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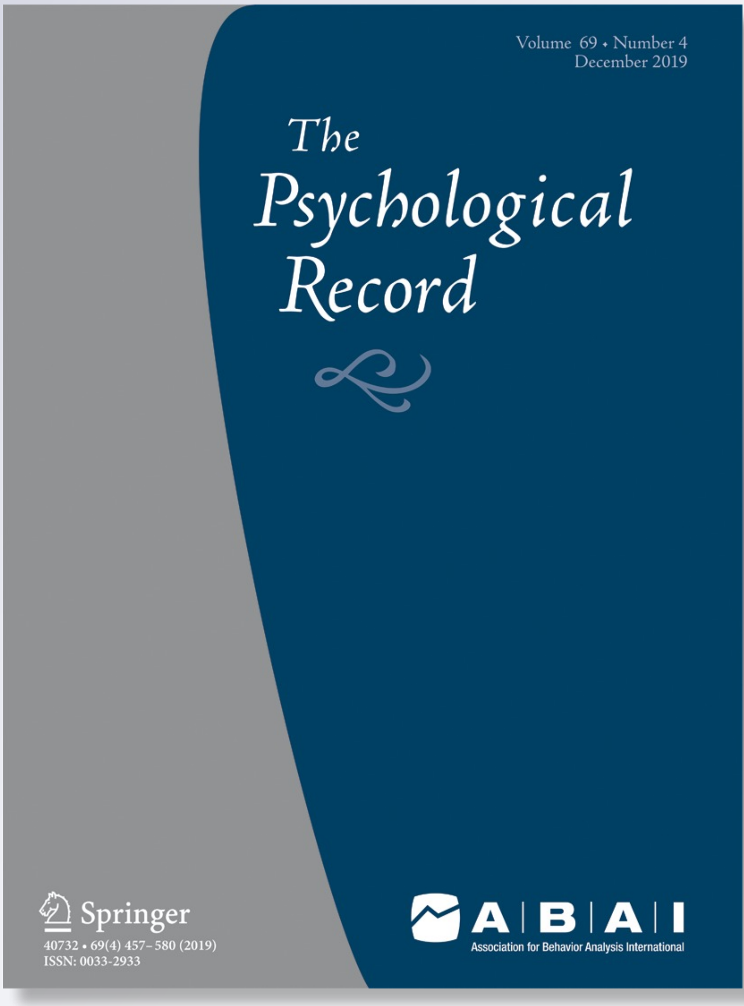

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ORIGINAL ARTICLE

Symbolic Generalization of Discriminative Functions in Accordance with a Five-Member Comparative Relational Network

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Abstract

Three experiments investigated the symbolic generalization (transformation) of discriminative (bar-pressing) functions in accordance with a five-member arbitrary relational comparative network (A–B–C–D–E) in adults. Following nonarbitrary relational training and testing to establish the contextual functions of MORE-THAN and LESS-THAN for two abstract images, participants received arbitrary relational training and testing. One group received training on "More-than" baseline relations (e.g., B > A, C > B, D > C, and E > D) and another group received training on "Less-than" baseline relations (A < B < C < D < E). Both groups were then tested on a combination of "More-than" and "Less-than" relations (e.g., C > A and A < C, etc.) and exposed to a bar-press training phase, which trained a low, steady rate bar-pressing response function to the middle stimulus (C) in the relational network. In Experiment 1, testing involved a quasi-random order of presentation of probe stimuli and half of the participants responded in accordance with the predicted relational network (i.e., pressed less to A and B and more to D and E, than to C). In Experiment 2, none of the participants showed the predicted performance when the probe stimuli were presented in a fixed order (A–B–C–D–E), whereas three out of four participants in Experiment 3 responded in accordance with the predicted relational network when the test was repeated. These findings indicate the importance of identifying methodological factors that may potentially influence the symbolic generalization of discriminative functions.

Keywords Symbolic generalization · Transformation of functions · Comparative · More than/less than · Discriminative functions · Humans

Symbolic generalization, or transformation of functions, refers to an empirical phenomenon whereby, when a psychological function is acquired by one member of a network of derived relations, the functions of other members of the network change in accordance with the particular derived relation and functions involved, without further training (Dymond & Rehfeldt, 2000; Hayes, 1991). For instance, Dymond and Barnes (1995) showed transformation of functions via derived "more" and "less" (i.e., comparative) relations. They first established contextual cue functions of "more" and "less" in two arbitrary shapes by employing multiple exemplar training of the selection of physically more and less, respectively, in the presence of the two shapes. These cues were then used to train and test a network of derived comparative relations between arbitrary stimuli such that B2 was derived as less than B1 and C2 was derived as more than B1. Next, they were trained in self-discriminative response functions with respect to three different complex schedules of reinforcement such that they had to choose B1 if they had previously emitted one response, a novel stimulus X1 if they had not emitted a response, and a novel stimulus X2 if they had emitted two responses. They subsequently showed transformation of the functions of the B2 and C2 stimuli in accordance with "less" and "more" relations with B1, respectively, such that, in an analogous context to the self-discriminative function training, participants chose B2 if they had not emitted a response and C2 if they had emitted two responses, in the absence of any further training.

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By now, substantial additional empirical evidence for symbolic generalization[1] has been provided, with studies showing this phenomenon occurring through a number of different patterns of derived relations and with multiple different functions (Dymond & Roche, 2013). Of particular interest to the present study, findings have demonstrated discriminative, self-discriminative, consequential, and Pavlovian eliciting functions, among others, may alter or transform in accordance with comparative (more and less) relations (Dougher, Hamilton, Fink, & Harrington, 2007; Dymond & Barnes, 1995; Whelan, Barnes-Holmes, & Dymond, 2006). For instance, Dougher et al. (2007) examined the transformation of discriminative and elicited functions within a three-member comparative relational network. Participants were first exposed to a relational training phase in which they were presented with one of three arbitrary sample stimuli (A, B, and C) in the top portion of the computer screen, and three comparison stimuli in the bottom portion of the screen. The comparison stimuli were physically similar but differed in terms of size (i.e., small, medium, and large). The purpose of this phase was to train participants to select the smallest comparison in the presence of stimulus A, the medium comparison in the presence of stimulus B, and the largest comparison in the presence of stimulus C. Once participants met criterion at testing, they were exposed to a bar press training and test phase. They were initially trained to press the spacebar at a steady rate to the B stimulus. Once they pressed the spacebar at a constant rate for three consecutive trials in the presence of stimulus B, they were exposed to a test phase involving trials on which either the A, B, or C stimulus was presented by itself and they were required to press at a certain rate in response. Results demonstrated that participants pressed slower to stimulus A and faster to stimulus C than they did to B. During a subsequent phase of the experiment, participants were exposed to respondent conditioning with stimulus B, and testing with stimuli A and C. Thus, stimulus B was paired with a mild shock, and changes in skin conductance were employed as the dependent variable. The researchers found that six out of eight participants demonstrated smaller skin conductance changes to stimulus A, and larger changes to stimulus C, than to stimulus B.

