JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2006, **86,** 317–335 NUMBER 3 (NOVEMBER)

THE TRANSFORMATION OF CONSEQUENTIAL FUNCTIONS IN ACCORDANCE WITH THE RELATIONAL FRAMES OF MORE-THAN AND LESS-THAN

Robert Whelan,[1] Dermot Barnes-Holmes[2] and Simon Dymond[3]

UNIVERSITY COLLEGE DUBLIN[1]

NATIONAL UNIVERSITY OF IRELAND, MAYNOOTH,[2] AND

UNIVERSITY OF WALES, SWANSEA[3]

Across three experiments, the transformation of consequential functions in accordance with a seven-member relational network (A–B–C–D–E–F–G) was investigated. In this network, the relational rankings ranged from A, ranked the least, to G, ranked the most. In the first phase, contextual cues for more-than and less-than were established by training participants across multiple exemplars to select comparisons containing larger quantities in the presence of the former cue, and fewer quantities in the presence of the latter cue. Participants then were trained in six conditional discriminations (i.e., A<B, B<C, C<D, E>D, F>E, and G>F) with the contextual cues as samples and nonsense words as comparisons, and all possible derived relations were tested (e.g., B<F). In a subsequent phase, the D stimulus was paired with the delivery of points. Next, a test for a transformation of consequential functions was presented in either simultaneous discrimination tasks (Experiments 1 and 2) or a free-operant schedule task (Experiment 3), each of which employed members of the relational network as consequences. In all experiments, participants consistently emitted the response that produced the derived consequential stimulus that was ranked higher in the relational network, thus demonstrating a transformation of consequential functions. In Experiment 2, the baseline conditional discriminations were altered in a reversal design, and Experiment 3 examined generalization of the derived performance to a schedule-based task, with and without detailed instructions. Overall, the study demonstrated a transformation and generalization of consequential functions in accordance with the relational frames of More-than and Less-than, and bears relevance to the literature on transitive inference.

Key words: consequential functions, transformation of functions, relational frames of More-than/Less-than, reversal design, generalization, mouse click, human adults

---

A basic tenet of behavior analysis is that responses become more or less probable because of the consequences that they produce. Consequential stimuli that occur contingent on a behavior and increase response probability are termed reinforcers, and consequential stimuli that occur contingent on a behavior and decrease response probability are termed punishers. Studies of reinforcement and punishment often manipulate the reinforcing or punishing functions of stimuli through deprivation operations or by pairing a neutral stimulus with either a primary or conditioned reinforcer: these processes are relatively well understood (e.g., Hendry, 1969; Williams, 1994). Furthermore, according to Pavlov (1927) and Skinner (1953), language can mediate conditioning effects that maintain the relationship between behavior and the primary reinforcer. Skinner suggested that intervening conditioned reinforcers bridge the temporal gaps between responses and unconditioned reinforcers such as food, and ''among the conditioned reinforcers responsible for the strength of [this] behavior are certain verbal consequences…'' (p. 77). The processes involved in indirect, verbal consequences are not well understood and have been the focus of only three published laboratory studies (Greenway, Dougher, & Wulfert 1996; Hayes, Kohlenberg, & Hayes, 1991; Whelan & Barnes-Holmes, 2004). In these studies, *derived stimulus relations* and

---

Material from this article was presented at the annual meeting of the Association for Behavior Analysis, San Francisco, May 2003. The research was conducted as part of Robert Whelan's doctoral research program, under the supervision of Dermot Barnes-Holmes, and was funded by the Irish Research Council for the Humanities and the Social Sciences (Government of Ireland Scholarship). Sincere thanks to Eoghan Ryan for helpful comments on an earlier version of this manuscript.

Correspondence and requests for reprints should be sent to Robert Whelan, Department of Psychiatry and Mental Health Research, St. Vincent's University Hospital, Elm Park, Dublin 4, Ireland. E-mail: robert.whelan@ucd.ie

doi: 10.1901/jeab.2006.113-04

transformation of function seemed to play important roles.

The term ''derived stimulus relations'' refers to the emergence of relations that are not explicitly trained. For example, if a verbally able human participant is trained, in a matching-to-sample context, to match A to B and B to C, he or she will likely also match B to A and C to B (mutual entailment, which describes the relations between two stimuli), and A to C and C to A (combinatorial entailment, which refers to a derived relation in which two or more stimulus relations combine), without reinforcement (see Fields, Adams, Verhave, & Newman, 1990; Hayes, Barnes-Holmes, & Roche, 2001; Sidman, 1992). Furthermore, the functions of stimuli related through mutual and combinatorial entailment may be altered in accordance with the entailed relations. In this way, stimuli may acquire control over behavior in the absence of direct training, and this has been referred to as a ''transfer of functions'' (Dougher & Markham, 1994; Hayes, 1991). The transfer of functions through equivalence relations has been demonstrated with discriminative, self-discriminative, respondent-eliciting, extinction, sexual arousal, avoidance-evoking, and consequential functions in adults, children, and developmentally disabled individuals (for a review, see Dymond & Rehfeldt, 2000).

The transfer of consequential functions (both reinforcement and punishment) through three-member equivalence classes was demonstrated by Hayes et al. (1991), indicating that consequential functions given to one member of an equivalence class may transfer to other members of that class. The basic procedure was as follows. Using a computer-based sorting task, an arbitrary stimulus was established as a conditioned reinforcer (B1) and another stimulus as a conditioned punisher (B3). Next, participants were presented with a series of conditional discriminations (A–B then A–C) and subsequent testing for symmetry and equivalence responding. Having passed these tests, thus indicating the formation of equivalence classes, participants were exposed to the transfer of consequential functions test, which was similar to the sorting training task with the exception that participants were asked to sort novel nonsense syllables, and the C1 and C3 stimuli were used as feedback. Eight of 9 participants exposed to this procedure demonstrated the predicted transfer of consequential control from the B to the C stimuli. Subsequent experiments by Hayes et al. (1991) replicated and extended this basic effect.

Since Hayes et al.'s (1991) research, several studies have provided empirical evidence that it is possible for human participants to respond in accordance with relations other than equivalence, such as Same and Opposite (e.g., Dymond & Barnes, 1995, 1996; O'Hora, Roche, Barnes-Holmes, & Smeets, 2002; Steele & Hayes, 1991; see Hayes et al., 2001, for a review). Whelan and Barnes-Holmes (2004) extended Hayes et al.'s findings by examining a transformation[1] of consequential functions in accordance with these two relations (Same and Opposite). Whelan and Barnes-Holmes first established an arbitrary stimulus, B2, as a conditioned punisher through direct pairing with a loss of points. Following nonarbitrary relational training, participants were exposed to arbitrary relational training in order to establish a relational network in which A1 was the same as B1 and C1, and was opposite to B2 and C2. Subsequently, C2 (based on its Same relation with B2) functioned as a punisher, and C1 (based on its Opposite relation with B2) functioned as a reinforcer in a simultaneous discrimination task. Critically, the C1 stimulus acquired reinforcing functions, based on the derived relation of Opposite, although no such function had actually been established for any member of the relational network. It remains to be seen if a transformation of consequential functions can be demonstrated in accordance with other multiple stimulus relations such as More-than and Less-than.

An empirical demonstration of a transformation of functions in accordance with the relations of More-than and Less-than was first reported by Dymond and Barnes (1995). The first phase of their study consisted of nonarbitrary relational training (i.e., with stimuli that were related to each other along consistent physical dimensions) and testing to establish the three contextual cues of *same,*

[1] Because functions given to one stimulus do not always transfer to related stimuli, but rather seem to be transformed in accordance with the variety of relational patterns described above, the term *transformation* will be used hereafter as a generic replacement for the term *transfer* (see Dymond & Rehfeldt, 2000, for a detailed discussion).

more-than, and *less-than* (e.g., participants were trained to select a six-star comparison in the presence of a three-star sample, given the more-than cue). Participants then were trained in six arbitrarily applicable relations (i.e., with stimuli that were unrelated to each other along any consistent physical dimensions) using the three contextual cues. The three most important emergent relations were: C1 same as B1, C2 more than B1, and B2 less than B1. On a subsequent task involving a computer keyboard, participants were trained to choose B1 if they had emitted one spacebar-press only. All four participants exposed to this procedure subsequently demonstrated transformation of the one-response function consistent with this relational network: participants chose C1 following one response, C2 following two responses, and B2 following no responses. Recently, Reilly, Whelan, and Barnes-Holmes (2005), using a procedure similar to that employed by Dymond and Barnes (1995), trained and tested a five-member relational network that included both mutually and combinatorially entailed More-than and Less-than relations.

