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A FUNCTIONAL-ANALYTIC MODEL OF ANALOGY: A RELATIONAL FRAME ANALYSIS

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The aim of this study was to explore a behavior-analytic model of analogical reasoning, defined as the discrimination of formal similarity via equivalence–equivalence responding. In Experiment 1, adult humans were trained and tested for the formation of four three-member equivalence relations: A1-B1-C1, A2-B2-C2, A3-B3-C3, and A4-B4-C4. The B and C stimuli were three-letter nonsense syllables, and the A stimulus was a colored shape. Subjects were then successfully tested for equivalence–equivalence responding (e.g., matching B1/C1 to B2/C2 rather than B3/C4). These tasks were designed such that equivalence–equivalence responding might allow subjects to discriminate a *physical* similarity between the relations involved. Some participants (color subjects) received only equivalence–equivalence tasks in which they might discriminate a color relation, whereas others (shape subjects) were given tasks in which they might discriminate a shape relation. A control group received both types of task. In a subsequent test for the discrimination of formal similarity, color subjects matched according to color, shape subjects matched according to shape, and the control group showed no consistent matching pattern. In Experiment 2, adult humans showed a transformation of the functions of a block-sorting task via this basic model of analogy. Empirical and conceptual issues related to these results are discussed.

Key words: analogy, relational frame theory, equivalence–equivalence, relations between relations, model, humans

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When human subjects are trained in a series of overlapping conditional discriminations using a matching-to-sample format, they will often demonstrate a number of untrained or derived responses in subsequent relevant tests. For example, if a subject is trained to choose a stimulus, B, given a second stimulus, A, and is also trained to choose a third stimulus, C, given A, he or she may, without further training, choose A given B and A given C (i.e., symmetrical responding) and choose C given B and B given C (i.e., combined symmetrical and transitive responding). When a subject produces such a response pattern, the stimuli involved are said to participate in a derived equivalence relation.

An array of empirical evidence now exists to link the phenomenon of derived equivalence responding to human language. For example, equivalence responding has been observed in a wide variety of verbally able human adults, but it has not yet been demonstrated unequivocally in verbally deficient humans or in nonhumans (see Barnes, McCullagh, & Keenan, 1990; Devany, Hayes, & Nelson, 1986; Dugdale & Lowe, 1990; Hayes, 1989; Sidman et al., 1982). Even in those cases in which equivalence has been demonstrated in subjects with severe learning disabilities, basic receptive language skills were present (Carr, Wilkinson, Blackman, & McIlvane, 2000). In addition, a wealth of empirical research on equivalence and other derived relations has shown their generativity (e.g., Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989; Saunders, Wachter, & Spradlin, 1988; Sidman & Tailby, 1982), their sensitivity to contextual control (e.g., Bush, Sidman, & de Rose, 1989; Roche, Barnes-Holmes, Smeets, Barnes-Holmes, & McGeady, 2000; Wulfert, Greenway, & Dougher, 1994), and the ease with which a transfer of functions across such relations may be demonstrated (Barnes & Keenan, 1993; Dougher & Markham, 1994; Hayes, Kohlenberg, & Hayes, 1991). These findings provide additional evidence for the parallel between equivalence relations and language, and indicate that equivalence and derived relations more generally can provide a useful model of language and other examples of complex human functioning (e.g.,

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Fields, Verhave, & Fath, 1984; Sidman, 1986; Wulfert et al., 1994).

One behavioral account that has attempted to explain the relationship between derived stimulus relations and human language is relational frame theory (Hayes, Barnes-Holmes, & Roche, 2001). This theory adopts the position that both phenomena are examples of the same behavioral process—arbitrarily applicable relational responding. Nonarbitrary forms of relational responding such as identity and oddity matching, for example, are well known in behavior analysis (e.g., Kastak & Schusterman, 1994). In both types of matching, the relational response is controlled in part by the nonarbitrary or formal relation between sample and comparison stimuli. Relational frame theory argues that relational responding may be brought under contextual control in which the relational responses are determined not by the formal properties of the related events but by additional contextual cues. For example, if X is specified as the same as Y, then a verbally competent human may state that ''Y is the same as X,'' based on the contextual control established by the verbal community for the word *same*. In this case, the relation of sameness established between X and Y is applied arbitrarily (by the verbal community) and is not determined by the physical relation between the stimuli. Arbitrarily applicable relational responses such as this define relational frames.

According to relational frame theory, responding in accordance with relational frames involves the following three properties: mutual entailment, combinatorial entailment, and the transformation of function (O'Hora, Roche, Barnes-Holmes, & Smeets, 2002). Mutual entailment occurs when, in a given context, if Stimulus A bears a relation to Stimulus B, then a further derived relation between B and A is mutually entailed. The type of relation depends on the type of trained relation between A and B (Hayes, 1994). For instance, if Stimulus A bears a *same as* relation to B, then the relation ''B is the same as A'' is entailed. Trained and mutually entailed relations are not, however, always identical. For instance, given ''A is more than B,'' a *less than* relation is mutually entailed between B and A (i.e., B is less than A). Combinatorial entailment is more complex. For example, if Stimulus A bears a relation to B and B bears a relation to C, then a relation between A and C can be derived. The nature of this derived relation depends on the nature of the trained relations. For example, if A is *more than* B and B is *more than* C, then a *more than* relation between A and C is derived by combinatorial entailment (i.e., A is more than C) and a *less than* relation is entailed between C and A (i.e., C is less than A). Transformation of function occurs when Stimulus A is related to Stimulus B, and A acquires a psychological function by virtue of this relation. In certain contexts, therefore, the stimulus functions of B will be transformed in accord with the A-B relation. For example, if A is more than B, and A actualizes fear, then B will actualize less fear than A.

Numerous studies have now provided empirical evidence to support the concept of multiple relational frames (Dymond & Barnes, 1994, 1995, 1996; Hayes, 1991; Roche & Barnes, 1996; Roche, Barnes, & Smeets, 1997; Roche et al., 2000). Relational frame theory also makes specific predictions about higher levels of relational complexity in which relational frames are related to relational frames, thereby giving rise to what are referred to as relational networks (Stewart, Barnes-Holmes, Hayes, & Lipkens, 2001; Stewart, Barnes-Holmes, Roche, & Smeets, 2001). Relational frame theory thus makes the specific prediction that derived relations may be related to other derived relations (an empirical example of such complex relational responding will be described below). More important in the context of the current research, relational frame theory argues that responding in accordance with relations between relations (hereafter referred to as relating relations) provides the theoretical basis for a functional analysis of the key behavioral properties of analogical reasoning (Barnes, Hegarty, & Smeets, 1997; Stewart, Barnes-Holmes, Roche, & Smeets, 2001).

Barnes et al. (1997) provided a behavioral analogue of analogical reasoning based on what they referred to as equivalence–equivalence responding (see also Lipkens, 1992). In their words:

> Consider . . . the following question based on the classic proportion scheme (A : B :: C : ?); ''apple is to orange as dog is to (i) sheep or

(ii) book?" If "apple" and "orange" participate in an equivalence relation in the context "fruit," and "dog" and "sheep" participate in an equivalence relation in the context "animals," then we would expect a person to pick "sheep" as the correct answer. In effect, the response would be in accordance with the derived equivalence relation between two already established separate equivalence relations. . . . We take the view that equivalence–equivalence responding is an example of a relational network as defined by relational frame theory (e.g., Barnes & Holmes, 1991; Barnes, 1994; Hayes, 1991, 1994). (p. 3)

The first experiment reported by Barnes et al. (1997) examined the relations between two separate equivalence relations and between two separate nonequivalence relations. Subjects were first trained and tested for the formation of four three-member equivalence relations (train AB and AC, and test BC and CB). After passing the equivalence test, subjects were tested to determine whether they would relate pairs of stimuli to other pairs of stimuli based on their participation in equivalence relations. In effect, subjects were presented with samples that contained two stimuli from one derived equivalence relation (e.g., B1/C1), and were given the opportunity to choose comparisons that contained two stimuli from a second, separate derived equivalence relation (e.g., B3/C3). All subjects successfully related equivalence relations to other separate equivalence relations and related nonequivalence relations (e.g., B1/B2) to other separate nonequivalence relations (e.g., B3/C4), in the absence of explicit reinforcement (this basic effect has recently been replicated with adults and 9- and 5-year-old children by Carpentier, Smeets, & Barnes-Holmes, in press). Experiment 2 employed the same procedures as Experiment 1, except that subjects were exposed to the equivalence–equivalence test before being exposed immediately, and without further training, to the standard equivalence test. Again, all subjects successfully related equivalence relations to other separate equivalence relations and related nonequivalence relations to other separate nonequivalence relations.