Dougher et al. (2007) can be argued to represent the first demonstrations of the transformation of rate of bar pressing as a discriminative function and the transformation of eliciting functions via "more" and "less" relations. However, the scope of these findings may be limited due to the training and testing protocol employed. In typical transformation of functions research, especially involving derived nonsameness relations (e.g., Dymond & Barnes, 1995), the researchers first establish arbitrary stimuli as contextual cues for generalized relational responding using a training protocol in which responding in accordance with physical (nonarbitrary) relations between stimuli is reinforced in the presence of those arbitrary stimuli. Then, in a later stage of the procedure, those cues are used to establish an arbitrary relational network. As such, the training and testing of the derived relational network is entirely separate from the nonarbitrary relational training and testing protocol used to establish the contextual cues.

This was not the case in Dougher et al. (2007). It could be argued that the procedure they used produced functions of a relatively small set of stimuli in A, a relatively medium set of stimuli in B and a relatively large set of stimuli in C. Thereafter through further conditional discriminative training, these functions might have simply transferred to the arbitrary stimuli used as comparisons in subsequent experiments and these directly acquired nonarbitrary functions might have resulted in the functional patterns displayed by participants (i.e., as opposed to via transformation of functions through relational frames induced by more conventionally produced contextual control stimuli). To the extent that this might have been the case, this could limit or even preclude the utility of these stimuli as relational contextual cues because the direct transfer of particular nonarbitrary qualities to stimuli (e.g., arbitrary stimuli employed subsequently in a study) is not a process that can facilitate relational framing of such stimuli in truly arbitrarily applicable fashion.

In contrast to the A, B, and C stimuli that feature in Dougher et al. (2007), the contextual cue stimuli produced by more conventional training processes used within RFT research are not based on simple conditional discriminative procedures involving direct association between the cue stimuli and other stimuli with particular nonarbitrary qualities but instead feature in formats in which the arbitrary stimuli to be established as contextual cue accompany multiple exemplars of the reinforcement of a relational response between at least two other stimuli. Such training thereby directly confers a relational control function to the cue stimulus rather than allowing the possibility that it might simply be acquiring nonarbitrary functions of associated stimuli. As a result of this training, the resulting cue stimuli can facilitate relational framing of subsequent arbitrary stimuli in a truly arbitrarily applicable way independent of the transfer of nonarbitrary functions.

Apart from this, even if the relations between the stimuli involved in the three stimulus networks used in Dougher et al. (2007) can be argued to be derived, the type of derivation involved was limited to "more than" relations. In both Experiments 1 and 2, which showed the transformation of function, the trained relations in the key transformation of function effects were always relations of "less than" and thus the derived relations were always relations of "more than". Hence this is another potential limitation. This and the phenomenon described in the previous paragraph are limitations with respect to the significance of the basic

[1] The terms "symbolic generalization" and "transformation of functions" will be used interchangeably (Dymond, Bennett, Boyle, Roche, & Schlund, 2018).

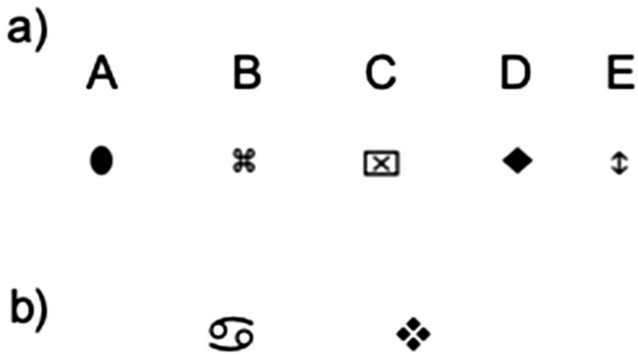

Fig. 1. Experimental stimuli. **a** The five abstract images employed during arbitrary relational training and testing, and labeled A, B, C, D and E in the interests of clarity (participants were never exposed to these labels). **b** The two contextual cues from the Wingdings font for more-than and less-than, respectively (counterbalanced across participants)

empirical effect, not least regarding the modeling of human language processes, which is a key application of transformation of function research. The first limits the model with respect to simulating the highly abstract nature of language whereas the second limits it with respect to the potential range of derived relations.

Thus, the present study focused on extending the line of research reported by Dougher et al. (2007) by examining whether transformation of rate of bar pressing as a discriminative function might be demonstrated using procedures more conventional within RFT research and examining both derived "less-than" and "more-than" relations.

Table 1 Training and test trials received by the "all-more" and "all-less" groups in Experiments 1–3.

Group	Relation type	Test trial type
		Test 1
		Specific relations in each group
All-less	Baseline	A < B B < C C < D D < E
	ME	B > A C >B D > C E > D
All-more	Baseline	B > A C > B D > C E > D
	ME	A < B B < C C < D D < E
		Test 2
		Specific relations in each group
All-less	Baseline	A < B B < C C < D D < E
All-more	Baseline	B > A C > B D > C E > D
		Relations common to all groups
	CE1	C > A D > B E > C A < C B < D C < E
	CE2	D > A E > B A < D B < E

"Baseline" refers to test trials involving directly trained relations, and the acronyms ME, CE1, and CE2 refer to test trials for mutually entailed and one- and two-node combinatorially entailed relations, respectively. The inequality symbols, < (LESS-THAN) and > (MORE-THAN), denote the contextual cue that was presented: This indicates which comparison should be "selected over" the other, with the reinforced comparison to the left, and the punished comparison to the right of the inequality symbol. It is important to note that the actual contextual cues used in the present study consisted of abstract visual images, and not the inequality symbols described here, which are used for the purposes of clarity

Experiment 1

In Experiment 1, participants were first exposed to nonarbitrary relational training and testing to establish the contextual functions of MORE-THAN and LESS-THAN for two abstract images. Arbitrary relational training and testing followed, where one group of participants received training on "More-than" baseline relations (e.g., B > A, C > B, D > C, and E > D) and another group received training on "Less-than" baseline relations (A < B, B < C, C < D, and D < E). Both groups were tested with a combination of "More-than" and "Less-than" relations (e.g., C > A and A < C; see Table 1 for a list of the arbitrary training and test relations to which participants in the All-More and All-Less groups were exposed). Next, participants were exposed to a bar-press training phase, which trained a steady rate bar-pressing response function to the middle stimulus (C) in the relational network. A test for transformation of discriminative functions followed, in which participants were exposed to probe trials involving all members of the relational network (A–B–C–D–E). In this test phase, the members of the relational network were presented three times each in a quasi-random order within a test block (in the corresponding phase in Dougher et al. (2007), test stimuli were each presented once in a fixed order). It was predicted that participants would respond "more" to the stimuli higher in the network (e.g., D and E), and "less" to the stimuli lower in the network (e.g., A and B), as evidenced by bar-pressing rates. Predicted performance consisted of a higher rate of bar pressing to stimuli derived as more and a lower rate of bar pressing to stimuli derived as less; heretofore, we will signify this as simply "pressed more" and "pressed less," respectively, to particular stimuli.