An analysis of the transformation of consequential functions in accordance with combinatorially entailed relations of more-than and less-than likely would have implications for an understanding of relational responding in the natural environment. To illustrate, consider a first-time visitor to the USA who is told that coins (a monetary reinforcer) range in value from a penny, to a nickel, to a dime, to a quarter, and finally, to a one-dollar coin. The visitor may then derive a number of combinatorially entailed relations among these coins in accordance with More-than and Less-than relational frames. The relative reinforcing functions of any pair of these coins would likely be affected in accordance with the specified and derived More-than and Less-than relations. For example, given a choice between a penny and a nickel, the visitor would choose the latter, but given the choice between a nickel and dollar, the visitor would choose the dollar. Note that the selection of one stimulus over another is enough to infer the relative values of the other members of the network (Potts, 1974; i.e., a nickel is less than a dime, which is less than quarter, which is less than a dollar. Therefore, a nickel is less than a dollar).

The present study sought to model the relational performance described above (specifically, the transformation of consequential functions in accordance with More-than and Less-than relational frames). Across three experiments, participants were exposed to a procedure designed to establish a relational network A–B–C–D–E–F–G in which the relational rankings ranged from A (putatively ranked the least) to G (putatively ranked the most), using a similar procedure to that described by Reilly et al. (2005). Subsequently, the middle-ranking stimulus was paired with the delivery of points, and finally a test for transformation of consequential functions was presented. In Experiment 1, participants were required to emit one of two responses, each of which produced a specific stimulus from the relational network. Consistently emitting a response that produced the consequential stimulus that was ranked higher in the relational network demonstrated the predicted transformation of consequential functions. In Experiment 2, the relative reinforcing values of the derived consequential stimuli were manipulated by altering the contingencies among the directly trained relations. In Experiment 3, generalization of the derived performances was tested in a schedule-based task, in full-instruction and minimal-instruction conditions.

EXPERIMENT 1

METHOD

Participants

Eight participants (aged 17–20; 5 male, 3 female) were university students recruited through personal contacts and notice-board advertisements and were paid €20 (approximately $25) contingent on successfully completing all phases of the experiment. None of the participants had knowledge of derived relations or transformation of function.

Apparatus and Setting

Participants were seated at a table in an experimental room containing an Apple Macintosh^{TM} iBook computer with a 12.1 in. display. Presentation of stimuli, participants' responses, and response times were controlled and recorded by the computer program *PsyScope* (Cohen, MacWhinney, Flatt, & Provost, 1993; see also Roche, Stewart, & Barnes-Holmes, 1999). All responses were made by moving and clicking a Macintosh™ optical mouse.

Procedure

All participants were trained and tested individually during sessions that lasted between 35 and 90 min each. If a participant did not complete the experiment in one session then he or she was asked to return on a subsequent day and was reexposed to the procedure from its beginning in a session that lasted between 30 and 60 min. The procedure consisted of: Phase 1, nonarbitrary relational training and testing; Phase 2, arbitrary relational training and testing; Phase 3, training stimulus-consequence relations; Phase 4, establishing consequential functions; and Phase 5, a simultaneous discrimination phase that tested for the transformation of consequential functions.

Phase 1: Nonarbitrary relational training and testing. The aim of this phase was to establish functions of more-than and less-than for two contextual cues that were to be used in the arbitrary relational training and testing phase (see Figure 1, upper panel). The instructions for this phase appeared on the computer screen, and were as follows.

> During this phase of the experiment you will be presented with shapes at the top of the screen and two sets of shapes at the bottom of the screen. You must learn to always choose the correct set of shapes at the bottom of the screen.
> Later, the two sets of shapes will be replaced by nonsense words. Once again you must learn to always choose the correct nonsense word. This can only be done through trial and error.
> The computer will tell you when you are finished.

There were 16 stimulus sets employed in this phase, each composed of images of different quantities of a particular object, here termed ''Few'' for the smallest amount, then ''Intermediate'' (note: not necessarily the midpoint of the smallest and greatest amounts), and ''Many'' for the greatest amount. For example, one stimulus set was composed of images of three, five, and nine dots. For the purposes of clarity, the following convention will be used to describe both the nonarbitrary and arbitrary relational training and testing probes: the contextual cue is given first in capitals, followed by the comparison stimuli in square brackets, with the reinforced stimulus given first.

Given that each set was composed of three stimuli, and that two contextual cues were employed, the following six conditional discriminations were generated: LESS-THAN [Few/Intermediate], LESS-THAN [Few/Many], LESS-THAN [Intermediate/Many], MORE-THAN [Intermediate/Few], MORE-THAN [Many/ Intermediate], and MORE-THAN [Many/Few]. The reader should note that the LESS-THAN and MORE-THAN cues controlled a relative, rather than an absolute, relational response. For example, in the presence of the MORE-THAN cue, the five-circle choice was correct when three circles was the other choice, but was incorrect when nine circles was the alternative. This training in relative, rather than absolute relational responding was incorporated into all of the stimulus sets, which were as follows (the quantities of the particular object that composed each set are in parentheses): apples (1, 4, 7), basketballs (1, 2, 8), beakers (1, 3, 6), toy blocks (1, 3, 7), boats (1, 2, 3), cherries (4, 6, 18), dots (3, 5, 9), hats (1, 3, 7), ladybirds (2, 4, 8), leaves (1, 3, 5), pencils (1, 2, 3), pigs (3, 12, 18), pumpkins (1, 2, 3), tractors (1, 2, 3), traffic lights (1, 3, 4), and turtles (2, 3, 4).

Participants were presented with eight different stimulus sets in the nonarbitrary relational training phase and eight novel stimulus sets in the nonarbitrary relational testing phase. On all trials, the two comparison stimuli appeared simultaneously in a row at the bottom of the screen, and then 1 s later the contextual cue appeared at the top of the screen. The contextual cue and comparison stimuli remained on the screen together until the participant selected one of the comparison stimuli (by clicking over it with the mouse). The position of the comparison stimuli (left or right) was counterbalanced across trials. During the nonarbitrary relational training phase, feedback was presented immediately following a response in the center of the screen for 1.5 s, and consisted of the word ''Correct'' or ''Wrong''. All trials were followed by an intertrial interval (ITI) of 2.5 s during both nonarbitrary relational training and testing.

In the presence of the MORE-THAN contextual cue, selecting the image that portrayed the

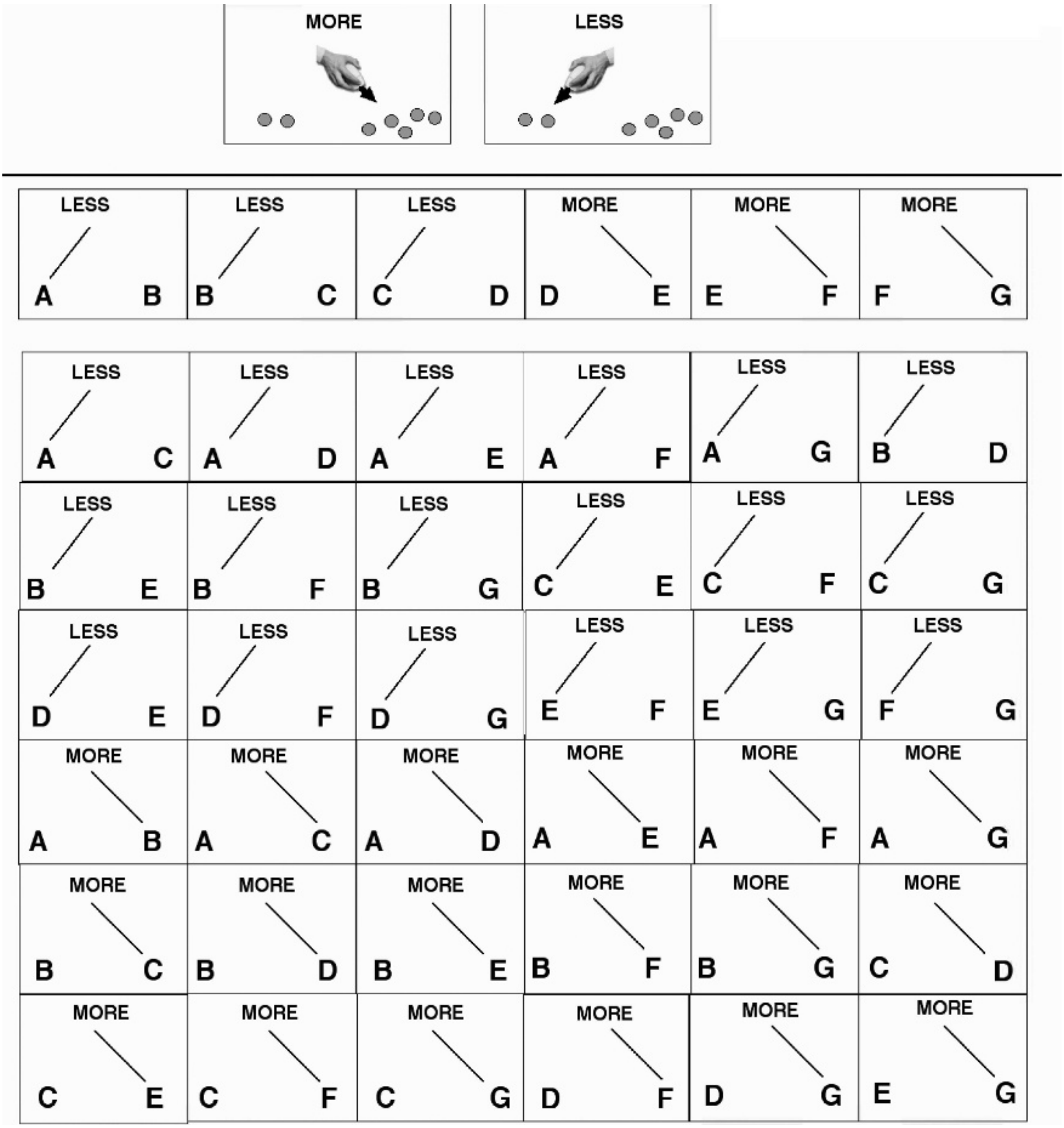

Fig. 1. Schematic representations of the arbitrary relational training (top panel) and testing (lower panel) trial types. The relational words ''MORE'' and ''LESS'' are used for the sake of clarity—participants were not exposed to these labels but rather to arbitrary shapes.