Although Barnes et al. (1997) provided one of the first empirical behavioral demonstrations of analogical reasoning, their theoretical model lacked one critical element involved in analogy as typically observed in the natural environment: formal or nonarbitrary relations. For illustrative purposes, consider the proportion scheme as outlined above: A : B :: C : D (i.e., A is to B as C is to D). In this highly abstract case, the actual Stimuli A, B, C, and D are completely arbitrary. However, in most cases of analogy, the arbitrary relations appear to be determined to some degree by the nonarbitrary relations that occur among some of the stimuli that participate in the network. Consider the example provided by Barnes et al.: Apple is to orange as dog is to sheep. In this example, the arbitrary equivalence relation between the words *apple* and *orange* is based, to some degree, on the nonarbitrary or physical relation of similarity between actual apples and actual oranges (i.e., both are small, spherical, edible, sweet, etc.). Similarly, the arbitrary equivalence relation between the words *dog* and *sheep* is based on the nonarbitrary relation of similarity between actual dogs and actual sheep (i.e., in general, they are four legged, mobile, hairy, etc.). Thus, the equivalence–equivalence or analogical relation between the equivalence relations *apple–orange* and *dog–sheep* may be traced back to the formal relations that are obtained between particular objects in the environment.

In a subsequent study, the Barnes et al. (1997) model and experimental preparation were extended by demonstrating equivalence–equivalence responding based on the abstraction of common formal properties (Stewart, Barnes-Holmes, Roche, & Smeets, 2001). College students were taught, using a delayed matching-to-sample procedure, to choose a particular nonsense syllable in the presence of each of four blue and four red geometric shapes. In a subsequent test, all 9 subjects demonstrated equivalence formation based on the abstraction of color by consistently matching nonsense syllables related to same-colored shapes to each other. Most subjects then showed equivalence–equivalence responding in which equivalence relations from the previous part of the experiment were related to other equivalence relations and nonequivalence relations were related to other nonequivalence relations.

Stewart, Barnes-Holmes, Roche, and Smeets (2001) thus provided an analysis of analogy incorporating nonarbitrary properties, which arguably are an essential aspect of this phenomenon. This theoretical model might also be extended to capture one of the core properties of analogical language more generally. For illustrative purposes, consider the analogy, ''an atom is like the solar system.'' In this example, the relation of the electrons to the nucleus is brought into an equivalence relation with the relation of the planets to the sun. In this case, a listener may relate a nucleus and its electrons in the same way that the listener relates the sun and the planets (i.e., hub to satellite). From this perspective, analogies are often used to help a listener discriminate a formal or nonarbitrary relation between two events (Stewart, Barnes-Holmes, Hayes, & Lipkens, 2001). In the experimental protocol used by Stewart et al. (2001), however, subjects were first required to discriminate the formal color or age relations to form the separate equivalence relations. Thus, when subjects subsequently formed the complete equivalence–equivalence relational network, it did not give rise to the discrimination of a new formal relation. The present study developed a model and experimental analogue to assess the emergence of this type of discrimination, which apparently characterizes analogical language. The protocol involved training and testing four three-member equivalence classes, testing for equivalence–equivalence responding using tests designed to establish particular patterns of nonarbitrary relational responding along the dimensions of shape and color, and then testing for discrimination of nonarbitrary similarity.

EXPERIMENT 1

METHOD

Subjects

Seven subjects (5 women and 2 men), ranging in age from 18 to 21 years, participated in this experiment. All 7 subjects were 1st-year psychology undergraduates. All subjects were recruited through personal contacts, and none had any prior experience in the areas of stimulus equivalence or relational frame theory. When the experiment was finished each subject was thanked and debriefed.

Apparatus and Materials

Each subject was seated at a table in a small experimental room containing an Apple Macintosh™ microcomputer (Performa 630) that displayed both colored stimuli and black characters on a white background. Stimulus presentation and the recording of responses were controlled by the computer, which was programmed using PsyScope, a graphical system for the design of psychology experiments (see Roche, Stewart, & Barnes-Holmes, 1999).

Computer-generated stimuli. The experimental stimuli included four colored shapes: a red square (A1), a red circle (A2), a blue square (A3), and a blue circle (A4). Each colored shape measured approximately 22.5 cm^2. Eight nonsense syllables were also used: zid (B1), cug (B2), kel (B3), jom (B4), dax (C1), rog (C2), tob (C3), and paf (C4). These nonsense syllables and the four colored shapes will be referred to using their respective alphanumeric labels. Subjects never saw these labels.

Matching to sample. The experiment involved conditional discrimination matching-to-sample (MTS) training, during which the colored shapes served as sample stimuli and the nonsense syllables served as comparisons. For MTS trials, the sample stimulus appeared in the center of the screen. Following a 1.5-s delay, four comparison stimuli appeared, one in each of the four corners of the screen. On each MTS trial the position of the comparison stimuli was varied randomly (i.e., the reinforced comparison could appear in any one of the four corners of the screen with equal probability).

Subjects chose a comparison by moving the cursor over the comparison with the mouse and then clicking the mouse button. The correct completion of an MTS training trial removed the stimulus display and produced the word ''correct'' in the center of the screen, accompanied simultaneously by the computer-generated spoken word ''correct.'' The incorrect completion of an MTS training trial removed the stimulus display and produced the word ''wrong'' in the center of the screen accompanied simultaneously by the computer-generated spoken word ''wrong.'' A 1-s intertrial interval, in which the screen cleared and remained blank, followed all programmed consequences. On all test trials the computer omitted all feedback messages and proceeded directly to the intertrial interval.

Procedure

All 7 subjects were trained and tested individually during sessions that lasted between 45 and 110 min each, depending on subject availability and preference. A subject who did not complete the experiment in one session was asked to return (usually the following day). The maximum number of sessions required to complete the experiment was two. To ensure that the previously established performances were still intact, at the beginning of the next session the subject was reexposed to those stages of the experiment that he or she had previously completed. On some occasions, therefore, a subject could successfully complete a particular stage in the experiment, but would be reexposed to that stage for a second time.

Training. Each subject was seated in front of the computer monitor and keyboard and wore a set of headphones through which he or she could receive aural feedback from the computer. The experimenter left the room and the subject then read the following instructions on the computer screen:

> In a moment some objects will appear on this screen. Your task is to first look at the object in the center of the screen and then at the objects in each of the four corners of the screen. You then have to choose one of the four ''corner situated'' objects and you can do this by placing the mouse cursor on top of it and then clicking the mouse button. So, if you want to choose the object in the upper left corner, click on the object in the upper left corner; if you want to choose the object in the upper right corner, click on the object in the upper right corner; if you want to choose the object in the lower left corner, click on the object in the lower left corner; and if you want to choose the object in the lower right corner, click on the object in the lower right corner. Click the mouse when you are ready to begin.

On each MTS trial one of four colored shapes (A1, A2, A3, or A4) was presented as a sample, followed 1.5-s later by four comparison stimuli. This training phase involved two conditional discriminations, each of which involved four trial types (see Figure 1, top). In both of these conditional discriminations, each of the four colored shapes served as the sample in one of the four tasks. In one of the conditional discriminations (A-B), the nonsense syllables B1, B2, B3, and B4 served as comparisons in all four trial types.

Trial types were presented in blocks of 56 trials. For the first 20 trials in a block, each of the four MTS trial types from the A-B conditional discrimination was presented in a quasirandom order (i.e., each trial type was presented five times). For the second 20 trials, each of the four MTS trial types from the A-C conditional discrimination was presented in a quasirandom order (again, each trial type was presented five times). For the final 16 trials in a block, each of the eight trial types (i.e., both A-B and A-C) was presented twice. These blocks of 56 trial types were presented to the subject until he or she produced at least six of seven correct responses on each of the eight trial types involved. At this point, the equivalence test occurred.

Equivalence test. Having received training in A-B and A-C relations, the subjects were now tested for B-C and C-B equivalence relations. Before this equivalence test, subjects were provided with instructions, on the computer screen, that were identical to those presented at the beginning of the conditional discrimination training.

Testing consisted of eight MTS trial types designed to test all of the experimenter-designated emergent relations. In four of the trial types, which tested for B-C relations, each of the four B stimuli served individually as the sample in the center of the screen, and all four of the C stimuli served as comparisons, one in each of the four corners of the screen. In the remaining four trial types, which tested for C-B relations, the format was similar except that the C stimuli served as samples and the B stimuli served as comparisons. Test trials were presented in blocks of 40. For the first 20 trials, each of the four B-C relations was tested five times in a quasirandom order, and for the remaining 20 trials, each of the four C-B relations was tested five times in a quasirandom order (see Figure 1). No feedback occurred on any trial.