Method

Participants Seventeen participants, eight males and nine females, between 19 and 36 years old (M_{age} = 23.88, SD = 5.56), were recruited through personal contacts and notice-board announcements at Swansea University and paid £8 on completion.

Apparatus and Setting The study was conducted in a quiet experimental room (2 x 3 m) using a standard desktop computer with a 16-inch display screen. All stimulus presentation and data recording were controlled via custom software written in Visual Basic.NET.

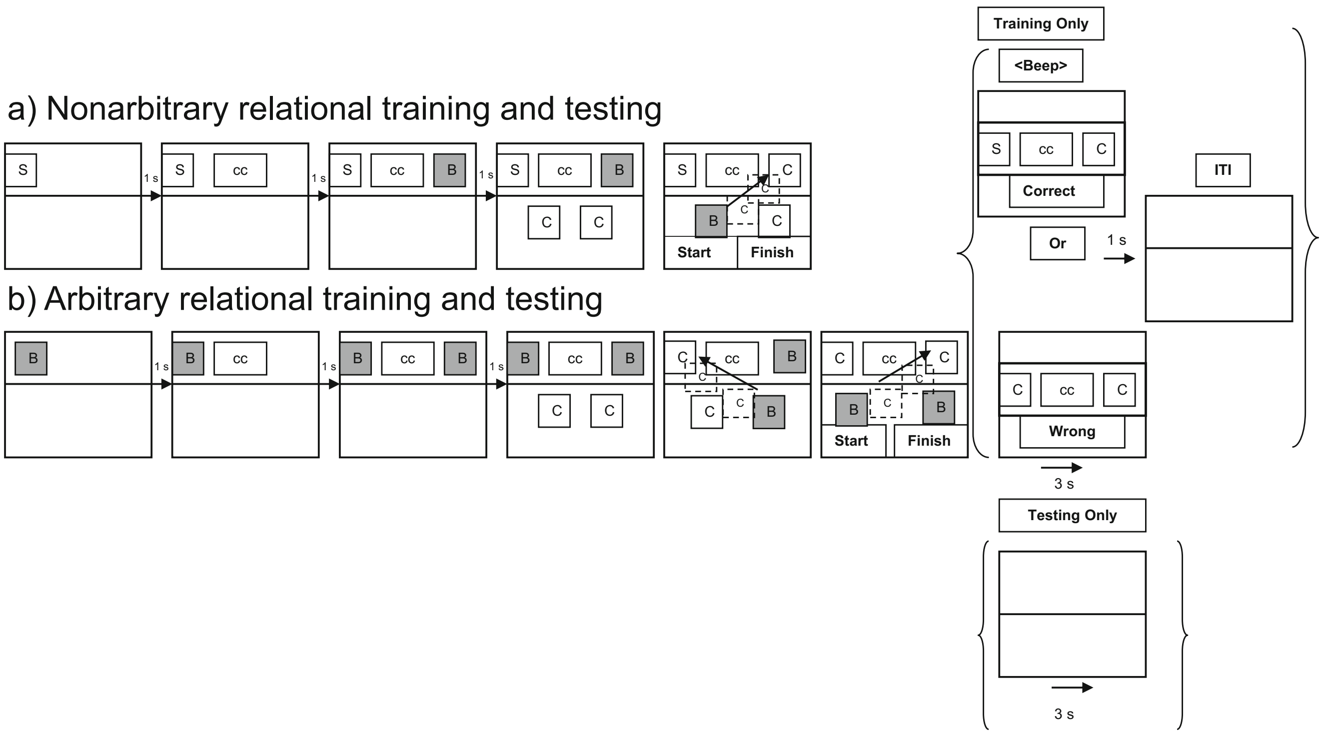

Fig. 2. Schematic diagram of the Relational Completion Procedure. The sequence of presentation of stimuli during the constructed-response (**a**) nonarbitrary and (**b**) arbitrary relational training and test phases. *Note*: S = sample; B = blank square; cc = contextual cue; C = comparison; ITI = inter-trial interval. A dashed line represents dragging of a comparison stimulus. "Finish" and "Start" indicate the confirmatory response buttons, respectively. Arrows pointing from B to C illustrate that once selected, the comparison stimulus moved to the top portion of the screen, while its original screen position was replaced by a blank square. See text and Munnelly et al. (2013) for further details

Materials and Stimuli Two arbitrary images from the Wingdings font were employed as the contextual cues for MORE-THAN and LESS-THAN, respectively, and assignment was counterbalanced across participants. Twenty-eight stimulus sets consisting of images of varying quantities of objects were used as relata during nonarbitrary relational training and testing. For the arbitrary relational training and testing phases, five abstract images (see Fig. 1) were used as stimuli (A–B–C–D–E).

Procedure The general nonarbitrary and arbitrary procedural sequence was based on the Relational Completion Procedure previously employed by Munnelly, Freegard, and Dymond (2013) and was as follows: *Phase 1A: Nonarbitrary Relational Training* and *Phase 1B: Nonarbitrary Relational Testing; Phase 2A: Nonarbitrary Relational Training* and *Phase 2B: Nonarbitrary Relational Testing; Phase 3: Arbitrary Relational Training; Phase 4: Arbitrary Relational Test 1; Phase 5: Arbitrary Relational Test 2*. Following the nonarbitrary and arbitrary relational training and test phases, participants were exposed to *Phase 6: Bar-press training with stimulus C and testing with stimuli A, B, C, D, and E.*

Nonarbitrary and arbitrary relational training. During the nonarbitrary and arbitrary relational training and test phases, the computer screen was divided in two, the top portion (roughly two-thirds) of the screen was blue, whereas the bottom portion was white. During Phases 1–5, a blank yellow square appeared first in the upper left-hand side of the screen. Following a delay of 1 s, the contextual cue (e.g., MORE-THAN/LESS-THAN) appeared in the upper center of the screen, and a blank yellow square was presented following a 1 s delay in the upper right-hand side of the screen. Following a further delay of 1 s, two comparison stimuli appeared simultaneously in the lower portion of the screen (see Fig. 2; please note that this figure is not intended to represent the proportions of the screen but only to convey the response requirements and main processes at work during relational training and testing). The left/right positioning of these comparisons was counterbalanced across trials.

In order to make a response, participants were required to "construct" their responses, from left to right in the upper portion of the computer screen. That is, they were instructed to place one of the comparison stimuli in the upper-left blank yellow square and the other comparison in the upper-right blank yellow square. This was achieved by placing the mouse cursor over the comparison stimulus that they had selected as their response. Immediately upon making this selection, a red border appeared around the comparison stimulus to highlight their selection. Participants then clicked on, and held down the left mouse button, while dragging their selection to the blank yellow square. Releasing the left mouse button allowed the selected comparison to "drop" into the blank yellow square. At the same time, the screen position from which the comparison stimulus originated was replaced by a blank yellow square.