greater quantity of a particular object was reinforced. For example, if the comparison stimuli were two dots and five dots, then choosing the stimulus containing five dots was followed by ''Correct'' (see Figure 1, upper panel). In the presence of the LESS-THAN contextual cue, selecting the stimulus that portrayed the lesser quantity of a particular object was followed by ''Correct'' (see Figure 1, upper panel). There were 48 trial types that could be generated from the 8 stimulus sets, and trial types were selected randomly without replacement until, if applicable, all 48 trials had been presented, in which case the trial order was reshuffled. Each participant was required to choose the correct comparison stimulus across 10 consecutive trials in order to reach the mastery criterion for this phase.

Immediately upon reaching the mastery criterion for nonarbitrary relational training, participants were exposed to a nonarbitrary relational test phase. Feedback was terminated without warning, and the eight novel stimulus sets were employed. Participants were presented with 16 test trials that were drawn randomly from the 48 possible trial types. If a participant failed to produce 16 correct responses, he or she was reexposed to nonarbitrary relational training before returning to the nonarbitrary relational test phase (no participant failed on the second exposure). Having passed this test phase, participants proceeded immediately to Phase 2.

Phase 2: Arbitrary relational training and testing. The aim of this phase was to train responding in accordance with a linear-ranking relational network composed of seven arbitrary stimuli. The position and the timing of stimuli and intertrial intervals were the same as those employed during the nonarbitrary relational training. The six trial types were as follows; LESS-THAN [AB], LESS-THAN [BC], LESS-THAN [CD], MORE-THAN [ED], MORE-THAN [FE], MORE-THAN [GF] (see Figure 1, lower panel, first row). In this case, however, the comparison stimuli were arbitrary three-letter nonsense syllables (e.g., ''ZID'', ''VEK''). Each participant was assigned randomly 7 nonsense syllables from a set of 10. Relational training trials were presented quasirandomly in blocks of 18 trials, with each trial type presented randomly three times within each block. Participants were required to respond correctly across 16 of the 18 trials, with no more than one error on any one trial type, in order to reach the mastery criterion for the relational training.

Upon reaching this criterion, participants were immediately exposed to the relational test phase; feedback was terminated without warning during this phase. Participants were presented with 36 conditional discriminations each presented twice (see Figure 1, lower panel, lower six rows) in a random order. Participants were required to respond correctly across all trials in this phase in order to reach the mastery criterion. Failure to reach the criterion resulted in reexposure to Phase 1 with a maximum of five reexposures.

Phase 3: Training stimulus–consequence relations. During this phase participants were presented on each trial with one of eight

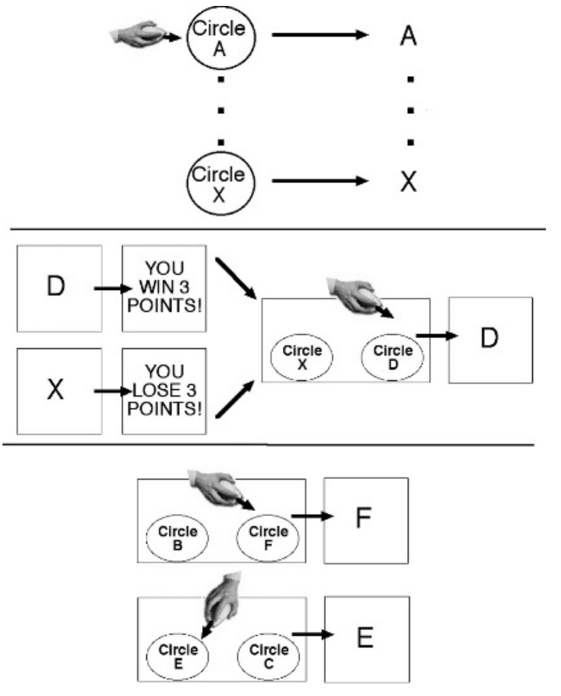

Fig. 2. Diagrammatic representations of the typical experimental tasks presented during Phases 3–5 in Experiments 1 and 2. The response is illustrated with a picture of a hand and a computer mouse. An arrow indicates that the screen on the right followed the screen on the left. Experimental stimuli are labeled using alphabetical characters for the sake of clarity—participants were not exposed to these labels.

circles, each with a different arbitrary pattern inscribed within the circle, and were required to click on the circle with the mouse (see Figure 2, upper panel). Responses produced the appropriate member of the relational network (A, B, C, D, E, F, and G) or a novel stimulus (X) that was to be established as a CS− in the next phase. In other words, each circle was consistently paired with a particular consequential stimulus: clicking on Circle A produced A, Circle B produced B, Circle C produced C, Circle D produced D, Circle E produced E, Circle F produced F, Circle G produced G, and Circle X produced X (see Figure 2, upper panel).

Each circle was presented individually in the middle of the screen. The phrase ''Click on the circle'' appeared in the upper-right corner of the screen. When the participant clicked on the stimulus the screen cleared, and then a member of the relational network or the novel stimulus appeared immediately, remaining on the screen for 2 s. The next trial commenced after 1.5 s. Trials were presented in blocks of 8, with each of the circles presented once in a random order within each block. The instructions were as follows.

> During this part of the experiment you are required to click on each circle as it is presented on the screen. The computer will ask if you want to repeat this phase of the experiment. Press 'Y' for Yes or 'N' for No.

Following each block of eight trials the phrases ''Do you need more practice?'' and ''Press 'Y' for Yes or 'N' for No'' appeared in the middle of the screen. If participants pressed the ''Y'' key on the computer keyboard they were presented with another block of eight trials; if participants pressed the ''N'' key they were exposed to Phase 4.

Phase 4: Establishing consequential functions. The aim of this phase was to establish the ''D'' stimulus as an S+, to establish the novel nonsense word (X) as an S−, and to assess the consequential functions of these stimuli by employing them as consequences in a simultaneous discrimination task. This phase was composed of two blocks: one block consisting of 10 trials of stimulus-pairing, the other consisting of 8 trials of simultaneous discriminations.

The stimulus-pairing procedure involved pairing the D stimulus with a gain of points and pairing the X stimulus with a loss of points. At the beginning of each stimulus-pairing trial, the screen was blank, except for the top right-hand corner that contained the phrase ''You Cannot Press Now.'' Within each 10-trial block, the trials were presented randomly with the constraint that the D stimulus was presented seven times and the X stimulus three times. This presentation ratio was included because an equal number of presentations could result in a zero or negative ''score'' at the end of this phase. Pilot studies had indicated that participants tended to ignore this type of pairing procedure if the scores seemed to cancel each other out. The amount of points won or lost on any particular trial varied between 1 and 3 points and was chosen at random by the computer program.

Three seconds after the start of a trial, either D or X appeared in the center of the screen for 1.5 s and was then removed. After a 0.5 s delay, the phrase ''You Have Won __ Points!'' or ''You Lose __ Points!'' appeared in the center of the screen (see Figure 2, middle panel), where the number of points was a randomly generated integer between 1 and 3. Participants were given feedback on their overall scores every four trials, on average. If the participant pressed any key during a stimulus-pairing trial, the computer screen color turned from dark green to blue for 10 s, and the phrase ''Illegal Response'' appeared in white letters in the middle third of the screen; key presses by the participant during this timeout did not have any effect. When the 10-s timeout was completed the participant was exposed to the same trial again. The overall scores, when they appeared, were in the top left corner of the screen and were preceded by the words ''Your Score: ''. The instructions for this phase were as follows;

> During this part of the experiment you are required to simply look at the screen and observe when you win points and when you lose points. You will also be presented with two circles and you must choose the circle that you think will get you the most points.