Subjects were exposed to the equivalence test until they chose the same comparison at least four times out of every five exposures to a particular trial type, irrespective of whether their response patterns were consistent with

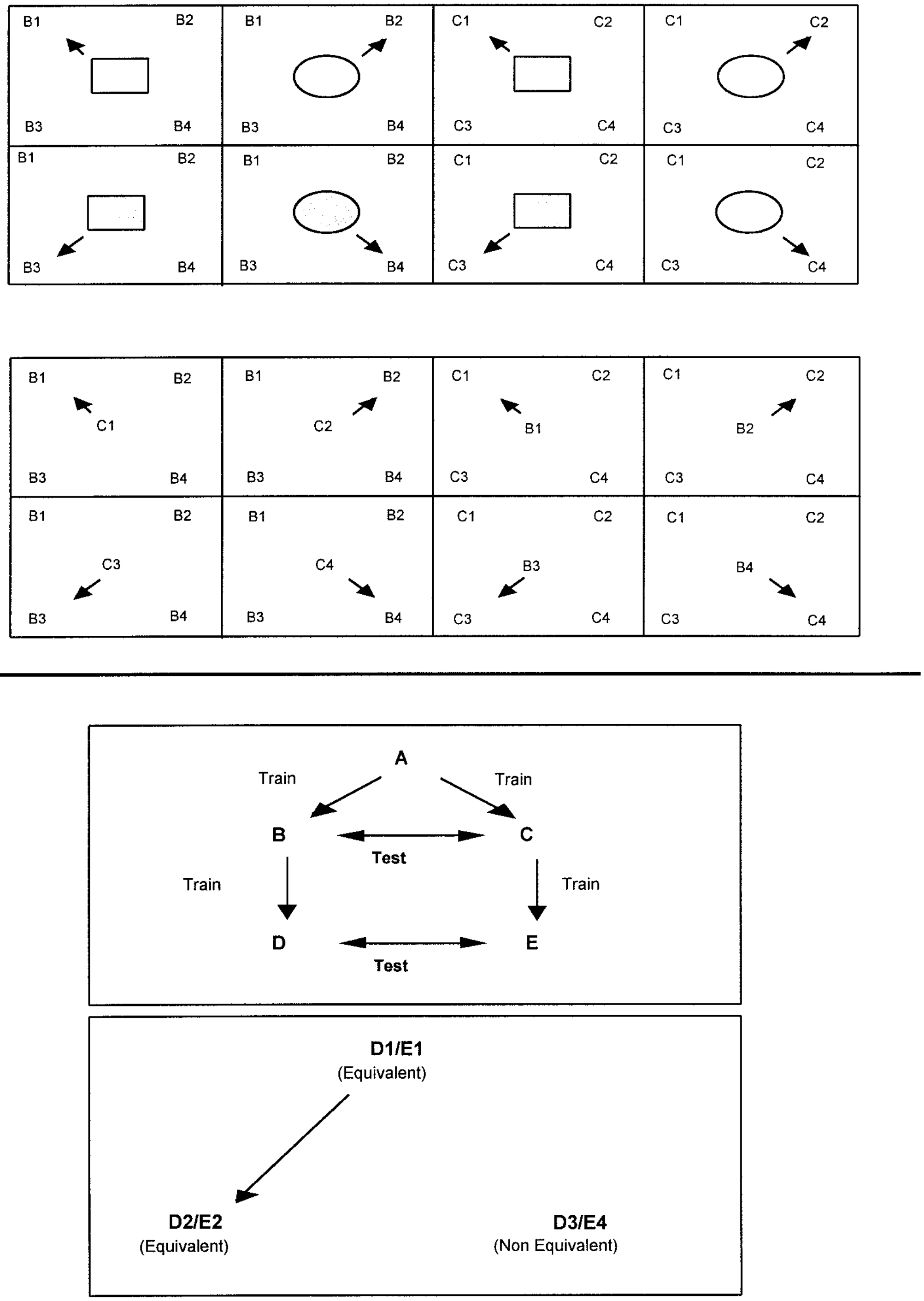

Fig. 1. Top: MTS equivalence training and testing. In the upper box are the eight trial types presented to subjects during MTS equivalence training. The four trial types on the left were for training A-B relations, and the four on the right were for training A-C relations. The eight trial types presented to subjects during MTS equivalence testing are in the lower box. The four trial types on the left were for testing B-C relations, and the four trial types on the right were for testing C-B relations. The experimenter-designated correct choice in each task is indicated by the arrow. Bottom: the equivalence relations that were trained and tested during Experiment 2. In the upper box is a schematic diagram showing the equivalence relations that were trained and tested during Experiment 2. In the lower box is an example of one of the DE-DE tasks presented to subjects during the equivalence–equivalence tests of Experiment 2.

the predicted relations. If a subject chose the correct comparison five times out of five across seven of the trial types but emitted only three correct responses on the eighth, he or she failed to meet the four-same-responses-out-of-five test criterion despite achieving 95% correct. Inconsistency after four exposures to testing defined terminal performance.

Equivalence–equivalence test. During this second test, subjects were presented with one pair of nonsense syllables as the sample stimulus and two other pairs of nonsense syllables as the comparison stimuli (see Figure 2). The syllable pair that served as the sample always included two nonsense syllables that participated in an experimenter-designated equivalence class (e.g., B1/C1). Of the two syllable pairs that served as comparison stimuli, one always included two experimenter-designated equivalent nonsense syllables (e.g., B2/C2), and the other always included two experimenter-designated nonequivalent nonsense syllables (e.g., B3/C4). It was predicted that subjects would show equivalence–equivalence responding by consistently matching the equivalent-pair comparisons to the equivalent-pair samples.

Before exposure to equivalence–equivalence tests, each subject was assigned to one of three groups: color, shape, or control. For color subjects, the equivalence–equivalence test consisted of four matching-to-sample trial types (see Figure 3, bottom), which may be represented as the following stimulus triads (the sample in each triad is first and the experimenter-designated correct comparison is in italics): B1/C1, *B2/C2*, B3/C4; B3/C3, *B4/C4*, B1/C2; B2/C2, *B1/C1*, B4/C3; B4/C4, *B3/C3*, B2/C1. These trial types were presented in a quasirandom order, with each occurring five times within a block of 20 trials. Given any one of these four particular equivalence–equivalence trial types, a subject who responded correctly could also discriminate a formal similarity in terms of color between the correctly chosen comparison and the sample stimulus. For example, matching B2/C2 to B1/C1 involved matching one equivalent pair to another pair, and each of these pairs contained elements that were related to other stimuli (i.e., A1 and A2) that were identical in color but not in shape (in this case, A1 was a red square and A2 was a red circle).

For shape subjects, the equivalence–equivalence test also consisted of four matching-to-sample trial types (see Figure 3, bottom), which may be represented as the following stimulus triads: B1/C1, *B3/C3*, B2/C4; B2/C2, *B4/C4*, B1/C3; B3/C3, *B1/C1*, B4/C2; B4/C4, *B2/C2*, B3/C1. These trial types were presented in a quasirandom order, with each occurring five times within a block of 20 trials. Given any one of these particular equivalence–equivalence trial types, a subject who responded correctly could also discriminate a formal similarity in terms of shape between the correctly chosen comparison and the sample stimulus. For example, matching B3/C3 to B1/C1 involved matching one equivalent pair to another pair, and each of these pairs contained elements that were related to other stimuli (i.e., A1 and A3) that were identical in shape but not in color (in this case, A1 was a red square and A3 was a blue square).

Finally, for control subjects, the equivalence–equivalence test consisted of all eight of the MTS trial types presented to the other two groups (i.e., all eight of the trial types displayed in Figure 3, bottom). These eight trial types were presented in a quasirandom order, with each occurring five times within a block of 40 trials. Subjects in this group who displayed consistently correct responding could thus discriminate formal similarities in terms of both shape and color, depending on the trial type presented.

Criterion. As in the equivalence tests, subjects in the equivalence–equivalence tests were required to reach a stability criterion of 80% consistent responding. This meant that subjects were exposed to their assigned regime of equivalence–equivalence testing until they chose the same comparison at least four times in every five exposures to a particular trial type, irrespective of whether their response patterns were consistent with the predicted relations. Inconsistency after four exposures to testing defined a subject's terminal performance.

