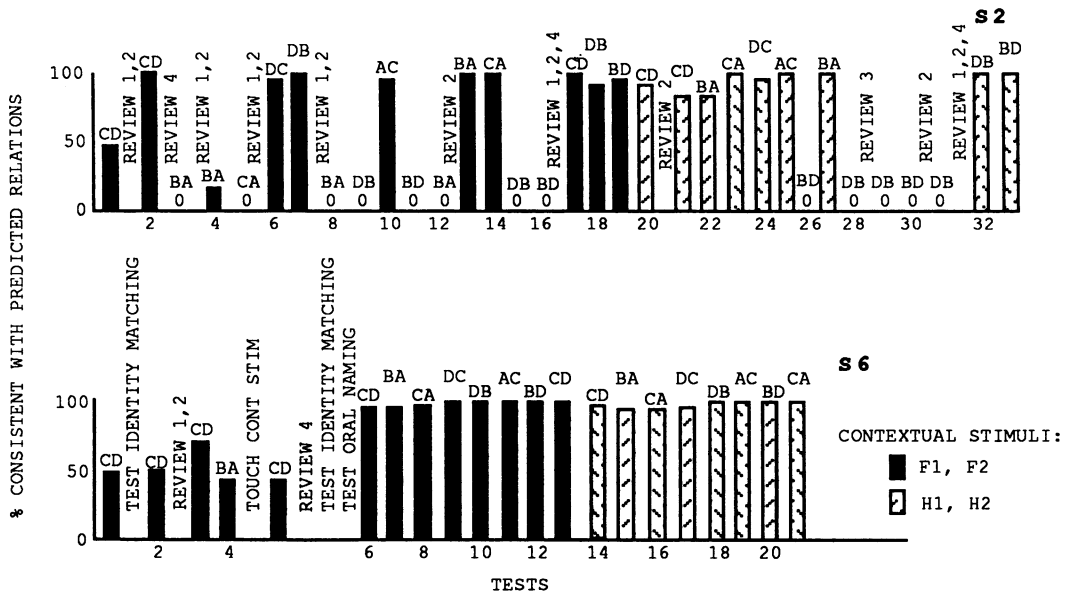


Fig. 4. Results of Phase 6 tests for transfer of control from auditory contextual stimuli to equivalent visual stimuli F1, F2 (solid bars) and H1, H2 (stippled bars) for Subjects 2 and 6. Each bar represents performance on 48 test trials.

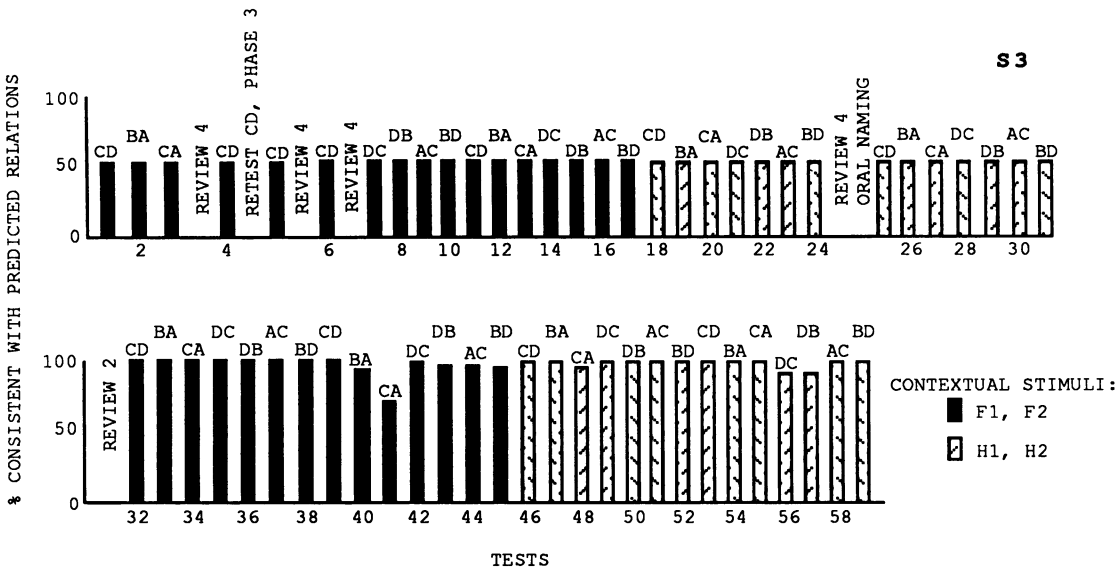


Fig. 5. Results of Phase 6 tests for transfer of control from auditory contextual stimuli to equivalent visual stimuli F1, F2 (solid bars) and H1, H2 (stippled bars) for Subject 3. Each bar represents performance on 48 test trials.