Immediately following the 10 trials of stimulus pairing, participants were exposed to eight simultaneous discrimination probe trials that used the D stimulus and the X stimulus as differential consequences. Responses during this task had no effect on the participants' scores, and scores were never presented to the participant during simultaneous discrimination trials. On the top right of the screen was the phase ''Click On A Circle To Choose It''. The Circles D and X (the S+ and S− stimuli, respectively) appeared in the bottom left and right of the screen: these positions were counterbalanced randomly across trials. Clicking on Circle D produced the D stimulus, which appeared in the middle of the screen for 2 s. Similarly, clicking on Circle X produced X as a consequence (see Figure 2, middle panel). The aim of these simultaneous discrimination probe trials was to determine the relative reinforcing value of D and X, following their prior pairing with point gain and point loss. In order to reach mastery criterion for this phase, participants were required to choose the stimulus that produced the D stimulus across all eight trials of the simultaneous discrimination task before proceeding to Phase 5; otherwise, participants

Table 1

Data for Participants 1–5 in Experiment 1 (F = fail; P = pass). The total number of trials in each test phase also is displayed.

P	Phase 1: Nonarbitrary relational		Phase 2: Arbitrary relational		Phase 4: Establish consequential functions /8	Phase 5: Transformation of consequential functions test / 42
	Training	Testing /16	Training	Testing /72		
1	67	16 P	36	72 P	8P	37
2	14	16 P	36	30 F		
	10	16 P	18	37 F		
			18	28 F		
			18	72 P	8 P	19
3	15	16 P	36	72 P	8 P	42
4	13	16 P	72	57 F		
	10	16 P	36	40 F		
			36	72 P	7 F	
					8 P	40
5	13	10 F				
	16	16 P	72	52 F		
			36	52 F		
			18	72 P	8 P	40

were exposed to another 10 stimulus pairings and eight simultaneous discrimination probes.

Phase 5: Test for transformation of consequential functions. The aim of this phase was to determine if the members of the relational network would function as differential consequences in a simultaneous discrimination task. The simultaneous discrimination trials were similar to those presented in Phase 4 except that instead of Circle D and Circle X, Circles A, B, C, D, E, F, and G were employed across trials as the S+ and S− stimuli, and the members of the relational network were employed as the corresponding consequences. It was predicted that participants would choose the higher-ranking stimulus from the relational network (see Figure 2, bottom panel).

Participants 1 and 2 were presented with interpolated simultaneous discrimination probes and stimulus-pairing trials, in a manner similar to Phase 4, presented in blocks of eight trials (in a ratio of 7:1 respectively). Forty-two simultaneous discriminations were presented in a random order, testing each possible simultaneous discrimination twice (with left–right position counterbalanced for each trial type) and six stimulus-pairing trials were presented. However, this interpolation of simultaneous discrimination and stimulus-pairing trials was problematic (especially in the case of Participant 2, see Results section). Therefore, subsequent participants were simply presented with the 42 simultaneous discrimination trials. The instructions for Participants 1 and 2 were the same as those presented in Phase 4, and the instructions for the remaining participants were as follows: ''During this part of the experiment you will be presented with two circles and you must choose the circle that you think will get you the most points.''

This was the final phase of the experiment. At the end of the experiment each participant was thanked, paid, and fully debriefed.

Results and Discussion

Three of the 8 participants who began Experiment 1 failed to produce relation-consistent responding within six exposures to the relational training and testing procedures (Phase 2). These 3 participants were excluded from further participation and their data are not presented.

The remaining participants, numbered 1–5, were trained to respond in accordance with a linear-ranking relational network of seven arbitrary stimuli. Table 1 displays the detailed results for these participants.

Participant 1. Participant 1 required 67 trials in order to reach the nonarbitrary relational training mastery criterion and passed the nonarbitrary relational test on his first attempt. This participant reached the mastery criterion for the arbitrary relational training phase after two blocks, and passed the arbitrary relational test on his first attempt. In Phase 4, Participant 1 selected Circle D, the stimulus that produced D, across all 8 simultaneous discrimination trials. In Phase 5, this participant selected the stimulus that produced the higher-ranking member of the relational network across 37 of 42 trials.

Participants 2–5. In Phase 1, Participants 2–5 required a maximum of two exposures in order to reach the mastery criterion. All participants passed Phase 2, requiring between one and four exposures in order to reach the mastery criterion. All participants, with the exception of Participant 2, successfully completed the test for transformation of consequential functions, selecting the stimulus that produced the higher-ranking member of the relational network across at least 40 of 42 trials.

Four of 5 participants consistently selected the stimulus that produced the higher-ranking member of the relational network in Phase 5, thus demonstrating a transformation of consequential functions in accordance with the relational frames of More-than and Less-than. However, Participants 1 and 2 chose the higher-ranking member of the relational network across 37 and 19 trials, respectively. Upon closer inspection of the data, it emerged that the incorrect responses by both Participants 1 and 2 occurred immediately following a stimulus-pairing trial during which the X stimulus had been presented. Furthermore, during debriefing Participant 2 indicated that he had changed his preference for the higher-ranking consequence on the basis of the preceding stimulus-pairing trial, during which the X stimulus was presented. It appeared, therefore, that the presentation of a Circle X–X stimulus-pairing trial may have functioned as a punisher for the derived relational response that preceded that trial. This conclusion is supported by the fact that Participants 3–5 did not produce similar errors when the interpolated stimulus-pairing trials were removed from the transformation of consequential functions test.

EXPERIMENT 2

Relational frame theory contends that stimulus functions may be transformed in accordance with a large variety of patterns, and thus it is scientifically useful to discriminate these patterns from each other. The patterns are considered to be generalized operant classes and are normally categorized as specific relational frames defined in terms of mutual and combinatorial entailment and transformation of functions. If relational frames are instances of operant behavior, it follows that altering the baseline relational training contingencies will lead, in appropriate contexts, to the derivation of newly entailed relations and the transformation of functions in accordance with these relations. In order to test this prediction, participants in Experiment 2 were trained and tested with two relational networks using a reversal design. In this way, we sought to examine if altering the baseline contingencies would lead to predictable changes in performance on the transformation of consequential functions test.

METHOD

Participants

Four university students (aged 17–20; 2 male, 2 female) were recruited and remunerated for their participation in same manner as Experiment 1. None of the participants had knowledge of relational frame theory or similar research.

Procedure

The procedure for Experiment 2 was similar to that of Experiment 1, except that following the test for transformation of consequential functions (Phase 5) the relations among the stimuli in the relational network were manipulated using a reversal design. Specifically, following the first test for the transformation of consequential functions, participants were reexposed to Phase 1, which remained identical throughout the experiment. However, in Phase 2, the arbitrary relational training trials were altered. In the case of Participant 6, all the relations among the stimuli in the relational network were simply reversed (i.e., the relational network changed from A<B<C<D<E<F<G to G<F<E<D<C<B<A). For Participants 7–9 the relational network was entirely reordered. That is, every stimulus in the relational network had a different position in the linear ranking string following Phase 2. Specifically, for Participant 7 the relational network changed to F<C<G<E<B<D<A; for Participant 8 the relational network changed to D<G<A<F<D<B<C; and for Participant 9 the relational network changed to B<F<D<A<G<E<C.

Table 2

Data for Participants 6–9 in Experiment 2 (F = fail; P = pass). The total number of trials in each test phase also is displayed.

P	Condition	Phase 1: Nonarbitrary relational		Phase 2: Arbitrary relational		Phase 4: Establish consequential functions /8	Phase 5: Transformation of consequential functions test /42
		Training	Testing /16	Training	Testing /72		
6	Baseline	12	16 P	90	67 F		
				18	63 F		
				18	72 P	7 F	
						8 P[a]	
	New session						
	Baseline	10	16 P	18	72 P	8 P	42
	Alteration 1	10	16 P	36	72 P	8 P	42
	Alteration 2	10	16 P	18	72 P	8 P	42
7	Baseline	15	16 P	54	72 P	8 P	42
	Alteration 1	10	16 P	72	72 P	8 P	42
	Alteration 2	10	16 P	36	72 P	8 P	42
8	Baseline	10	16 P	72	62 F		
				18	72 P	6 F	
						8 P	42
	Alteration 1	10	16 P	108	72 P	8 P	42
	Alteration 2	10	16 P	36	72 P	8 P	42
9	Baseline	14P	16 P	54	72 P	8 P	40
	Alteration 1	10P	16 P	72	72 P	8 P	42
	Alteration 2	10	16 P	36	72 P	8 P	42

[a] Session terminated at this point.

Finally, all participants were reexposed to the entire procedure, during which the original baseline relations were reestablished. The instructions for each phase remained the same across the reversals. Participants were not told that the baseline relations would be altered.