Test for discrimination of formal similarity. Subjects who successfully completed the equivalence–equivalence test were then exposed to the test for formal similarity. The purpose of this test was to determine whether subjects who demonstrated equivalence–equivalence responding in the previous phase would now

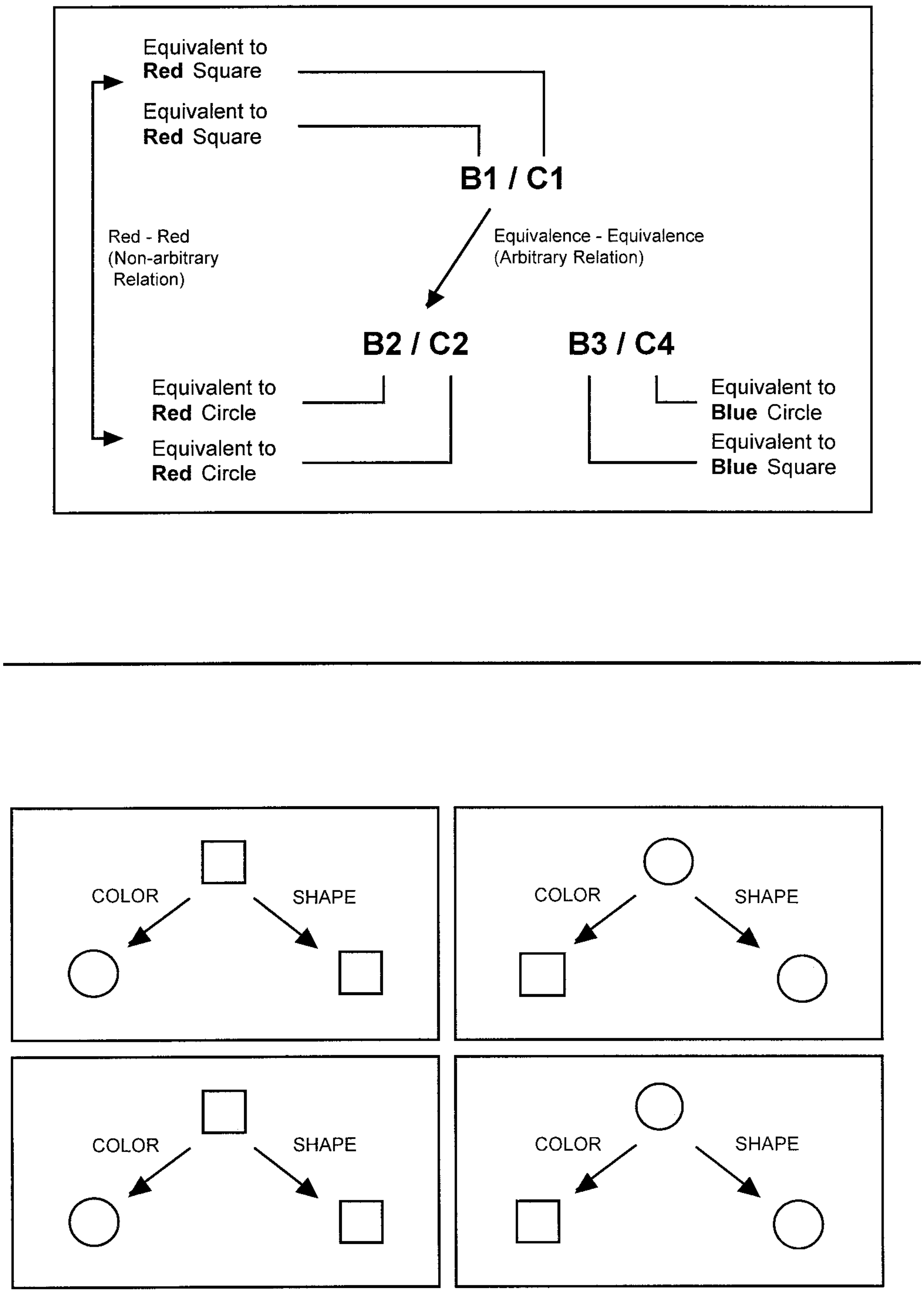

Fig. 2. Top: a schematic representation of the important relations, both arbitrary and nonarbitrary, involved in Stages 2 and 3 of the relational frame theory model of analogy (see text for details). Bottom: tasks received by subjects during the test for analogical responding. Subjects in the color group, who had been given equivalence–equivalence tests that facilitated the discrimination of similarity along the formal dimension of color, responded to these tasks by choosing on the basis of color. Subjects in the shape group, who had been given equivalence–equivalence tests that facilitated the discrimination of similarity along the formal dimension of shape, responded to these tasks by choosing on the basis of shape. The experimenter-designated correct choice in each task is indicated by the arrow.

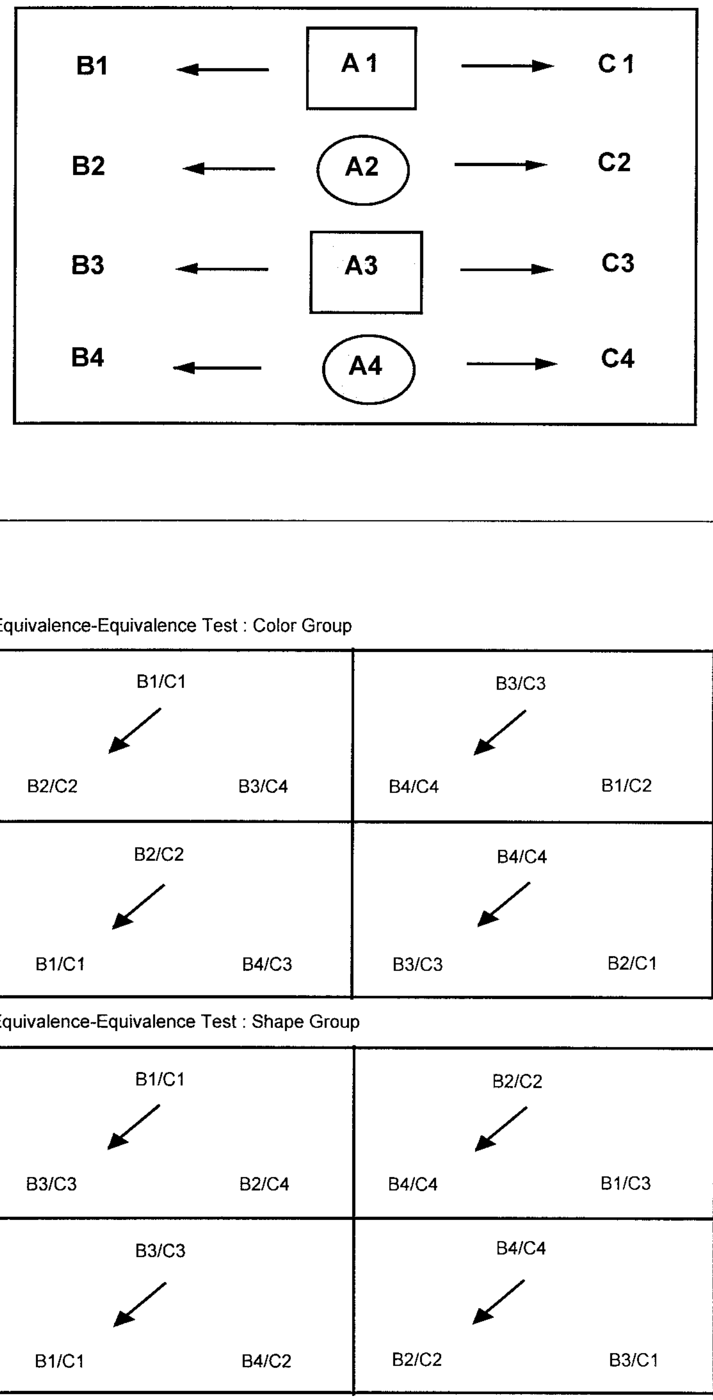

Fig. 3. Top: a schematic representation of Stage 1 of the RFT model of analogy, in which certain elements of the subject's relational network remain as yet unrelated. The diagram shows the four separate relational networks present in the subject's behavioral repertoire after initial (equivalence) training and testing. Note that eight of the 12 stimuli appearing in the initial phase of the experiment (i.e., B1, B2, B3, B4, C1, C2, C3, and C4) were nonsense syllables, whereas the remaining four stimuli (i.e., A1, A2, A3, and A4) were colored shapes. Bottom: tasks presented to subjects during the equivalence–equivalence testing phase of the experimental analogue of analogy (Experiment 1). For the 2 color group subjects, the tasks presented included only the four tasks in the uppermost set; for the 3 shape group subjects, the tasks presented included only the four tasks in the lowermost set; and for the 2 subjects in the control group, the tasks were a quasirandom mix of both color group and shape group tasks. The experimenter-designated correct choice in each task is indicated by the arrow.

Table 1

Numbers of trials required by each subject to complete conditional discrimination training, numbers of correct responses on equivalence and equivalence–equivalence tests, and numbers of responses produced by each subject in accord with color and shape, respectively.