Once both comparisons were placed in the blank yellow squares, two confirmatory response buttons appeared simultaneously at the bottom of the screen. One button was labeled "Finish Trial," and by hovering the mouse cursor over this button, a small text box with the caption "Click here to Finish Trial" appeared onscreen. The second button was labelled "Start Again" and hovering over this button produced the caption "Click here to Start Again." If the participant pressed the "Start Again" button, this canceled the selection and resulted in all stimuli returning to their positions before the selection was made. That is, the comparison stimuli that were selected returned to the lower left and right portions of the screen, whereas the blank yellow squares returned to the upper left and right of the screen.

All stimuli remained onscreen until the participant pressed the "Finish Trial" button. Training trials were then followed by feedback presented on a blue background for 3 s. When a participant made a correct response, feedback consisted of, from left to right, the comparison stimulus, contextual cue, and the comparison stimulus the participant had selected (i.e., dragged and dropped) on the previous trial. A yellow border surrounded all three images, and the word "Correct!" was presented in black underneath. A brief audible beep was presented following the word "Correct!" The only difference between feedback for a correct selection, and feedback for an incorrect selection, was that the word "Correct!" was replaced by the word "Wrong," and no audible tone followed feedback. In testing trials, no feedback was presented, and instead the screen cleared and remained blue for 3 s. An intertrial interval (ITI) of 1 s followed each trial, wherein the computer screen cleared and remained blue for the duration of the ITI.

A task "feedback thermometer" was displayed in the center, right-hand side of the screen during all training and testing phases (Fienup, Covey, & Critchfield, 2010). During training, the thermometer displayed the mastery criterion needed to complete training (e.g., "You need this many correct to move on: 10") and the current number of correct responses (e.g., 6 out of 10), and the latter was incremented following every correct response. During testing, the thermometer displayed the total number of trials in the particular test phase and the current trial number, and the latter was incremented following every response.

Phase 1A: *Nonarbitrary relational training.* The purpose of this phase was to train participants to "construct" the relation between two comparison stimuli, in the presence of a particular contextual cue (e.g., MORE-THAN/LESS-THAN). In each trial, participants were presented with a blank yellow square, a contextual cue, and another blank yellow square in the upper portion of the screen and two comparison stimuli in the lower portion. For example, they might have been presented with MORE-THAN as the cue, and pictures of four and two bicycles, respectively, as the comparisons. A correct response in that case would have involved "dragging" and "dropping" the four bicycles to the upper-left blank yellow square and the two bicycles to the upper-right blank yellow square, *in that left-to-right sequence*. Any variations to this sequence resulted in comparison returning to their starting positions. On the other hand, if LESS-THAN was presented as the cue with the same comparisons, then placing the two bicycles in the upper-left square, and the four bicycles in the upper-right square was correct. Feedback was presented following all training trials.

Participants were presented with four stimulus sets during training, and mastery criterion was set at 10 consecutive correct responses. If they met the training criterion, they were immediately exposed to the nonarbitrary relational test phase. If they failed to meet it within 240 training trials, they were then exposed to a second nonarbitrary relational training phase, with four novel stimulus sets.

Phase 1B: *Nonarbitrary relational test.* This phase was similar to Phase 1A. Participants were presented with four novel stimulus sets, and all feedback was omitted. They were presented with a total of eight test trials and were required to respond correctly across all eight trials in order to progress to the next phase. If they failed to meet this criterion, they were reexposed to nonarbitrary relational training (Phase 1A) involving the same four stimulus sets followed once again by a nonarbitrary relational test if they passed.

Phase 2A: *Nonarbitrary relational training.* This phase was identical to Phase 1A with the exception that participants were presented with four novel stimulus sets. A second nonarbitrary training phase was conducted because previous research has suggested that additional training may more readily facilitate the emergence of derived comparative responding (Vitale, Barnes-Holmes, Barnes-Holmes, & Campbell, 2008).

Phase 2B: *Nonarbitrary relational testing.* This phase was identical to Phase 1B, with the exception that participants were presented with four novel stimulus sets.

Phase 3: *Arbitrary relational training.* During this phase, the comparison stimuli consisted of arbitrary images, which, for purposes of clarity, are labeled A, B, C, D, and E (Fig. 1). Participants were presented with training trials in a linear order, and training pairs differed between the All-More and All-Less training groups. The All-More group were trained B > A, C > B, D > C, and E > D, in the presence of the MORE-THAN contextual cue and the All-Less group on A < B, B < C, C < D, and D < E, in the presence of the LESS-THAN contextual cue. All training pairs were presented in this order for both groups (see Table 1).

For both groups, the four training pairs were presented for a total of three times each, resulting in a block of 12 training trials. Mastery criterion for the arbitrary relational training phase was set at 12 out of 12 correct responses (i.e., 100% accuracy) on any given block. Training blocks were repeated until participants achieved this criterion.

Phase 4: *Arbitrary relational test 1.* Upon reaching arbitrary relational training criterion, participants were exposed to an arbitrary relational test phase that probed for mutual entailment (i.e., deriving a relation in the opposite direction to that trained; e.g., if A > B is trained then B < A may be derived) with respect to trained arbitrary relations, alongside maintenance of those trained relations. All feedback was now omitted, and participants were presented with 4 baseline trials and 4 test trials each presented four times for a total of 32 trials (see Table 1). The mutual entailment trial type differed between the groups; the All-More group received A < B, B < C, C < D, and D < E, whereas the All-Less group received B > A, C > B, D > C, and E > D.

Mastery criterion for this phase was set at a minimum mean of 12 out of 16 correct responses on the baseline relations. For the mutually entailed relations, participants were required to make three out of four correct responses on each individual mutually entailed trial type. If participants were successful in meeting criterion for both baseline and mutually entailed relations, they progressed to a second arbitrary relational test phase. If they failed to reach this mastery criterion, they were reexposed to the experimental task from the beginning for a maximum of three further exposures.

Phase 5: *Arbitrary relational test 2.* This test phase commenced immediately upon the successful completion of Phase 4. Participants were presented with probes for one- and two-node combinatorially entailed relations (i.e., derived relations based on the combination of taught relations; e.g., if A > B and B > C are taught then A > C and C < A may be derived), as well as the four baseline relations. Each trial type was presented four times, in a quasi-random order, which resulted in a total of 56 test trials (see Table 1). Participants were again required to make a minimum mean of 12 out of 16 correct responses on the baseline relations. All participants (i.e., in both groups) were presented with the same one- and two-node combinatorially entailed relations (one- and two-node derived relations are based on the combination of two and three taught relations, respectively).

Participants had to make a minimum of three out of four correct responses on each individual one- and two-node test trial in order to progress to Phase 6. If this criterion was not met, they were reexposed to the entire task from Phase 1, for a maximum of three further exposures.