Results and Discussion

All 4 participants produced relation-consistent responding within six exposures to arbitrary relational training and testing (Phase 2). Successful completion of the transformation of function test was defined as consistently choosing the stimulus that produced the higher-ranking member of the linear string as a consequence. Table 2 displays the results for Participants 6–9.

All participants in Experiment 2 passed Phase 1 on their first attempt, passed Phase 2 within three exposures, and reached the criterion in Phase 4 within a maximum of two exposures. In Phase 5, all participants chose the stimulus that produced the higher-ranking member of the relational network across at least 40 of 42 simultaneous discrimination trials. Following the alteration of the baseline contingencies in Phase 2 (arbitrary relational training and testing), all participants successfully completed the test for transformation of consequential functions, choosing the stimulus that produced the higher-ranking member of the relational network across all 42 probe trials. On reexposure to the baseline contingencies in Alteration 2, all participants chose the stimulus that produced the higher-ranking member in the transformation of consequential functions test, thus demonstrating the participants' sensitivity to alterations of the previously trained baseline contingencies.

EXPERIMENT 3

Greenway et al. (1996) examined the questions of whether or not derived consequential functions would generalize to other experimental contexts. Participants were first exposed to training designed to establish three 3-member equivalence classes. Next, reinforcement and punishment functions were trained to B1 and B3, respectively, and these functions subsequently were tested in a matching-to-sample task. The transfer of function from the B stimuli to the C stimuli then was tested in a letter-choice task, in which the C stimuli were employed as differential consequences. Eleven of the 12 participants exposed to this procedure displayed a transformation of the consequential functions in accordance with the trained and tested equivalence classes, although some participants required additional training that resulted in the generalization of the B functions.

Experiment 3 sought to determine if consequential functions established via derived More-than and Less-than relations would generalize to other experimental contexts. Following the suggestion of Greenway et al. (1996), Experiment 3 employed a free-operant schedule-based task in which stimuli from the relational network were presented as consequences. In the schedule we employed, the D stimulus was available on every trial. In addition, it was possible to produce the B stimulus if the background color was yellow (50% of trials), or the F stimulus if the background color was blue (50% of trials). We predicted that if the background color was yellow, the D stimulus would be chosen over the B stimulus, whereas if the background color was blue, the F stimulus would be chosen over the B stimulus, thus demonstrating that B was the weakest reinforcer, F the strongest reinforcer, and D a reinforcer of intermediate value.

Method

Participants

Twelve participants (aged 18–25; 5 male, 7 female), numbered 10–21, were recruited and remunerated for their participation in the same manner as in the previous experiments. None of the participants had knowledge of relational frame theory or similar research.

Procedure

Phases 1–2: Nonarbitrary and arbitrary relational training and testing. The relational training and testing procedure was similar in some ways to that described in Experiments 1 and 2, but had a number of important differences. Specifically, we trained a smaller relational network first and then expanded it, in an attempt to increase the number of participants who would complete the experiment (Fields et al., 1997). Participants first were trained and tested on a five-member relational network (B-C-D-E-F) and then were exposed to the following trial types: LESS-THAN [BC], LESS-THAN [CD], MORE-THAN [ED], MORE-THAN [FE]. Eight consecutive correct responses were required in order to proceed to the arbitrary relational test, in which all possible derived relations and all trained relations were presented once (i.e., a total of 20 trials), in the absence of corrective feedback. A maximum of 10 exposures to the arbitrary relational test could occur. Participants were reexposed to nonarbitrary training and testing and to arbitrary training between test exposures.

On passing the arbitrary relational test, the network was expanded to 7 members by presenting two further trial types during the arbitrary relational training phase (LESS-THAN [AB], MORE-THAN [GF]), in addition to the four trial types described above. The two additional trial types were presented twice in an eight-trial block; the original trial types were presented once each. Sixteen consecutive correct responses were required in order to proceed to the arbitrary relational test, in which all possible 36 derived relations and all six trained relations were presented once (i.e., a total of 42 trials) in the absence of corrective feedback. The mastery criterion in the arbitrary test was set at 100%. If a participant failed the arbitrary test, then he or she was reexposed to nonarbitrary training and testing and to arbitrary training and testing with the seven-member relational network.

Generalization test. In this phase, an additional motivating operation (MO; Michael, 2000) was employed in order to enhance the reinforcing value of the members of the relational network. Specifically, the D stimulus was paired with ''10 tokens'', and the number of tokens obtained was correlated with increased probability of a monetary reward. This was necessary because we had observed that some participants quickly became bored with the schedule tasks and tended to respond erratically unless this additional MO was in effect.

At the beginning of this phase, participants were presented with the following instructions (for ease of communication, the nonsense words used are represented by the letters B, D, and F, which represent stimuli from the relational network—participants never saw these letters):

> This is a situation in which you can earn tokens toward winning €100. Each time you earn 100 tokens, you will receive one raffle ticket to win the €100, which will be randomly drawn at the end of the study. On the next screen, simply press on ''D'' and carefully note what happens.

On the next screen, the D stimulus appeared in the middle of the screen, where it remained until the participant clicked on it. When the participant did so, the screen cleared immediately, and the phrase ''10 TOKENS!'' appeared for 2 s. When this phrase disappeared, the next trial commenced. Participants were exposed to eight such trials. When these trials were over, the following instruction appeared on the screen.

> This is a situation in which you can earn tokens toward winning €100. Each time you earn 100 tokens, you will receive one raffle ticket to win the €100, which will be randomly drawn at the end of the study. Try and earn as many raffle tickets as you can, by figuring out the best way to earn the most amount of tokens.

With the exception of Participant 17, all participants also were given the following instructions.

> Note the following: On every trial, it is possible to produce ''D'' by pressing on the spacebar at a certain time. However, by varying how much you press the spacebar you may produce either ''B'' or ''F''. A clue is to note the screen color—sometimes it will be blue, and sometimes it will be yellow. The first 15 trials do not count—so experiment to find out the best way to earn the most tokens. Remember, it is always possible to produce ''D'' tokens on every trial—but it is also possible to produce ''B'' or ''F'', depending on the screen color.

To evaluate the possibility that the detailed instructions might account for the performance in the schedule task, Participant 17 was given only the following instruction ''the first 15 trials do not count—so experiment to find out the best way to earn the most tokens''. The instructions were printed on a paper sheet and left beside the computer keyboard. A button at the bottom of the screen displayed the caption ''Please ask the experimenter now if you have any questions, otherwise press to proceed''. When the participant pressed this button, the generalization task began.

Participants were exposed to a two-component multiple schedule (see Figure 3 for a schematic representation) in which the consequential stimulus produced was contingent on the number of responses emitted in a preceding 15-s interval and on the background color of the computer screen, which was either blue or yellow (see Lippman, 2000, Experiment 2 for a similar procedure; Lippman & Tragesser, 2003). The background color on the first trial was counterbalanced across participants, and each color appeared on 5 of every 10 trials thereafter. The D stimulus always was available (i.e., irrespective of the background color) on a fixed-interval (FI) 15-s schedule, with the constraint that participants had not responded more than 10 times during the 15-s interval. Emitting more than 10 responses in the 15-s interval resulted in the presentation of the B stimulus if the background color of the screen was yellow. Emitting more than 10 responses in the 15-s interval resulted in the presentation of the F stimulus if the background color of the screen was blue. The consequential stimulus remained on the screen for 2 s and was followed by a 3-s ITI, during which the background color of the screen was black.

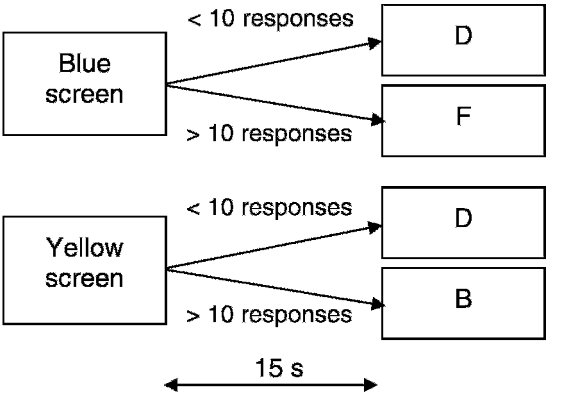

Fig. 3. A schematic of the schedule employed in Experiment 3. Each trial had an equal probability of having a blue or yellow screen.

During the ITI, a number of phrases appeared in a text box displayed in the center of the screen. The phrase ''This trial: '' appeared, followed by the consequential stimulus that had been produced on the previous trial (e.g., ''This trial: F''). There were three phrases below this, which read: ''Total D: '', followed by the total number of D stimuli that had been produced (e.g., ''Total D: 23''). There were also similar phrases that corresponded to the B and F stimuli. The next trial commenced following this ITI. After 15 trials, the phrase ''The task is starting for real. Try to earn as many tokens as possible!'' appeared in black letters across a red background, accompanied by a short beep above the text box during the ITI. After 30 and 60 trials (including the 15 training trials), a screen with the following caption appeared for all participants ''Please take a small break now of no more than about a minute. When you are ready to start again, press the space bar.'' Participants 10–16 also were presented with the following sentence, ''Remember, it is always possible to produce 'D' on every trial - but it is also possible to produce either 'B' or 'F'''. Pressing the space bar restarted the presentation of the generalization task. When participants had been exposed to 90 trials, the following statement appeared on the screen: ''Thank you. This is the end of the experiment. Please report to the experimenter.'' Participants were then thanked, paid, and debriefed.