		Test				
Subject	Train	Equiv	Equiv–equiv (color)	Equiv–equiv (shape)	Equiv–equiv (control)	Discrimination of formal similarity
Color						
1	168	34/40				
	56	40/40	20/20			20/20 color
2	224	38/40	19/20			20/20 color
Shape						
3	112	40/40		20/20		11/20 shape
	56	40/40		20/20		20/20 shape
4	168	40/40		20/20		20/20 shape
5	112	40/40		20/20		20/20 shape
Control						
6	168	23/40			40/40	15/20 color 5/20 shape
	56	40/40				
	56	40/40			40/40	7/20 color 13/20 shape
7	168	23/40				
	56	40/40			40/40	16/20 color 4/20 shape
	56	40/40			36/40	11/20 color 9/20 shape

successfully discriminate the predicted formal or nonarbitrary relations (i.e., either color or shape, depending on the particular equivalence–equivalence testing tasks that they had received). In this phase, subjects were presented with one colored shape as the sample stimulus and two other colored shapes as the comparisons. In each of the four different trial types, the sample stimulus was the same shape as, but a different color from, one of the two comparison stimuli, and the same color as, but a different shape from, the other comparison stimulus (see Figure 2, bottom). For example, in one trial type, the sample stimulus was a red square, and the two comparisons were a red circle and a blue square. The four trial types were presented five times each, in a quasirandom order, across a block of 20 trials. It was predicted that color subjects would show matching on the basis of color (in this example, they would be expected to choose the red circle in the presence of the red square), and that shape subjects would show matching on the basis of shape (in this example, they would be expected to choose the blue square in the presence of the red square). This prediction was based on the two different patterns of equivalence–equivalence responding, which should, according to the relational frame theory model of analogical reasoning, facilitate two different types of formal discrimination (i.e., color and shape). Consistent patterns of responding were not expected to occur for subjects who had received both types of equivalence–equivalence task (i.e., control subjects). Relational frame theory predicted this on the basis that exposure to both types of equivalence–equivalence test should fail to facilitate consistent responding in accord with either of the formal dimensions.

Results and Discussion

Table 1 presents (a) the number of trials required by each subject to complete the conditional discrimination training, (b) numbers of correct responses on the equivalence tests, (c) numbers of correct responses on the equivalence–equivalence tests, and (d) the number of responses produced by each subject in accord with color and shape, respectively.

For illustrative purposes, the data for Subject 1 will be described in detail. This subject required a total of 168 training trials before reaching the training criterion. She then failed the equivalence test on her first exposure (34 of 40 responses correct). After a further 56 training trials, she passed the equivalence test (100% correct). She was then exposed to the equivalence–equivalence test designed to facilitate the discrimination of a formal similarity in terms of color, and she responded correctly 100% of the time. Finally, when exposed to the test for the discrimination of formal similarity, she showed 100% matching on the basis of color.

Table 1 shows that all 7 subjects successfully completed the conditional discrimination training, equivalence testing, and equivalence–equivalence testing across several exposures. All of the color and shape subjects except one produced a consistent and correct performance on their first exposure to the test for the discrimination for formal similarity. Subject 3 (shape) showed random responding on his first exposure to this test. After being retrained and retested, however, he then matched with 100% accuracy on the basis of shape.

As predicted, both color subjects matched on the basis of color during the test for the discrimination of formal similarity (e.g., matching a red circle to a red square), whereas the 3 shape subjects matched on the basis of shape during this test (e.g., matching a red circle to a blue circle). No consistent pattern of responding emerged across control subjects, each of whom was tested twice. In conclusion, the data from this experiment provide support for the relational frame theory model of analogical reasoning in that each of the color and shape subjects showed equivalence–equivalence responding that led to a predicted discrimination of formal similarity.

EXPERIMENT 2

Experiment 2 was designed to extend Experiment 1 in three ways. First, it aimed to provide an experimental analogue of a transformation of functions, or change in behavior, via analogy. If a reader or listener understands the analogy "an atom is like the solar system," for example, then the analogy will probably change the functions of the word *atom* for that person. For example, the person might produce the words *hub* and *satellite* when asked to describe the structure of an atom. To develop procedures to examine such outcomes, it was important that the context for examining the transformation of functions was different from the test for the discrimination of formal similarity, but also that a discrimination along a formal dimension consistent with this test could still be demonstrated. To accomplish this, the transformation-of-function procedure involved responding to color and shape, but in a deliberately different context to that employed in the test for the discrimination of formal similarity.

The second extension of Experiment 1 involved increasing the number of stimuli that participated in the relational networks. If analogy is a relatively advanced form of verbal behavior, then the relational networks on which analogy is based may sometimes involve relatively extended and complex relations.

The third extension involved modifying the equivalence–equivalence test for 2 subjects. Previous subjects had been presented with a complex sample stimulus and two complex comparison stimuli on each trial. The complex sample stimulus and one of the complex comparisons were each composed of two equivalent elements, whereas the remaining comparison was composed of two nonequivalent elements. Thus far, we have argued that relating the former comparison to the sample constituted an equivalence–equivalence response. Matching these two complex stimuli, however, could be interpreted as simple equivalence responding in which all four stimuli are related to each other via the common property of color (or shape). Imagine, for example, that the sample is D1/E1 and the comparisons are D2/E2 and D3/E4. It is possible that subjects could choose D2/E2 not on the basis that the elements in both D1/E1 and D2/E2 are equivalent, but because D1, E1, D2, and E2 all participate in an equivalence class based on the abstraction of the nonarbitrary property of red. To provide evidence for equivalence–equivalence responding rather than simple equivalence responding, 2 subjects were provided with an equivalence–equivalence test involving three comparisons instead of the original two (see

Figure 4, top, for a schematic representation of one of the tasks). The third comparison included two stimuli that did not participate in the arbitrary equivalence relations but *were* equivalent on the basis of the common property of color (e.g., D2/E1). These subjects, therefore, could choose two of the three comparisons if they were responding according to a simple color-based equivalence relation. If, however, they were responding according to an equivalence–equivalence relation, only one comparison was the correct choice (see Figure 4, bottom, for a representation of each of the eight trial types).

Method

Subjects

Four men, 2 (Subjects 8 and 9) aged 19, 1 (Subject 10) aged 32, and the 4th (Subject 11) aged 40, participated in this experiment. Subjects 8 and 9 were nonpsychology undergraduates, Subject 10 was a full-time engineer, and Subject 11 was a laboratory technician. All were recruited through personal contacts, and none had any prior experience in the areas of stimulus equivalence or relational frame theory. The general conditions of participation in Experiment 1 (e.g., training and testing individually) applied.

Apparatus and Materials

The apparatus and materials were identical to those in Experiment 1 except for the addition of the following. A sorting task employed 16 wooden blocks that varied across the two dimensions of color and shape: Four blocks each were red, blue, yellow, and green, and for each color, one block was triangular, one was circular, one was a square, and the fourth was a rectangle. Four novel colored shapes (an orange diamond [A1], an orange cross [A2], a purple diamond [A3], and a purple cross [A4]) replaced the four colored shapes used in the first experiment. The stimuli also included eight additional nonsense syllables as follows: tez (D1), gol (E1), fot (D2), zem (E2), bup (D3), yim (E3), sar (D4), and lud (E4).

Procedure

The procedure for Experiment 2 was similar to that for Experiment 1, except for the following details.

Experimental sequence. The 4 subjects were trained and tested individually during 80- to 180-min sessions each. The maximum number of sessions required to complete the experiment was three.

Subjects were first exposed to a block-sorting task in which they could sort according to either shape or color. They were then exposed to a training and testing regimen similar to that in Experiment 1, in which the stimuli of the first equivalence–equivalence test depended on the pattern of block sorting exhibited during the baseline testing. All 4 subjects sorted according to shape and thus received the equivalence–equivalence color test. After receiving the color-biasing equivalence–equivalence test, it was predicted that subjects would match according to color in the subsequent (Stage 3) test. Upon completion of this training and testing regimen, the subjects were reexposed to the block-sorting task. It was predicted that the functions of this task would now be transformed such that subjects would sort the blocks on the basis of color. Upon completion of this second phase of block sorting, the subjects were retrained and retested. This time, however, subjects received the shape-biasing equivalence–equivalence test. Accordingly, it was predicted that subjects would now match according to shape in the Stage 3 test. Subjects were then reexposed to the block-sorting task, and it was predicted that they would now sort according to shape. Subjects were then reexposed to the whole sequence of training and testing twice more, once more involving the original equivalence–equivalence (color-biasing) test, and once more involving the second equivalence–equivalence (shape-biasing) test. Thus, the experiment involved three reversals.