Phase 6: *Bar-press training with stimulus C and testing with stimuli A, B, C, D, and E.* In this phase, participants were trained to press the spacebar on the computer keyboard at a steady rate when stimulus C was presented onscreen. The phase began with the following onscreen instructions:

During this part of the experiment, a symbol from the previous part will appear in the center of the computer screen. When you see the symbol, your task is to repeatedly press the spacebar on the keyboard for the entire time the symbol is presented. Do not just hold down the spacebar; press it repeatedly. Your task is to try and obtain a steady rate of spacebar presses in the presence of this symbol. Each time you press the spacebar, a mark will appear on the bottom of the computer screen. There is no feedback other than this during this phase of the experiment. The same symbol will appear repeatedly until you press the spacebar at a steady rate in the presence of this symbol. Later, a number of other symbols from the previous parts will be presented. Again, your task is to press the spacebar, at a rate you feel appropriate, for each new symbol. Please ask the experimenter if you have any questions.

Clicking on the OK button removed the instructions and signaled the start of Phase 6. The training phase aimed to establish a steady rate of bar pressing in the presence of stimulus C, which was presented in the center of the computer screen. Each time a participant pressed the spacebar, a dash appeared on the bottom of the screen to signal that one more bar press had been made. Participants were first exposed to a practice trial in which the experimenter showed how many bar-presses they were required to make to stimulus C during that trial by pressing the spacebar at a steady rate of one bar press per second for a duration of 30 s. The program was then restarted, and the experimenter instructed the participant to respond to the stimulus in exactly the same manner. In order to meet criterion on this test phase, participants were required to make 30 bar presses (+/- 10%) to stimulus C, for three consecutive trials. Training trials were repeated until this criterion was achieved. At that point, participants were immediately exposed to a test phase, in which each of the five stimuli from the previous phase (i.e., A, B, C, D, E) was presented by itself for a duration of 30 s. The stimuli were presented in a quasi-random order, for a total of three times each, resulting in a total of 15 test trials. No criterion was in place during testing. At the end of the 15th test trial, participants reported to the experimenter and were debriefed.

Results and Discussion

All-More Table 2 displays the trials to criterion for participants during the nonarbitrary and arbitrary relational

Table 2 Trials to criterion for the All-More and All-Less training groups during non-arbitrary and arbitrary relational training and number correct during arbitrary relational testing phases in Experiment 1

	Phases 1A & 2A: NARB Relational Training		Phase 3: Arbitrary Relational Training	Phase 4: Arbitrary Relational Test 1 (mutual entailment)		Phase 5: Arbitrary Relational Test 2 (combinatorial entailment)		
Participant	Training		Training	B	ME	B	CE1	CE2
All-More Group	1A	2A						
1	11	10	36	16/16	16/16	16/16	23/24	16/16
2	11	10	24	16/16	16/16	16/16	24/24	16/16
3	10	10	36	16/16	16/16	16/16	24/24	16/16
4	15	10	36	15/16	15/16	12/16	14/24	11/16
	10	10	36	16/16	16/16	15/16	23/24	16/16
5	11	10	36	16/16	16/16	16/16	24/24	16/16
6	23	10	36	11/16	11/16			
	10	10	24	16/16	16/16	16/16	24/24	16/16
7	18	10						
		10	36	16/16	16/16	14/16	24/24	16/16
8	11	10	36	16/16	16/16	16/16	24/24	16/16
9	24	10	24	15/16	16/16	16/16	24/24	16/16
All-Less Group	1A	2A						
10	11	10	24	16/16	16/16	16/16	24/24	16/16
11	12							
	10	10	60	16/16	16/16	13/16	19/24	13/16
	10	10	24	16/16	16/16	16/16	24/24	16/16
12	11	10	24	16/16	16/16	16/16	24/24	16/16
13	11	10	36	16/16	16/16	16/16	24/24	16/16
14	11	10	24	16/16	14/16			
	10	10	12	16/16	16/16	12/16	24/24	16/16
15	11	10	24	16/16	16/16	16/16	24/24	16/16
16	11	10	24	16/16	16/16	16/16	24/24	16/16
17	11	10	24	16/16	16/16	15/16	24/24	15/16

Note. NARB = Non-arbitrary; 'Training' refers to trials to criterion per indicated phase; 'B' (Baseline) refers to test trials involving directly trained relations; ME = mutually entailed; and CE1 and CE2 = one- and two-node combinatorially entailed relations, respectively. Data are displayed for the number of correct responses to the baseline and mutually entailed relations during Test 1 and also to the baseline and one- and two-node relations during Test 2

training phases. All nine participants required between 10 and 24 (NARB1: M = 14.00, SD = 5.31; NARB2: M = 10.00, SD = .00) trials to reach criterion during the non-arbitrary relational training phases. The number of trials required to achieve arbitrary relational training criterion ranged between 24 and 36 (M = 32.73, SD = 5.61). All nine participants successfully completed both arbitrary relational test phases and required between 1 and 2 (M = 1.22, SD = .44) exposures to testing to do so (see Table 2). When participants met Test 1 criterion, eight (P1, P2, P3, P4, P5, P6, P7, and P8) made no errors on the baseline relations, whereas one (P9) made one error. None of the participants made any errors on the mutually entailed relations when they met Test 1 criterion. When they met Test 2 criterion, seven (P1, P2, P3, P5, P6, P8, and P9) made no errors on the baseline relations, P4 made one error, and P7 made two errors. Seven participants (P2, P3, P5, P6, P7, P8, and P9) made no errors on the one-node relations, whereas two (P1 and P4) made one error. None of the participants made any errors on the two-node relations when they met Test 2 criterion.

Bar-Press Training with Stimulus C, and Testing with Stimuli A, B, C, D, and E In order to meet training criterion during Phase 6, participants were first required to make 30 spacebar presses (+/- 10%) across three consecutive exposures to stimulus C. Participants needed between 3 and 53 (M = 22.67, SD = 16.07) training trials to meet criterion.

They were then exposed to testing with stimuli A, B, C, D, and E, which were presented three times each in a quasi-random order. Results for each participant from this part of the experiment are discussed with respect to the number of bar presses participants made to each of the five stimuli the first, second, and third time they encountered these stimuli.