matching with card- and computer-presented stimuli, reviews of Phase 1 and 2 training, and instructions to touch the contextual stimulus before touching the sample on each trial. Prior to Test 6, this subject received a review of Phase 4 training, then an identity-matching set with stimuli on cards and the computer screen as before, except that the subject was asked to name the computer-presented sample to start each trial. Following her reply, a card with the corresponding stimulus was placed over the sample on the computer screen, and the subject was instructed to touch the identical comparison. During this test, Subject 6 produced the predicted oral names for the F and H stimuli for the first time, and identity-matching performance met criterion. The CD, BA, CA, DC, DB, AC, and BD relations then emerged under conditional control of the visual contextual stimuli F1 and F2. Thereafter, all tested relations were demonstrated under conditional control of H1 and H2 (Tests 14 through 21, lower portion of Figure 4).

Subject 3's results are shown in Figure 5. On initial tests for control of CD, BA, CA, DC, AC, and BD relations by F1 and F2 (Tests 1 through 17, upper portion of Figure 5), this subject responded as if the same contextual stimulus ("bem") were present on every trial (e.g., always responding to comparison D1 in the presence of sample C1, D2 in the presence of C2, etc.). Criterion performances were maintained on Phase 4 training reviews. A retest (after Test 4) showed that conditional control of the CD relations by the original dictated contextual stimuli remained perfect. Initial tests for control by H1 and H2 (Tests 18 through 24) yielded the same response pattern as the preceding tests. Then, after another Phase 4 review, oral naming of F1, H1, F2, and H2 was retested. The subject, who had failed to produce the predicted oral names on the first naming test, named F1 and H1 "bem" and F2 and H2 "zut" on this retest. Retests for control by contextual stimuli H1 and H2 produced the same pattern as before (Tests 27 through 31, upper portion of Figure 5). On a review of Phase 2 contextual control training ("bem," A1B1, A2B2 and "zut," A1B2, A2B1), performance was at criterion. Thereafter (Tests 32 through 59, Figure 5) Subject 3 demonstrated near-complete transfer of contextual control to the visual stimuli. She said that the solution had occurred to her "like a flashbulb" when she realized that the visual contextual stimuli "had to be there for some reason."

DISCUSSION

Results of the Phase 3 tests indicated that seven untrained conditional relations in each

of two equivalence classes emerged under the conditional control of dictated contextual stimuli (cf. Bush et al., 1989). Results of Phase 6 documented the transfer of conditional control of those relations to four novel visual stimuli that were related by equivalence to the original auditory contextual stimuli (cf. Gatch & Osborne, 1989). These findings were replicated across 6 adult subjects, and constitute strong evidence of second-order conditional control of untrained conditional relations. Subjects 1 and 2, however, did not demonstrate the emergence of conditional relations under second-order conditional control (Phase 3) until the preceding training had been reviewed several times and the tests were repeated. This also characterized the performances of Subjects 2, 3, and 6 on the Phase 6 tests for transfer of contextual control. Thus, the sequence and reiteration of training and testing phases also may have served to control these subjects' performances (cf. Sigurdardottir et al., 1990; Wulfert & Hayes, 1988).