Results and Discussion

Four of the 12 participants (Participants 18–21) failed to produce relation-consistent responding within 10 exposures to the relational training and testing procedures (Phase 2). Three of these 4 participants failed the arbitrary relational test, and the 4th did not reach the criterion on the arbitrary relational training after 75 min and wished to terminate the experiment. These participants were excluded from further participation in the study, and their data are not presented. On trials with a blue background color, generalization of consequential functions was demonstrated when the F stimulus was selected over the D stimulus (i.e., 10 or more responses). On trials with a yellow background color, generalization of consequential functions was demonstrated when the D stimulus was selected over the B stimulus (i.e., nine or fewer responses).

Participants required a maximum of two exposures to pass the nonarbitrary relational training and testing phases, and between one and nine exposures to pass the arbitrary relational training and testing phases. Table 3 displays detailed results for Participants 10–17 in those phases.

Figure 4 displays the results of the generalization test for Participants 10–17. Participants 10, 11, 14, 15, 16, and 17 tended to respond more than 10 times in the presence of the blue screen, thus producing the F stimulus, and fewer than 10 times in the presence of the yellow screen, thus producing the D stimulus. The B stimulus was rarely produced as a consequence. In contrast, the B and F stimuli tended to be produced equally often by Participants 12 and 13.

In conclusion, Experiment 3 demonstrated the generalization of consequential functions from the arbitrary relational testing context to a free-operant schedule-based task. The D stimulus was paired with ''10 tokens'', and the accumulation of tokens increased the probability of the participant winning money in a prize draw. Although participants were never given any information about the value of the B and F stimuli, the response patterns of Participants 10, 11, 14, 15, 16, and 17 indicated that the F stimulus was a more effective reinforcer for the bar-pressing response than was the B stimulus. This result is consistent with the predicted transformation of consequential functions for the D stimulus in accordance with the relational network. Furthermore, Participant 17 was given only minimal instructions, and yet responded in a similar manner, thus suggesting that the detailed schedule instructions were not necessary for successful transformation of function. The responses of Participants 12 and 13, however, did not seem to be controlled reliably by either the B or the F stimulus. The current results replicate and extend the findings of Experiments 1 and 2 and also extend those of Greenway et al. (1996) to multiple stimulus relations of More-than and Less-than.

GENERAL DISCUSSION

Experiment 1 demonstrated that a reinforcing function attached to one stimulus may transform the functions of related stimuli in accordance with relational frames of More-than and Less-than. The data from Experiment 2 indicate that the relative reinforcing values of emergent stimuli can be correspondingly altered by altering the directly trained relations. Experiment 3 demonstrated that derived consequential functions may generalize to a free-operant schedule task and that detailed task instructions are not necessary for this generalization to occur.

Consistent with other studies that examined multiple stimulus relations (e.g., Dymond & Barnes, 1995; O'Hora et al., 2002; Reilly et al., 2005; Steele & Hayes, 1991; Whelan & Barnes-

Table 3

Results for Participants 10–17 in the non-arbitrary and arbitrary relational training phases in Experiment 3 (F = fail; P = pass).

P	Network size	Phase 1: Nonarbitrary relational		Phase 2: Arbitrary relational	
		Training	Testing /8	Training	Testing
10	5	24/37	8P	8/9	15/20F
		8/8	8P	8/8	14/20F
		8/8	8P	8/8	16/20F
		8/8	8P	8/8	16/20F
		8/8	8P	8/8	16/20F
		8/8	8P	8/8	16/20F
		8/8	8P	8/8	16/20F
		8/8	8P	8/8	16/20F
		8/8	8P	8/8	20/20P
	7	8/8	8P	16/16	42/42P
11	5	15/23	8P	14/18	10/20F
		8/8	8P	15/16	8/20F
		8/8	8P	8/8	11/20F
		8/8	8P	8/8	20/20P
	7	8/8	8P	16/16	42/42P
12	5	11/15	8P	34/47	20/20P
	7	8/8	8P	20/22	42/42P
13	5	13/22	7F		
		21/30	8P	26/37	19/20F
		8/8	8P	8/8	20/20P
	7	8/9	8P	17/20	38/42F
		8/8	8P	12/12	39/42F
		8/8	8P	15/16	42/42P
14	5	11/13	8P	9/10	15/20F
		8/8	8P	8/8	20/20P
	7	8/8	8P	16/16	42/42P
15	5	9/14	2F		
		8/9	8P	9/11	14/20F
		8/8	8P	8/8	17/20F
		8/8	7F		
		8/8	8P	8/8	14/20F
		8/8	7F		
		8/8	8P	8/8	20/20P
	7	8/8	8P	16/17	42/42P
16	5	8/9	8P	22/32	18/20F
		8/9	8P	8/8	20/20P
	7	8/8	8P	17/20	40/42F
		8/8	8P	12/12	42/42P
17	5	11/12	8P	11/17	19/20F
		8/8	8P	8/8	20/20P
	7	8/8	8P	18/21	37/42F
		8/8	8P	20/21	42/42P

Holmes, 2004), the current data are not readily interpretable in terms of equivalence classes. The terms used to describe the properties of an equivalence relation—reflexivity, symmetry, and transitivity—do not seem to be applicable to the kinds of relational performances demonstrated in the current experiments. Indeed, the properties of more-than and less-than responding seem to have more in common with temporal or order relations (Stromer & Mackay, 1993). These relations are irreflexive, asymmetrical, transitive, and connected. First, the relation that the A stimulus has with itself is not reflexive: it cannot be more than or less than itself. Second, if A is more than B, it does not follow that B is also more than A: the relation is not symmetrical. The relations are transitive, if B is more than A and C more than B, and then C is more than A. The relations also are connected, that is, ‘‘all stimuli that participate in a specific more-than or less-than relation are, ipso facto,

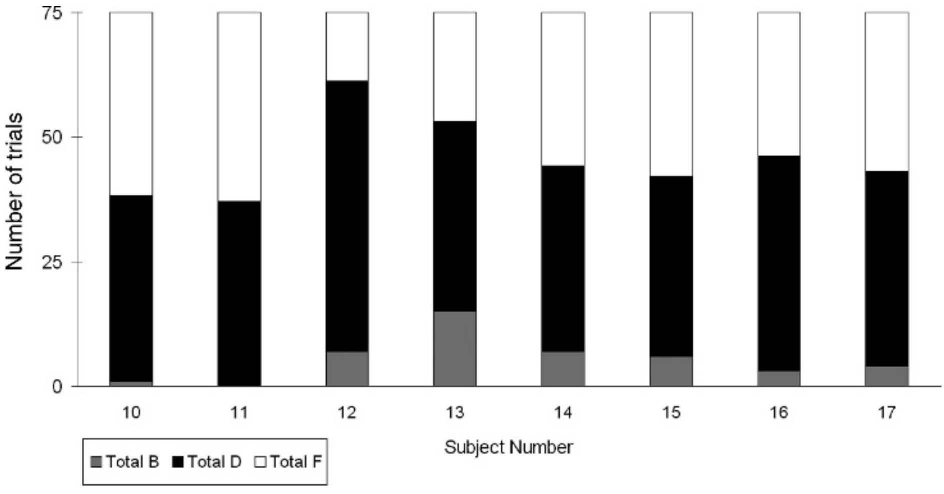

Fig. 4. A stacked bar chart representing the proportion of each consequential stimulus presented across the final 75 trials of the generalization test phase by Participants 10–17 in Experiment 3. The reader should note that it was possible to produce the B and the F stimulus only on a maximum of 50% of the trials.

related to each other, and the relation is therefore connected'' (Dymond & Barnes, 1995, p. 183). The current data, therefore, support and extend not only studies within the literature on relational frame theory, but also those studies that have attempted to extend Sidman's set theory analysis of equivalence classes (e.g., Sidman, 1994) to nonequivalence relations (e.g., Green, Stromer, & Mackay, 1993).