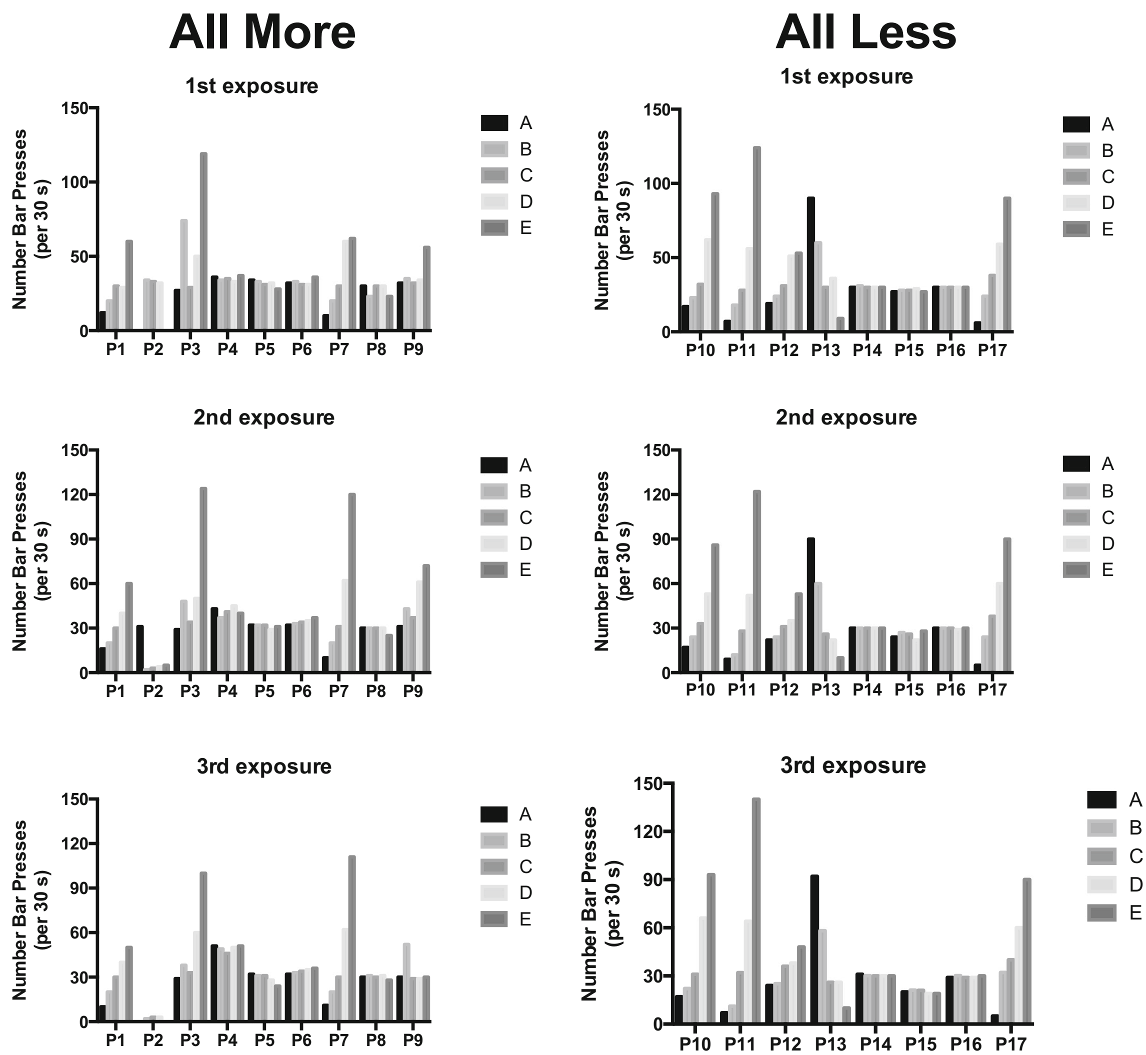

Fig. 3. The number of bar presses made per 30 s to stimuli A, B, C, D and E, for the *All-More* group (right panels) and *All-Less* group (left panels) for the first, second and third exposure to the bar press test phase in Experiment 1. The upper figure refers to the number of bar presses (per 30 s) that participants made the first time they encountered each stimulus during testing, the middle figure refers to the number of bar presses made the second time they encountered the test stimuli, whereas the bottom figure refers to number of bar presses made the third and final time they encountered these stimuli

In total, three out of nine participants (P1, P6, and P7) in the All-More group pressed the spacebar "less" to stimuli A and B, and "more" to stimuli D and E than to stimulus C. P7 was the only participant to do so consistently across all three exposures to the test stimuli. P1 and P6 demonstrated transformation on their second and third exposures but not their first. P3 showed a pattern of transformation for three of the four untrained stimuli (i.e., A, D, and E) across three exposures but not for B. Thus, this participant might be argued to have produced a partial pattern of transformation. None of the remaining participants produced any consistent "more" or "less" responding.

All-Less Table 2 displays the trials to criterion for participants during the nonarbitrary and arbitrary relational training phases. All eight participants only required between 10 and 12 (NARB1: M = 10.82, SD = .60; NARB2: M = 10.00, SD = .00) trials to reach criterion during the nonarbitrary relational training phases. The number of trials required to meet the arbitrary relational training criterion ranged between 12 and 60 (M = 27.60, SD = 12.71). All eight successfully completed both arbitrary relational test phases, requiring between 1 and 2 (M = 1.25, SD = .47) exposures to testing to do so (see Table 2). When participants met the Test 1 criterion, none made errors on the baseline or mutually entailed relations. When they met the Test 2 criterion, six made no errors on the baseline and two-node relations (P10, P11, P12, P13, P15, and P16), whereas one (P17) made one error and one (P14) made four errors. None of the eight participants made errors on the one-node relations when they met the Test 2 criterion.

Bar Press Training with Stimulus C, and Testing with Stimuli A, B, C, D and E Participants were first required to make 30 spacebar presses (+/- 10%), across three consecutive exposures to stimulus C. Participants needed between 3 and 31 ($M = 7.63$, $SD = 9.61$) trials to reach criterion.

Half of the All-Less participants (P10, P11, P12, and P17) showed transformation of functions of all four untrained stimuli for all three exposures; that is, all four pressed the spacebar “more” to stimuli D and E and “less” to A and B than to C (see Fig. 3).

Overall, in the All-Less group also, there was variation across participants. Only half (P10, P11, P12, and P17) demonstrated the predicted transformation of functions (though all four displayed consistent transformation across all exposures to the test stimuli). Of the participants that failed to demonstrate the predicted pattern, P13 showed the opposite of this pattern, P14 and P16 responded almost equivalently to all test stimuli, and P15 responded the same number of times to B and C and “less” to A, D and E.

Binomial Probability Analysis To analyze the pattern of transformation of functions from across both groups in Experiment 1, we employed binomial probability analysis to test the likelihood that the overall pattern of transformation of functions might have been seen by chance alone. To show bar pressing in accordance with A < B < C < D < E it can be considered that four response patterns as follows are required: A < B, B < C, D > C, E > D. It can be assumed that if a participant is simply guessing then each of these unidirectional relations might have a 50% chance of occurring. Hence chance alone would mean that the overall pattern would have a .5*.5*.5*.5 chance, which is a probability of 0.0625. Experiment 1 can be seen as having a total of 51 (17 by 3) trials (opportunities to pass or fail to show the pattern) with a total of 19 successes across both groups. Given a probability of success on each trial of 0.0625, the probability of this pattern or better occurring by chance is $p < 0.000001$.

The results of Experiment 1 showed considerable variation in responding across participants during the test for transformation of discriminative functions. These findings are in contrast to those of Dougher et al. (2007), in which all eight participants in Experiment 1, and five out of six in Experiment 2 responded in accordance with the rank ordering of the three-member network (A < B < C). One factor that differed between the studies was the order of stimulus presentations during transformation tests. In the present study, the stimuli were presented in a quasi-random order, three times each within a test block. In contrast, in the Dougher et al. study the test stimuli were presented once each in a fixed stimulus sequence (e.g., A–B–C). In order to determine whether the sequence of stimulus presentation during transformation tests influences performances, and hence reduce the variability seen thus far, Experiment 2 adopted a fixed-order method of stimulus presentation.