Block sorting. For this experimental task, subjects were presented with the 16 wooden blocks described previously and a box containing four compartments. Before each individual block-sorting trial, subjects were read the following instructions by the experimenter; "Please sort these wooden blocks into different piles in any way you think might be correct, by dropping them into the compartments of this box. Call me when you are finished." The experimenter then left the room. When the subject had finished, the experimenter returned to the room and recorded the manner in which the blocks had been sorted. Sorting according to color was de-

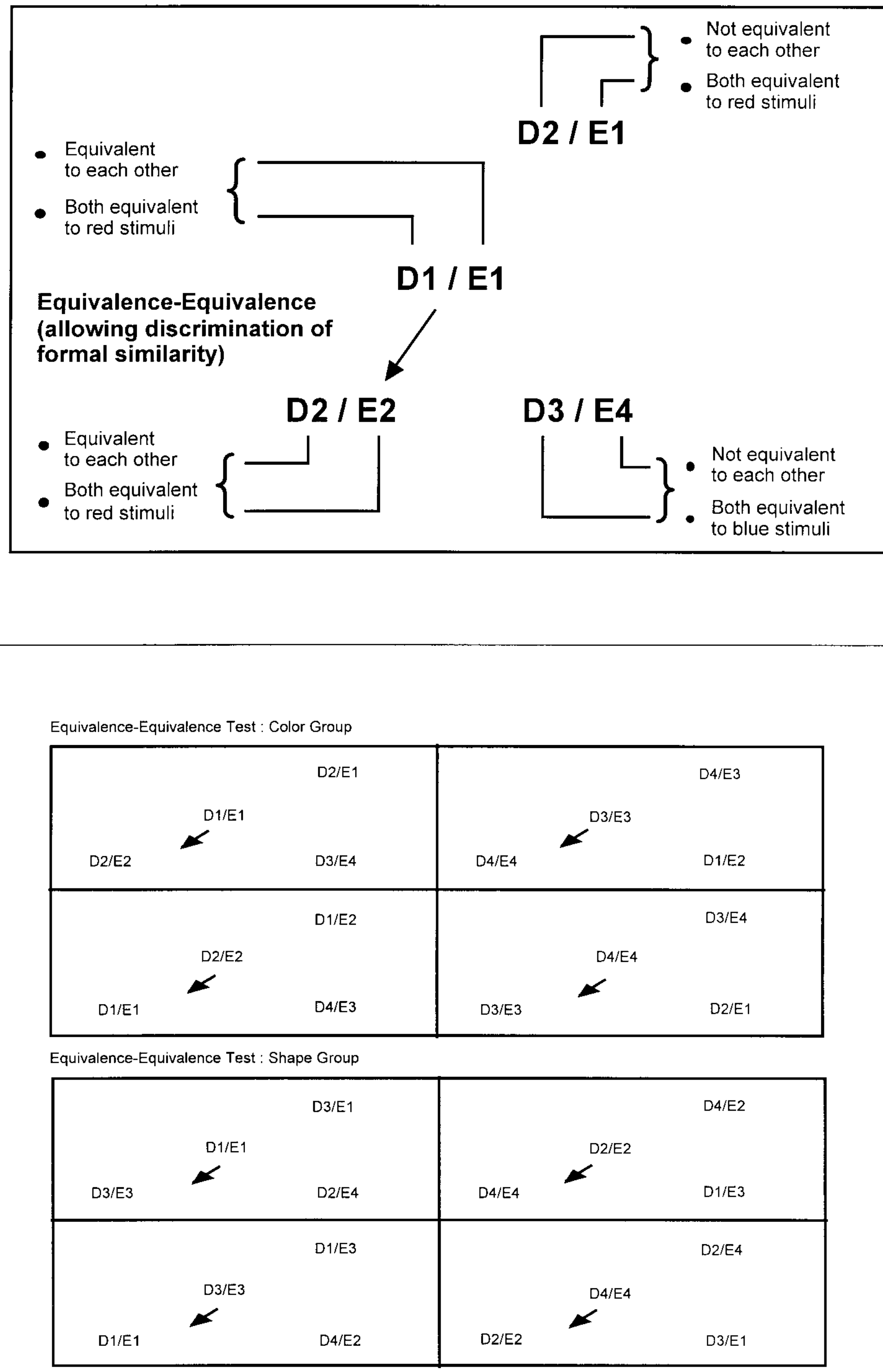

Fig. 4. Top: a schematic representation of the important relations, both arbitrary and nonarbitrary, involved in equivalence–equivalence testing for Subjects 10 and 11 (see text for details). Bottom: tasks received by Subjects 10 and 11 during the test for analogical responding in Experiment 2. The upper panel is a representation of equivalence–equivalence tests designed to facilitate the discrimination of similarity along the formal dimension of color. The lower panel is a representation of equivalence–equivalence tests designed to facilitate the discrimination of similarity along the formal dimension of shape. The experimenter-designated correct choice in each task is indicated by the arrow.

fined as placing the blocks into the four compartments with only one color in each compartment. Sorting according to shape was defined as placing the blocks into the four compartments with only one shape in each compartment. Sorting was designated ''other'' if the subject sorted according to neither of the two aforementioned patterns. The block-sorting procedure was conducted four times during this and all subsequent phases of block sorting, so that by the end of this phase, the data from four separate exposures had been recorded.

Training and testing. The training and testing regimen was similar to that in Experiment 1, except that equivalence training and testing involved two stages rather than one. The procedures for the first stage were identical to those in Experiment 1 (i.e., A-B and A-C training followed by B-C and C-B equivalence testing). The second stage, which commenced upon successful completion of the first, consisted of D-B and E-C training followed by D-E and E-D equivalence testing (Figure 1, bottom). The training was similar to that of Stage 1 except that, across the eight trial types, eight novel arbitrary stimuli (D1, D2, D3, D4, E1, E2, E3, and E4) were presented as samples, with the original eight arbitrary stimuli from Stage 1 presented as comparisons (see Figure 5, top). Subjects who successfully completed the training were then exposed to the equivalence testing. This test was similar to the equivalence testing of Stage 1, except that the novel D and E stimuli replaced the B and C stimuli employed previously (see Figure 5, top).

For Subjects 8 and 9, equivalence–equivalence testing was also similar to that employed in the first experiment, except that the novel D and E stimuli replaced the B and C stimuli employed previously (see Figure 4, top). For Subjects 10 and 11, however, one additional and important procedural difference occurred in the equivalence–equivalence test. During this test, one pair of nonsense syllables was presented in the center of the screen as the sample stimulus, and three other pairs of nonsense syllables were presented in the lower left, lower right, and upper right corners of the screen as the comparison stimuli (see Figure 4, top). The syllable pair that served as the sample always included two syllables that participated in an experimenter-designated equivalence class (e.g., D1/E1). Of the three syllable pairs that served as comparison stimuli, one (D2/E2) always included two experimenter-designated equivalent syllables that participated in the same formal relation (e.g., color) as the elements of the sample stimulus. A second (D2/E1) always included two nonequivalent syllables that participated in the same formal relation as the elements of the sample stimulus. The third (D3/E4) always included two nonequivalent syllables, neither of which participated in the same formal relation as the elements in the sample stimulus. It was predicted that subjects would show equivalence–equivalence responding by consistently matching the equivalent-pair comparison to the equivalent-pair sample. Such a performance would indicate that subjects were in fact showing equivalence–equivalence responding as opposed to simple equivalence responding based on the abstraction of the common property of color.

For Subjects 10 and 11, as for Subjects 8 and 9, there were two separate types of equivalence–equivalence test (see Figure 4, bottom): one during which the subject might discriminate a formal similarity based on color and one during which the subject might discriminate a formal similarity based on shape. In all other respects, details of these tests were identical to those completed by Subjects 8 and 9.

Results and Discussion

The results of Experiment 2 are presented in Table 2. For illustrative purposes, the data for Subject 8 will be described in detail. In all four initial exposures to the block test, this subject demonstrated sorting according to shape. He was then exposed to a total of 224 A-B/A-C training trials before demonstrating B-C/C-B equivalence relations (39 of 40 correct). He was next exposed to 168 D-B/E-C training trials but he failed the first test for D-E/E-D equivalence (8 of 40 correct). Following reexposure to A-B/A-C training (56 trials), B-C/C-B testing (40 of 40 correct), and D-B/E-C training (56 trials), this subject again failed the D-E/E-D equivalence test. After 24 hr, he was reexposed to A-B/A-C training (56 trials), B-C/C-B testing (40 of 40 correct), B-D/E-C training (56 trials), and D-E/E-D testing, which he passed for the first time