The results of the current study also are consistent with recent research that established a three-element relational network (i.e., ''small'' stimulus < ''medium'' stimulus < ''large'' stimulus) using procedures broadly similar to those described in the present study (i.e., nonarbitrary and arbitrary relational training and testing). Dougher, Hamilton, Fink, and Harrington (2003) demonstrated that operant stimulus functions can be transformed in accordance with nonequivalence relations, or what the authors refer to as ''generalized relational stimuli.'' In a schedule task, the ''medium'' sample stimulus was used to train a bar press at a certain rate. In the test for transformation of function, participants pressed slower in the presence of the ''small'' sample stimulus, and pressed faster in the presence of the ''large'' sample stimulus, despite the fact that they had not previously emitted a bar-press response in the presence of these sample stimuli. The current data support and extend this recent work by: (a) demonstrating the transformation of consequential rather than discriminative functions, (b) extending the number of stimuli in the relational network from three to seven, and (c) showing generalization of the derived performances from an arbitrary relational testing context to a free-operant schedule-based task.

Unlike many other studies on multiple stimulus relations and the transformation of functions, the current experimental work is notable in that the effects of the baseline contingences on the transformation of function were shown to be reliably alterable across a reversal design (Experiment 2). Furthermore, in demonstrating predictable alterations in the relational testing performances, and the transformation of consequential functions, changes in relational responding were shown through both mutual and combinatorial entailment. In contrast, other researchers have reported difficulty in demonstrating such reversals in the study of stimulus equivalence classes (Pilgrim & Galizio, 1990, 1995, 1996; Roche, Barnes, & Smeets, 1997; Saunders, Drake, & Spradlin, 1999; Spradlin, Cotter, & Baxley, 1973). That is, the performances following the reversal in baseline contingencies indicated that mutually entailed relations were sensitive to the reversal, but combinatorially entailed relations were not. This discrepancy between the current study and previous research might be explained in terms of the very different procedures employed. For example, the current study involved nonarbitrary relational training to establish contextual cues for more-than and less-than relations, training and testing the relevant conditional discriminations in the presence of these cues, and also training and testing for a transformation of consequential functions. In contrast, the equivalence studies cited above involved training and testing equivalence relations in the absence of programmed contextual control or tests for transformation of additional stimulus functions. On balance, a number of equivalence studies have demonstrated reliable control by reversed baseline contingencies (e.g., Saunders et al., 1999; Smeets, Barnes-Holmes, Akpinar, & Barnes-Holmes, 2003), and thus further research is needed to understand the variables at work. In any case, the current data clearly show that altering the baseline contingencies for multiple stimulus relations appears to produce reliable and predictable changes in both mutually and combinatorially entailed relational responses.

In the current study, the members of the relational network were employed as consequential stimuli in a simultaneous discrimination task (Experiments 1 and 2). Thus, the relative reinforcing effectiveness of the stimulus always was assessed in relation to another simultaneously available reinforcer. The current study did not, however, assess the relative reinforcing value of the stimuli within the network in tasks in which only one reinforcer was available at a given time. Imagine, for example, that two stimuli that differed from each other in terms of reinforcing value, based on the relational network, were used in different components of the same schedule of reinforcement. Would response patterns observed across the two components reflect the relative values of the two reinforcers? For example, would the more-valuable stimulus produce greater resistance to extinction than the less-valuable stimulus (Plaud, Gaither, & Lawrence, 1997), or a contrast effect if the relational stimuli were employed in a multiple schedule (McSweeney & Norman, 1979)? Future research should examine these issues.

In the present study, only two members of the relational network were employed as consequences at any one time. However, this does not preclude inferences about the relationship among other stimuli in the relational network. For instance, in Experiment 1, in a simultaneous discrimination involving the F and B stimuli as consequences, the response that produced F was more probable. There was no contextual cue presented in this phase, and thus the preference for the F stimulus was likely determined by the history of relational responding to the C, D, and E stimuli, which linked F to B. In fact, one could argue that the study presented the participants with a type of transitive inference (TI) task (e.g., Acuna, Sanes, & Donoghue, 2002).

The current research also may be relevant to the literature on human and nonhuman TI performances (Lazareva, et al., 2004; Zentall & Clement, 2001). Particularly pertinent are the arguments of Markovits and Dumas (1992) and Russell, McCormack, Robinson, and Lillis (1996) who claimed that there may be two different types of TI performances. Specifically, two types of procedure have been used—one involves training a series of overlapping simultaneous discriminations (e.g., A+B−, B+C−, C+D−, & D+E−; Lazareva et al., 2004) and the other involves presenting a verbal premise in which several terms are ordered along a certain dimension (e.g., ''John is taller than Bill; Bill is taller than Tom; Tom is taller than Pat''; Potts, 1974). In the first task, described as an *associative* task, the stimuli are not related to each other along a linear dimension (i.e., the task consists of overlapping simultaneous discriminations). On test trials involving a nonadjacent pair, such as B and D, choosing the former stimulus over the latter is predicted (e.g., von Fersen, Wynne, Delius, & Staddon, 1991). Results in this type of TI task, it has been argued, may be a function of a value transfer between and among the S+ and S− stimuli (see Zentall & Clement, 2001, for a recent review of this issue). In the second type of TI task, described as a *logical* task, experimental preparations typically require the ordering of several terms along a certain dimension, followed by a question regarding the relation between two of the nonadjacent terms. For example, participants might be informed verbally that: ''John is taller than Bill; Bill is taller than Tom; Tom is taller than Pat. Who is taller: John or Pat?'' In this case, the answer ''John'' would indicate TI (e.g., Potts, 1974; Russell et al., 1996).

One important problem that has been discussed in the literature (Russell et al,

1996) is the difficulty in comparing and contrasting human and nonhuman performance on logical TI tasks. Because these tasks involve presenting verbal instructions, it is difficult to construct a meaningful version of a logical TI task for nonhuman participants. Doing so would require extensive language training for the animals in question, with all of the interpretative problems that arise in this area (e.g., Pinker, 1995; Savage-Rumbaugh, Shanker, & Taylor, 1998). Nevertheless, demonstrating logical TI in nonhumans is important if the argument is to be sustained that critical features of nonhuman cognition are broadly similar to those found in human cognition (e.g., McGonigle & Chalmers, 1992).

The procedures reported in the current study may provide an opportunity for exploring logical TI abilities in nonhumans without having to provide an extensive language-training history. Specifically, the experimental procedures could be adapted to the nonhuman laboratory in that all of the training and testing trials could be presented, in principle, without any verbal instruction, using procedures typically employed to study conditional discriminations with nonhumans (Schusterman, Gisiner, Grimm, & Hanggi, 1993). Given that these procedures would involve discriminating along a formal dimension (based on the nonarbitrary training, and subsequent control by the contextual cues), it could reasonably be defined as a type of logical TI task. Thus, if nonhumans produced performances broadly similar (i.e., transitive inference) to those seen in the current study with humans, this finding would indicate that nonhumans also are capable of a type of logical TI that has not yet been reported in the literature. Such a finding could have important implications for the comparative analyses of human and nonhuman cognition (Delius & Siemann, 1998; Dymond, Roche, & Barnes-Holmes, 2003; Skinner, 1953).

The present experiments, and in particular Experiment 3, employed detailed instructions with verbally sophisticated adults, and thus the impact of the participants' preexperimental verbal histories remains unclear. On balance, it should be noted that detailed instructions were not used in all of the experimental phases. Indeed, the crucial tests for derived transformation were presented immediately on reaching the training criteria and were not signaled in any other manner and hence could not exert discriminative control over the test performances. Furthermore, the results of Participant 17, who was presented with minimal instructions, suggest that detailed instructions are not necessary for successful performance. Nonetheless, future research should seek to extend the basic analyses of the transformation of consequential functions by modifying the current procedures and instructions for use with different participant populations such as young children and individuals with minimal verbal repertoires (see Murphy, Barnes-Holmes, & Barnes-Holmes, 2005).

In conclusion, the present study provided the first empirical demonstration of a transformation of consequential functions in accordance with more-than and less-than relations, reversal of the derived transformation performance through multiple alterations in the baseline contingencies, and generalization across experimental tasks. The current experiments thus represent another step towards a more complete analysis of the acquisition and maintenance of derived consequential functions in adult humans.

REFERENCES

Acuna, B. D., Sanes, J. N., & Donoghue, J. P. (2002). Cognitive mechanisms of transitive inference. *Experimental Brain Research, 146,* 1–10.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). Psyscope: An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments & Computers, 25,* 257–271.

Delius, J. D., & Siemann, M. (1998). Transitive responding in animals and humans: Exaptation rather than adaptation? *Behavioral Processes, 42,* 107–137.

Dougher, M. J., Hamilton, D. A., Fink, B. C., & Harrington, J. (2003, May). *Generalized relational stimuli and the transformation of operant and respondent stimulus functions.* Paper presented at the 29th Annual Convention of the Association for Behavior Analysis, San Francisco, CA.

Dougher, M. J., & Markham, M. R. (1994). Stimulus equivalence, functional equivalence, and the transfer of function. In S. C. Hayes, M. Sato, & K. Ono (Eds.), *Behaviour analysis of language and cognition* (pp. 71–90). Reno, NV: Context Press.

Dymond, S., & Barnes, D. (1995). A transformation of self-discrimination response functions in accordance with the arbitrarily applicable relations of sameness, more-than, and less-than. *Journal of the Experimental Analysis of Behavior, 64,* 163–184.