Experiment 2

Experiment 2 sought to examine the potential facilitative effects of presenting the five members of the relational network in a fixed order during the transformation tests. Thus, after training with stimulus C, participants were given one test exposure with stimuli presented in the following sequence: C, C, A, B, C, D, and E. Moreover, to demonstrate that prior nonarbitrary and arbitrary relational training and testing was necessary for the predicted transformation of functions to occur, several control participants were first trained to press the spacebar at a steady rate to stimulus C before being exposed to the same bar-press test as experimental participants.

Method

Participants Nine participants, five males and four females, ranging in age from 20 to 33 years ($M_{age} = 26.00$, $SD = 6.24$), were recruited through personal contacts at Swansea University and assigned to either the experimental (five participants) or the control group (four participants). Participants received either partial course credit or £5 on completion of the task.

Procedure The general procedure for Phases 1A–5 was identical to that employed in Experiment 1. The experimental participants were exposed to all of these phases as well as a modified Phase 6 (bar-press training and testing), whereas the four control participants were not exposed to nonarbitrary or arbitrary relational training and testing but received training and testing for the bar-press training phase alone. Two of the experimental participants were exposed to All-Less training of the baseline relations (P18 and P19), whereas three were exposed to All-More training (P20–P22). Phase 6 in Experiment 2 differed from Phase 6 in Experiment 1 in that participants were exposed to the test stimuli in a fixed (as opposed to random) order and were exposed to each only once (as opposed to three times).

Phases 1A–5. All phases and mastery criterion were identical to Experiment 1.

Phase 6. Bar-press training with stimulus C and testing with stimuli A, B, C, D and E. The bar-press training was identical to Experiment 1. However, during testing, all participants received one exposure to the test stimuli (A, B, D and E) and three exposures to the trained stimulus (C) in the following order: C, C, A, B, C, D, and E. Once again, no test criterion was employed.

Results and Discussion

Only the five experimental participants were exposed to relational training and testing. Of those, four (P18, P19, P21, and P22) successfully completed both arbitrary relational test phases, requiring between 1 and 2 (M = 1.50, SD = .58; see Table 3) exposures to testing to do so whereas P20, who was given All-More relational training, failed to meet the Test 1 criterion following the maximum of exposures to this test phase. Table 3 displays the trials to reach the criterion for the four successful participants during the nonarbitrary and arbitrary relational training phases. They required between 10 and 15 (NARB1: M = 12.00, SD = 2.37; NARB 2: M = 10.00, SD = .00) trials to reach the criterion during the nonarbitrary relational training phases. The number of trials required to meet the arbitrary relational training criterion ranged between 12 and 36 (M = 26.00, SD = 9.03) trials. A summary of performance accuracy during Tests 1 (mutual entailment) and 2 (combinatorial entailment) for these four participants can be seen in Table 3. When meeting the Test 1 criterion, three (P18, P21, and P22) made no errors on the baseline relations, whereas one (P19) made two errors and no-one made any errors on the mutually entailed relations. When meeting Test 2 criterion, three (P18, P19, and P22) made no errors on the baseline relations; one (P21) made one error; three (P19, P21, and P22) made no errors on the one-node relations; one (P18) made three errors; and two (P19 and P22) made no errors on the two-node relations, whereas one (P18) made one error, and another (P21) made three errors.

During Phase 6 discriminative function training, participants were first required to make 30 spacebar presses (+/-10%) across three consecutive exposures to stimulus C. Results demonstrated that they required between 3 and 20 (M = 10.50, SD = 7.94) trials to reach criterion. During Phase 6, none of the four participants showed the predicted transformation of functions.

Bar-press training with stimulus C and testing with stimuli A, B, C, D, and E

Experimental Participants None of the experimental participants (P18, P19, P21, and P22) produced a consistent, predicted performance (Fig. 4). P18 demonstrated the predicted transformation of functions to B and D, but not to A and E. P19 showed a pattern opposite to that predicted. P21 demonstrated the transformation of discriminative functions to A and B, but not to D or E. P22 pressed the spacebar "more" to A, B, D and E than to C whereas pressing "more" to D and E than to C would be predicted; P22 also pressed "more" to D than to E, though the latter should be ranked higher in the comparative relational network.

Control Participants The number of trials required by the control participants to meet training criterion ranged between 3 and 4 (M = 3.25, SD = .50). Three (P24, P25, and P26) pressed the spacebar an equal number of times to each of the five test stimuli when they were presented (see Fig. 4). P23 only responded when stimulus C was presented. That is, every time stimulus C was presented, P23 pressed the spacebar 30 times, but made no bar presses when the other members of the relational network were presented. Thus, the pattern of responding observed with the control participants would be expected given the fact that these participants did not receive relational training.

The fixed-order stimulus presentation during transformation tests (i.e., A–B–C–D–E) did not lead to the predicted patterns of performance for the experimental participants in Experiment 2 (and, likewise, for the control participants). It may have been beneficial to reexpose participants to additional training and test phases if they initially failed to display the predicted behavioral patterns. Experiment 3 therefore aimed to examine the effects of presenting the stimuli in the bar press training and test phases in a fixed order for a total of two times.

Experiment 3

Experiment 3 sought to further examine the potential facilitative effects of presenting the five members of the relational network in a fixed order during transformation tests. Control participants did not receive any nonarbitrary or arbitrary relational training and testing. Here, all participants were exposed to the Phase 6 bar-press training and fixed sequence testing twice.

Method

Participants Eight participants, three males and five females, ranging in age from 21 to 32 years (M_{age} = 26.50, SD = 1.23), were recruited through personal contacts and the psychology subject pool at Swansea University and randomly assigned to either the Experimental or Control group. Participants received either partial course credit or £5 on task completion.

Procedure The general procedure was identical to Experiment 2 with the exception that during Phase 6, participants were exposed to the bar-press training and fixed sequence testing twice.

Results and Discussion

Table 4 displays the trials to reach the criterion for the four experimental participants (P27, P28, P29, P30) during the nonarbitrary and arbitrary relational training phases. They required between 10 and 21 (NARB1: M = 14.00, SD = 4.24; NARB 2: M = 10.00, SD = 0.00) trials to reach the criterion during the nonarbitrary relational training phases. The number of trials required to

Table 3. Trials to criterion for experimental participants during nonarbitrary and arbitrary relational training and number correct during arbitrary relational testing phases in Experiment 2

	Phases 1A&2A: NARB Relational		Phase 3: Arbitrary Relational	Phase 4: Arbitrary Relational Test 1 (mutual entailment)		Phase 5: Arbitrary Relational Test 2 (combinatorial entailment)		
Participant	Training		Training	B	ME	B	CE1	CE2
18 (All-More)	11	10	24	15/16	14/16	6/16	1/24	1/16
	10	10	24	16/16	16/16	16/16	21/24	15/16
19 (All-Less)	15	10						
		10	36	14/16	16/16	16/16	24/24	16/16
20 (All-More)*	15	10	60	16/16	1/16			
	10	10	12	16/16	0/16			
	10	10						
	10	10	12	16/16	0/16			
		10	12	16/16	0/16			
21 (All-Less)	15	10	36	8/16	15/16			
	10	10	12	16/16	16/16	15/16	24/24	13/16
22 (All-More)	11	12	24	16/16	16/16	16/16	24/24	16/16