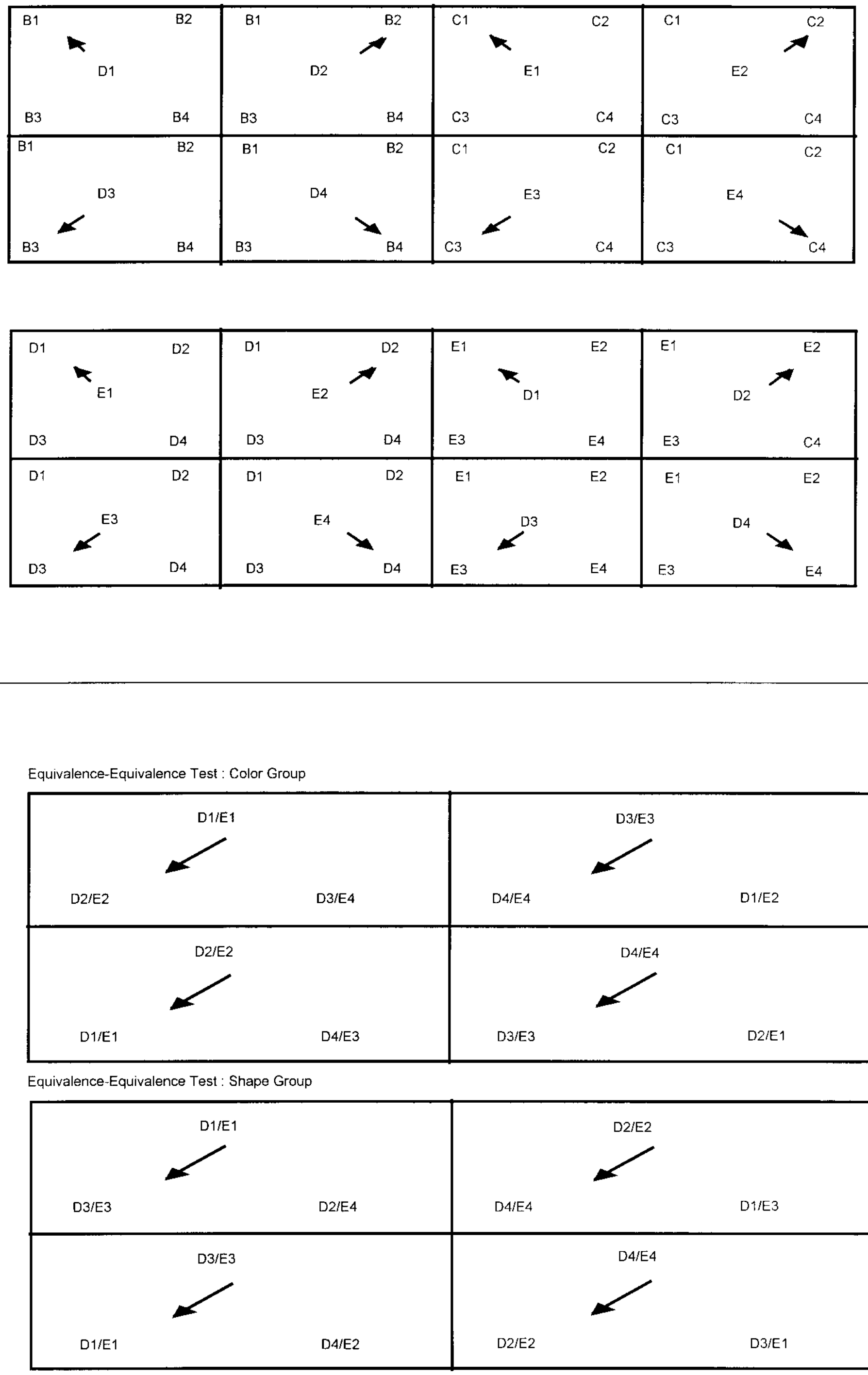

Fig. 5. Top: the eight trial types presented to subjects during the second phase of MTS equivalence training in Experiment 2. The four trial types on the left were for training D-B relations, and the four on the right were for training E-C relations. The eight trial types presented to subjects during the second phase of MTS equivalence training in Experiment 2 are shown in the lower panel. The four trial types on the left were for testing E-D relations, and the four trial types on the right were for testing D-E relations. The experimenter-designated correct choice in each task is indicated by the arrow. Bottom: tasks received by Subjects 8 and 9 during the test for analogical responding in Experiment 2. The upper panel represents equivalence–equivalence tests that facilitated the discrimination of similarity along the formal dimension of color. The lower panel represents equivalence–equivalence tests that facilitated the discrimination of similarity along the formal dimension of shape.

Table 2

Data for Subjects 8, 9, 10, and 11 in Experiment 2 including block-sorting patterns, number of trials required to complete conditional discrimination training, numbers of correct responses on equivalence and equivalence–equivalence tests, and numbers of responses produced in accord with color and shape (F = fail; P = pass). "Shape," "Color," and "Other" indicate that during the block-sorting test, the subject sorted the blocks based on shape, color, or neither, respectively.

				Test		Test			
Subject	Part	Block test (transfer of function)	Train A-B A-C	Equiv B-C C-B	Train D-B E-C	Equiv D-E E-D	Equiv–equiv (color)	Equiv–equiv (shape)	Discrimination of formal similarity
8	1	Shape							
		Shape							
		Shape							
		Shape	224	39/40 P	168	8/40 F			
			56	40/40 P	56	10/40 F			
			56[a]	40/40 P	56	39/40 P	20/20 P		2/20 color
			56		56		20/20 P		20/20 color
			56[a]	40/40 P	56	40/40 P	20/20 P		20/20 color
		Shape	56		56		20/20 P		20/20 color
		Shape	56		56		20/20 P		20/20 color
		Color	56		56		20/20 P		20/20 color
		Color							
	2		56		56			20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							
	3		56[a]	40/40 P	56	40/40 P	20/20 P		20/20 color
		Color							
		Color							
		Color							
		Color							
	4		56	40/40 P	56	40/40 P		20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							
9	1	Shape							
		Shape							
		Color							
		Shape	112	40/40 P	112	15/40 F			
			56	40/40 P	56	39/40 P			
			56[a]	40/40 P	56	40/40 P	20/20 P		20/20 color
		Color							
		Color							
		Color							
		Color							
	2		56[a]	40/40 P	56	40/40 P		20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							
	3		56		56		20/20 P		20/20 color
		Color							
		Color							
		Color							
		Color							
	4		56		56			20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							

Table 2
(*Continued*)

Subject	Part	Block test (transfer of function)	Train A-B A-C	Test: Equiv B-C C-B	Train D-B E-C	Test: Equiv D-E E-D	Test: Equiv–equiv (color)	Test: Equiv–equiv (shape)	Test: Discrimination of formal similarity
10	1	Shape							
		Shape							
		Other							
		Other	168	40/40 P	112	40/40 P	20/20 P		1/20 color
			56		56		20/20 P		1/20 color
			56		56		20/20 P		20/20 color
			56		56		20/20 P		20/20 color
		Shape							
		Color							
		Color							
		Color							
	2		56		56			20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							
	3		56		56		20/20 P		20/20 color
		Color							
		Color							
		Color							
		Color							
	4		56		56			20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							
11	1	Shape							
		Shape							
		Shape							
		Shape	112	38/40 P	112	2/40 F			
			56	40/40 P	56	3/40 F			
			56	40/40 P	56	9/40 F			
			56	40/40 P	56	40/40 P	20/20 P		1/20 color
			56		56		20/20 P		1/20 color
			56[a]	40/40 P	56	40/40 P	20/20 P		1/20 color
			56		56		20/20 P		20/20 color
		Color							
		Color							
		Color							
		Color							
	2		56		56			20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							
	3		56		56		20/20 P		20/20 color
		Color							
		Color							
		Color							
		Color							
	4		56		56			20/20 P	20/20 shape
		Shape							
		Shape							
		Shape							
		Shape							

[a] Start of a new training or testing session.

with 39 of 40 correct. He was then exposed to equivalence–equivalence testing designed to facilitate the matching of stimuli based on color (i.e., equivalence–equivalence color testing), which he passed with 100% correct.

On his subsequent and initial exposure to the Stage 3 test for the discrimination of formal similarity, the subject showed a low level (i.e., 2 of 20 responses) of matching on the basis of color. Consequently, he was reexposed to (a) A-B/A-C training (56 trials), (b) D-B/E-C training (56 trials), (c) equivalence–equivalence color testing (100% correct), and (d) the Stage 3 test, which now produced matching based on color (i.e., 20 of 20 color responding). Following a second 24-hr break, the subject was reexposed to the four training and testing stages listed above, and again produced 20 of 20 color matching responses. On reexposure to the block-sorting task, however, the subject sorted according to shape. He was, therefore, reexposed to the four training and testing stages listed above (which he completed successfully). He then sorted the blocks once again on the basis of shape, so he was reexposed to the entire sequence of training and testing once more. At this point, he sorted the blocks on the basis of color. In effect, the functions of the blocks had been transformed relative to the baseline performance.

In the next part of the experiment we attempted to reverse the patterns of behavior shown by the subject on the Stage 3 test and block-sorting test. During the first part, Subject 8 had received equivalence–equivalence tests designed to facilitate the matching of stimuli based on color, so during this second part he received equivalence–equivalence tests designed to facilitate the matching of stimuli based on shape. Consistent with the relational frame theory model of analogy, the subject now responded on the basis of shape during the Stage 3 test, and immediately showed a consistent pattern of sorting according to shape on the block-sorting test (see Table 2). Once again, the functions of the blocks had been transformed, but this time the transformation involved a reversal of the color-based sorting functions observed previously. The subject was then reexposed to a sequence of training and testing designed to facilitate the matching of stimuli based on color, and consequently showed responding on the basis of color during the Stage 3 test and sorting according to color on the block-sorting test (see Table 2). Finally, the subject was exposed for a second time to a sequence of training and testing designed to facilitate the matching of stimuli based on shape, and subsequently he showed responding on the basis of shape during the Stage 3 test and sorting according to shape on the block-sorting test (see Table 2).