In previous studies of contextual control of equivalence classes, first-order conditional control by contextual stimulus + sample compounds over selection of contextual stimulus + comparison compounds, rather than second-order conditional control by contextual stimuli, could not be ruled out. True second-order conditional control is inferred when contextual stimuli function independently of the stimuli with which they were presented in training (e.g., to control the emergence of specific untrained conditional relations). What evidence is there that our experiment demonstrated true second-order conditional control? First, the performances of all subjects showed that untrained conditional relations emerged under the control of "bem" and "zut." That is, the auditory contextual stimuli functioned independently of the specific visual samples and comparisons with which they had been related in training. Only four contextually controlled relations were trained, but the contextual stimuli controlled the emergence of 14 new conditional relations, 12 of which involved stimuli (C and D in both classes) that had never been presented with "bem" and "zut." Second, novel contextual stimuli controlled conditional relations involving stimuli with which they had never been presented. Two of the novel stimuli were members of an equivalence class with "bem," and two were members of an equivalence class with "zut." These novel visual stimuli functioned as contextual stimuli in the absence of the original conditions that produced contextual control. This transfer of function would not have occurred if subjects had learned merely to respond to compounds of auditory contextual stimuli and visual samples and comparisons.

Our training procedures differed from those used by Bush et al. (1989, Experiment 2) in a way that may have provided our subjects with an alternative basis for responding on tests. Bush et al. taught AB conditional relations in the presence of contextual stimuli and taught the other baseline conditional relations without contextual stimuli; we taught all conditional relations (including AB) without contextual stimuli first, and then imposed second-order control on the AB relations. Our procedures were based on research suggesting that second-order conditional control of conditional relations was achieved more readily when the lower-order relations were established first and then brought under second-order control than when second-order control was in effect from the outset (Kennedy & Laitinen, 1988; Serna, 1987). But our training might have established a response pattern that could be described by the following rule: In the presence of "bem," continue to touch the comparison that was reinforced with the sample previously; in the presence of "zut," touch the comparison that was not reinforced with this sample previously. If a relation of equivalence arose from the originally trained conditional relations, then the rule might be: In the presence of "bem," touch the comparison that is equivalent to the sample; in the presence of "zut," touch the comparison that is not equivalent to the sample. Responding consistent with this latter rule would produce the same outcomes as conditional control by contextual stimuli on our Phase 3 tests for untrained relations. This alternative explanation assumes that the trained relations had all the properties of equivalence before contextual control was imposed and before any tests for those properties were conducted (recall that we did not test for equivalence immediately after teaching the conditional relations). We cannot, however, dismiss the possibility that the contextual stimuli functioned as suggested by this alternative interpretation. Tests for the AD and CB relations (see Figure 1) in the

presence of the contextual stimuli, which we did not conduct, might have separated the two kinds of control. One such test trial would present "zut" as the contextual stimulus with A1 as the sample and D1 and D2 as comparisons. If "zut" controlled responding to nonequivalent comparisons, the predicted response on this trial would be to D2. But if "zut" controlled the structure of an equivalence class comprising A1B2C2D1, as we hypothesized, then the predicted response on this trial would be to D1. We did not conduct such tests because we did not expect the AD and CB relations to be sensitive to contextual changes, but the foregoing discussion should provoke some interesting and important experiments.

One weakness in our experiment was the use of two-choice match-to-sample tasks, which are prone to artifacts that can produce false positives on tests for emergent relations. Application of stringent criteria (at least 95% correct) for concluding that trained and emergent relations have developed is recommended when two-choice procedures are used (Sidman, 1987). Because our subjects were required to meet a criterion of 97% correct on each carefully balanced set of trials, and in many cases a large number of predicted untrained relations emerged immediately on testing, we are reasonably confident that the outcomes were due to equivalence rather than to extraneous sources of stimulus control. When subjects did not show the predicted control, however, artifactual control certainly could not be ruled out.

Gatch and Osborne (1989) reported that only 1 of their 6 subjects had difficulty on tests for transfer of control from visual contextual stimuli to four new but equivalent visual stimuli. Our subjects' difficulty on analogous tests might be attributable to transfer across modalities. This inference was supported by the comments made by 2 subjects when first confronted with visual contextual stimuli. Subject 5 stated, "I could ignore these or take them as nonverbal signals," and Subject 6 asked if ". . . the pictures made a difference." Subject 3 said that she initially ignored the visual contextual stimuli because they were pictures and not sounds, so she responded as if only one of the auditory contextual stimuli was present until she reported that the solution came to her "like a flashbulb" and she treated the visual contextual stimuli as equivalent to "bem" and "zut."

This experiment demonstrates only that it is possible to design experimental procedures that produce true second-order conditional control of equivalence class membership with normally capable adults. Whether Sidman's (1986) five-term contingency analysis is useful for explaining contextual control of equivalence classes in natural language situations remains to be seen.

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