Dymond, S., & Barnes, D. (1996). A transformation of self-discrimination response functions in accordance with the arbitrarily applicable relations of sameness and opposition. *The Psychological Record, 46*, 271–300.

Dymond, S., & Rehfeldt, R. (2000). Understanding complex behavior: The transformation of stimulus functions. *The Behavior Analyst, 23*, 239–254.

Dymond, S., Roche, B., & Barnes-Holmes, D. (2003). The continuity strategy, human behavior, and behavior analysis. *The Psychological Record, 53*, 333–347.

Fields, L., Adams, B. J., Verhave, T., & Newman, S. (1990). The effects of nodality on the formation of equivalence classes. *Journal of the Experimental Analysis of Behavior, 53*, 345–358.

Fields, L., Reeve, K. F., Rosen, D., Varelas, A., Adams, B. J., Belanich, J., & Hobbie, S. A. (1997). Using the simultaneous protocol to study equivalence class formation: The facilitating effects of nodal number and size of previously established equivalence classes. *Journal of the Experimental Analysis of Behavior, 67*, 367–389.

Green, G., Stromer, R., & Mackay, H. A. (1993). Relational learning in stimulus sequences. *The Psychological Record, 43*, 599–615.

Greenway, D. E., Dougher, M. J., & Wulfert, E. (1996). Transfer of consequential functions via stimulus equivalence: Generalization to different testing contexts. *The Psychological Record, 46*, 131–144.

Hayes, S. C. (1991). A relational control theory of stimulus equivalence. In L. J. Hayes, & P. N. Chase (Eds.), Dialogues on verbal behavior (pp. 19–40). Reno, NV: Context Press.

Hayes, S. C., Barnes-Holmes, D., & Roche, B. (2001). *Relational frame theory: A post-Skinnerian account of human language and cognition.* New York: Kluwer Academic/Plenum Press.

Hayes, S. C., Kohlenberg, B. S., & Hayes, L. J. (1991). The transfer of specific and general consequential functions through simple and conditional equivalence relations. *Journal of the Experimental Analysis of Behavior, 56*, 119–137.

Hendry, D. P. (1969). *Conditioned reinforcement.* Homewood, IL: Dorsey Press.

Lazareva, O. F., Smirnova, A. A., Bagozkaja, M. S., Zorina, Z. A., Rayevsky, V. V., & Wasserman, E. A. (2004). Transitive responding in hooded crows requires linearly ordered stimuli. *Journal of the Experimental Analysis of Behavior, 82*, 1–19.

Lippman, L. G. (2000). Contingent incentive value in human operant performance *The Psychological Record, 50*, 513–528.

Lippman, L. G., & Tragesser, S. L. (2003). Contingent magnitude of reward in modified human-operant DRL-LH and CRF schedules. *The Psychological Record, 53*, 429–442.

Markovits, H., & Dumas, C. (1992). Can pigeons really make transitive inferences? *Journal of Experimental Psychology: Animal Behavior Processes, 18*, 311–312.

McGonigle, B. O., & Chalmers, M. (1992). Monkeys are rational! *Quarterly Journal of Experimental Psychology, 45*, 189–228.

McSweeney, F. K., & Norman, W. D. (1979). Defining behavioral contrast for multiple schedules. *Journal of the Experimental Analysis of Behavior, 32*, 457–461.

Michael, J. (2000). Implications and refinements of the establishing operation concept. *Journal of Applied Behavior Analysis, 33*, 401–410.

Murphy, C., Barnes-Holmes, D., & Barnes-Holmes, Y. (2005). Derived manding in children with autism: Synthesizing Skinner's *Verbal Behavior*, with relational frame theory. *Journal of Applied Behavior Analysis, 38*, 445–462.

O'Hora, D., Roche, B., Barnes-Holmes, D., & Smeets, P. M. (2002). Response latencies to derived stimulus relations: Testing two predictions of relational frame theory. *The Psychological Record, 52*, 51–75.

Pavlov, I. (1927). *Conditioned reflexes.* New York: Oxford University Press.

Pilgrim, C., & Galizio, M. (1990). Relations between baseline contingencies and equivalence probe performances. *Journal of the Experimental Analysis of Behavior, 54*, 213–224.

Pilgrim, C., & Galizio, M. (1995). Reversal of baseline relations and stimulus equivalence: I. Adults. *Journal of the Experimental Analysis of Behavior, 63*, 225–238.

Pilgrim, C., & Galizio, M. (1996). Stimulus equivalence: A class of correlations, or a correlation of classes? In T. R. Zentall, & P. M. Smeets (Eds.), *Stimulus class formation in humans and animals* (pp. 173–195). New York: Elsevier.

Pinker, S. (1995). Why the child holded the baby rabbits: A case study in language acquisition. In L. R. Gleitman, M. Liberman, & D. N. Osherson (Eds.), *An invitation to cognitive science, Vol 1: Language* (2nd ed., pp. 107–133). Cambridge, MA: The MIT press.

Plaud, J. J., Gaither, G. A., & Lawrence, J. B. (1997). Operant schedule transformations and human behavioral momentum. *Journal of Behavior Therapy & Experimental Psychiatry, 28*, 169–179.

Potts, G. R. (1974). Storing and retrieving information about ordered relationships. *Journal of Experimental Psychology, 103*, 431–439.

Reilly, T., Whelan, R., & Barnes-Holmes, D. (2005). The effect of training structure on the latency of responses to a five-term linear chain. *The Psychological Record, 55*, 233–249.

Roche, B., Barnes, D., & Smeets, P. M. (1997). Incongruous stimulus pairing contingencies and conditional discrimination training: Effects on relational responding. *Journal of the Experimental Analysis of Behavior, 68*, 143–160.

Roche, B., Stewart, I., & Barnes-Holmes, D. (1999). *PsyScope*: An easy-to-use graphical system for designing and controlling equivalence experiments. *Experimental Analysis of Human Behavior Bulletin, 17*, 5–7.

Russell, J., McCormack, T., Robinson, J., & Lillis, G. (1996). Logical (versus associative) performance on transitive reasoning tasks by children: Implications for the status of animals' performance. *Quarterly Journal of Experimental Psychology, 49B*, 231–244.

Saunders, R. R., Drake, K. M., & Spradlin, J. E. (1999). Equivalence class establishment, expansion, and modification in preschool children. *Journal of the Experimental Analysis of Behavior, 71*, 195–214.

Savage-Rumbaugh, S., Shanker, S. G., & Taylor, T. J. (1998). *Apes, language, and the human mind.* Oxford: University Press.

Schusterman, R. J., Gisiner, R., Grimm, B. K., & Hanggi, E. B. (1993). Behavior control by exclusion and attempts at establishing semanticity in marine mammals using match-to-sample paradigms. In H. Roitblat, L. Herman, & P. Nachtigall (Eds.), *Language and communication: Comparative perspectives* (pp. 249–274). Hillsdale, NJ: Erlbaum.

Sidman, M. (1992). Equivalence: Some basic considerations. In S. C. Hayes, & L. J. Hayes (Eds.), *Understanding verbal relations* (pp. 15–27). Reno, NV: Context Press.

Sidman, M. (1994). *Equivalence relations: A research story.* Boston, MA: Authors Cooperative.

Skinner, B. F. (1953). *Science and human behavior.* New York: Macmillan.

Smeets, P. M., Barnes-Holmes, Y., Akpinar, D., & Barnes-Holmes, D. (2003). Reversal of equivalence relations. *The Psychological Record, 53,* 91–119.

Spradlin, J. E., Cotter, V. W., & Baxley, N. (1973). Establishing a conditional discrimination without direct training: A study of transfer with retarded adolescents. *American Journal of Mental Deficiency, 77,* 556–566.

Steele, D. L., & Hayes, S. C. (1991). Stimulus equivalence and arbitrary applicable relational responding. *Journal of the Experimental Analysis of Behavior, 56,* 519–555.

Stromer, R., & Mackay, H. A. (1993). Human sequential behavior: Relations among stimuli, class formation, and derived sequences. *The Psychological Record, 43,* 107–132.

von Fersen, L., Wynne, C. D. L., Delius, J. D., & Staddon, J. E. R. (1991). Transitive inference in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 17,* 334–341.

Whelan, R., & Barnes-Holmes, D. (2004). The transformation of consequential functions in accordance with the relational frames of Same and Opposite. *Journal of the Experimental Analysis of Behavior, 82,* 177–195.

Williams, B. (1994). Conditioned reinforcement: Experimental and theoretical issues. *The Behavior Analyst, 17,* 261–285.

Zentall, T. R., & Clement, T. S. (2001). Simultaneous discrimination learning: Stimulus interactions. *Animal Learning and Behavior, 29,* 311–325.

Received: September 30, 2004
Final acceptance: May 22, 2006