Table 2 shows that similar results were obtained from the other 3 subjects in this experiment, except that they completed the experimental sequence in a fewer number of training and testing trials.

In addition, Subjects 10 and 11 passed tests for equivalence–equivalence that involved a third comparison. This third comparison included two stimuli that did not participate in the experimenter-designated equivalence relations, but instead were equivalent on the basis of the same common formal property as the elements of the sample. If Subjects 10 and 11 had been responding according to simple equivalence relations based on formal properties, then this third comparison might have been chosen as readily as the equivalence–equivalence comparison. The consistent equivalence–equivalence responding by both subjects, however, appears to rule out an interpretation based on simple similarity-based equivalence responding.

GENERAL DISCUSSION

The results of these experiments provide strong empirical support for the relational frame theory interpretation of analogy. Experiment 1 provided an experimental analogue of the three stages of that interpretation: (a) equivalence responding prior to the presentation of the analogy; (b) equivalence–equivalence responding in accord with the analogy; and (c) the discrimination of formal similarity via the equivalence–equivalence responding in the second stage. The main result of this experiment was that 5 subjects successfully discriminated similarity along certain formal dimensions via experimentally induced equivalence–equivalence responding. Experiment 2 provided an experimental analogue of each of the three stages of the interpretation of analogy listed above as well as the transformation of complex stimulus functions (i.e., the block-sorting task). In this experiment, 4 novel subjects discriminated a similarity along a particular formal dimension and then showed the predicted transformation of functions. They were then exposed to the three stages of the experimental analogue again, except that this time they discriminated an alternative formal dimension via analogy, and, once again, the appropriate transformation of functions was observed. In two further exposures to the experimental analogue and subsequent block-sorting task, subjects demonstrated two further reversals of the transformation-of-function effect. Furthermore, for 2 of the subjects in Experiment 2, an important control measure was successfully introduced, thus further bolstering support for the current relational frame theory interpretation and model.

In Experiment 1, all but 1 subject, during Stage 3 testing, immediately matched the stimuli according to the appropriate formal dimensions ''specified'' in the preceding equivalence–equivalence test. In Experiment 2, however, all 4 subjects required at least two exposures to Stage 3 before showing the predicted performance. One possible reason for this difference is that the trained and tested equivalence classes contained five members, as opposed to three in Experiment 1. Another possible reason for the difference is that subjects in Experiment 2 received the block-sorting task before the start of the protocol, which may have, in some undefined way, affected their stimulus matching in Stage 3. One way to control for this latter effect in future research might be to train and test subjects using the same protocol as in Experiment 2 but without the initial block-sorting task.

A related issue is that the same subjects in Experiment 2 who required more than one exposure to the Stage 3 test also required more than one exposure to the block-sorting test before producing the predicted performance. Nevertheless, once the predicted block-sorting performance emerged, subjects demonstrated multiple reversals (shifting back and forth from color to shape, in line with the immediately preceding training and testing procedures). Relational frame theory emphasizes the importance of exemplar training in human language and cognition (see Hayes et al., 2001). From this perspective, a subject's first successful demonstration of a transformation of block-sorting functions might be viewed as a first exemplar, which then facilitated the subsequent correct performances.

One possible weakness of the current experimental analogue is that it is based on extensive training and testing. Understanding an analogy in the context of a natural language, for example, often occurs quickly and with relative ease. Indeed, the utility of analogical language is *based* upon the notion that it allows the relatively rapid discrimination of formal similarity between diverse events. Thus the current protracted experimental demonstration may appear to lack ecological validity. Note, however, that analogy in the natural environment requires previously established relational networks, whereas in the present study, new relational networks had to be established ab initio prior to testing for analogical responding. Thus, the majority of the time that each subject spent in the experiment was devoted to training and testing the equivalence relations on which analogical responding was based. One way in which to expedite the process might be to use alternative experimental preparations such as the relational evaluation procedure (see Barnes-Holmes, Healy, & Hayes, 2000; Hayes & Barnes, 1997), which is currently being developed in our laboratory. The key aspect of this procedure is that it allows subjects to evaluate, or report on, the stimulus relations with which they are presented. Subjects are required to confirm or deny the applicability of particular stimulus relations to other sets of stimulus relations. We have found that large numbers of relational responses may be observed with little or no training using this procedure, once a number of appropriate contextual cues have been established (O'Hora, Barnes-Holmes, & Roche, 2001).

The present results support the suggestion that the abstraction of a formal stimulus dimension via equivalence–equivalence responding may provide a functional analysis of the behavioral processes involved in understanding analogical language. Indeed, defining analogy as equivalence–equivalence responding may promote the development of more precise tests of analogical reasoning than many of those reported in the cognitive or developmental literature. Many such tests do not rule out nonanalogical sources of control. For example, in one study (Alexander et al., 1989) 4- and 5-year-old children received a series of geometrical analogy problems of the type, "A is to B as C is to ?" For example, in one problem, children were asked, "Big red circle is to small blue circle as big red square is to ?" Options that could be selected for the missing D term were small blue square, small red square, small red triangle, and big yellow square. Note that the composition of the D options allowed the problem to be solved through simple color matching (i.e., select D option of same color as B). In another study (Goswami & Brown, 1990), 5- and 9-year-old children received multiple analogy tasks such as, "Bird is to nest as dog is to ?" with corresponding response options kennel, bone, cat, or other dog. All of the 9-year-olds and most of the 5-year-olds demonstrated criterion performance, which was set at 60% or more analogies correct. Although these findings could indicate that children as young as 5 years are competent in making analogies, this conclusion is challenged by the fact that the children also performed well when the same tasks were presented without the A and B terms (e.g., dog is to ?; kennel, bone, cat, or other dog). In both of these examples, the tasks used were formally similar to analogical reasoning tasks, but performances could be accounted for by nonanalogical matching. Perhaps future studies that focus on analogical reasoning in children might use the concepts and procedures employed in the present study to determine whether young children are capable of demonstrating analogical reasoning when it is defined in behavioral terms. If analogical responding is found to be absent, then the present account explicitly identifies means of establishing particular operants that may constitute the core elements of analogy.

There are additional complexities involved in analogical reasoning that the present investigation did not address directly. Specifically, analogical reasoning in natural settings often involves responding in accord with both equivalence and relations other than equivalence (see Hayes, 1991, for a detailed description of nonequivalence relations). Consider, for example, the following problem that one might find in a standardized test for analogical reasoning: "3 is to Earth as 9 is to (a) Neptune, (b) Pluto, (c) 12, or (d) Uranus." According to relational frame theory, a solution to this problem depends on each of the terms participating in complex relational networks. For example, the word *Earth* must participate in a relation of equivalence with "planet that orbits the sun," and in a relational frame of comparison that establishes it as having the third orbiting position relative to the sun in the solar system. Pluto must also participate in frames of coordination and comparison, except that in this case, the planet is the ninth from the sun. Presuming that these relational networks have already been established through exposure to the wider verbal community (e.g., science classes in school), the juxtaposition of planets with numbers in the analogy task may well function as a contextual cue for relating the equivalence relation between 3 and Earth with the equivalence relation between 9 and Pluto. Thus, although various types of analogical reasoning may require varying levels of relational complexity, the core behavioral process from the relational frame theory perspective remains the relating of relations.

Although the present study demonstrates a plausible model of analogical reasoning, it might be argued that subjects' performances were based to a significant extent on an already well-established history of analogical reasoning. In other words, the investigation simply allowed subjects to extend an already existing repertoire of analogical reasoning to the demonstration of relating relational frames in the behavioral laboratory. The term *analogical reasoning*, however, is not a technical term in behavior analysis, and thus it carries no explanatory value. In contrast, the concept of a relational frame has been defined in functional-analytic terms. It makes little sense, therefore, to explain subjects' performances using nonbehaviorally defined concepts such as analogical reasoning or other commonsense categories of human language when a technical, behavioral nomenclature is available. Although the subjects brought extensive, unknown preexperimental histories to the laboratory, the present findings are entirely consistent with the relational frame theory argument that analogical reasoning involves the technically defined behavioral process of the relating of relational frames. Further empirical research with both adults and children will be needed to determine whether this is in fact the case.

In the present report, we have presented an experimental exploration of analogy based on equivalence–equivalence responding, one in which a listener or reader responds in accordance with a relation of equivalence between two equivalence relations. However, according to relational frame theory, analogies may involve relations of equivalence between other types of relations. For example, the analogy, ''an atom is like the solar system'' could be described as an equivalence relation between two hierarchical relations (in this case, *satellite of*, in that electrons and planets are satellites of the nucleus and the sun, respectively; see Hayes et al., 2001). Ongoing research in our laboratories is utilizing novel methods to analyze analogical language in which nonequivalence relations participate in the underlying relational networks.

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