NARB = Nonarbitrary. "B" (Baseline) refers to test trials involving directly trained relations; ME = mutually entailed; and CE1 and CE2 = one- and two-node combinatorially entailed relations, respectively. Data are displayed for the number of correct responses to the baseline and mutually entailed relations during Test 1 and also to the baseline and one- and two-node relations during Test 2

*participants who failed to complete the experiment

meet the criterion ranged between 12 and 24 (M = 20.00, SD = 6.19). All four participants also successfully completed both arbitrary relational test phases and required between one and three (M = 1.5, SD = 1.00) exposures to testing to do so. Regarding the Test 1 criterion, three (P27, P28, and P30) made no errors on the baseline and mutually entailed relations, whereas one (P29) made one error on the baseline relations. Regarding the Test 2

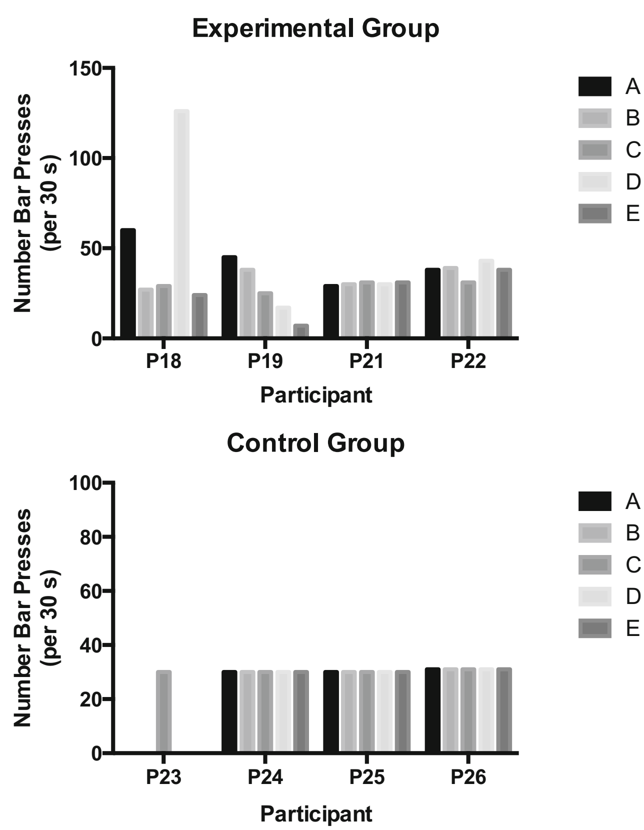

Fig. 4. The number of bar presses per 30 s to stimuli A, B, C, D and E for the four experimental (P18, P19, P20 and P22) and control (P23, P24, P25 and P26) participants in the bar-press testing phase of Experiment 2

criterion, no participant made errors on the baseline, or on one- or two-node relations.

Bar-Press Training with Stimulus C and Testing with Stimuli A, B, C, D, and E

Experimental Participants During bar-press training, all experimental participants required only three trials to reach criterion. Of the four participants that were exposed to tests for the transformation of functions, three (P27, P29, and P30) showed the predicted pattern of responding across the relational network by pressing the spacebar "more" to stimuli D and E and "less" to A and B than to C (see Fig. 5).

Control Participants The number of trials required by the control participants to meet the training criterion was three. None of the control participants produced consistent, predicted performances.

Binomial Probability Analysis

To analyze the pattern of transformation of functions across Experiments 2 and 3, we again employed binomial probability analysis. For this purpose, it was decided to amalgamate the data from these two experiments because they differed only in terms of the number of trials allowed. Again, the probability of the predicted transformation of functions being seen on a particular trial by chance alone is 0.0625. In the case of the amalgamated data for Experiments 2 and 3, it can be considered that there was a total of 12 trials with 6 of those successful. Given a chance probability of 0.0625, the probability of seeing a pattern of 6 out of 12 trials correct or better is p = 0.0000396205.

General Discussion

The present experiments were concerned with the symbolic generalization (transformation) of discriminative functions in accordance with a five-member comparative relational network (A–B–C–D–E), with a view to replicating and extending the related work of Dougher et al. (2007). Experiment 1 showed that 7 out of 17 participants responded unambiguously in accordance with the five-member relational network (i.e., press "less" to A and B and "more" to D and E than to C). These findings contrast with those of Dougher et al. in which all participants in Experiment 1 (eight out of eight), and five out of six in Experiment 2, responded "less" to the stimuli ranked lower in the network and "more" to the stimuli ranked higher in the network. The purpose of Experiment 2 was to address the fact that fewer than half of the participants in Experiment 1 displayed the predicted patterns of performance during transformation tests. In addition, Experiment 2 was concerned with whether the fixed order of stimulus presentation employed in the Dougher et al. study influenced performances at test. Thus, in Experiment 2, participants were presented with the test stimuli, once each, in a fixed order. In Experiment 3, participants were exposed to transformation training and testing for a total of two times, irrespective of their initial test performances. Findings revealed that none of the participants in Experiment 2 responded in accordance with the five-member relational network, whereas three out of four participants in Experiment 3 did.

Taken together, these findings provide conflicting evidence regarding the emergence of derived discriminative functions via comparative relations. For example, only half of the participants in Experiment 1 displayed responding consistent with the preestablished relational network, when the test stimuli were presented in a quasi-random order during transformation tests. In addition, none of the participants in Experiment 2 demonstrated

Table 4 Trials to criterion for experimental participants during nonarbitrary and arbitrary relational training and number correct during arbitrary relational testing phases in Experiment 3. also displayed is individual data for the four experimental participants

	Phases 1A & 2A: NARB Relational		Phase 3: Arbitrary Relational	Phase 4: Arbitrary Relational Test 1 (mutual entailment)		Phase 5: Arbitrary Relational Test 2 (combinatorial entailment)		
Participant	Training		Training	B	ME	B	CE1	CE2
27 (All-Less)	16	10	24	16/16	16/16	16/16	24/24	16/16
28 (All-More)	15	10	24	16/16	16/16	16/16	24/24	16/16
29 (All-More)	21	10	24	15/16	15/16	16/16	24/24	16/16
30 (All-Less)	12	10	24	16/16	16/16	14/16	12/24	3/16
	10	10	12	16/16	16/16	13/16	15/24	8/16
	10	10	12	16/16	16/16	16/16	24/24	16/16

NARB = Nonarbitrary. "B" (Baseline) refers to test trials involving directly trained relations; ME = mutually entailed; and CE1 and CE2 = one- and two-node combinatorially entailed relations, respectively. Data are displayed for the number of correct responses to the baseline and mutually entailed relations during Test 1 and to the baseline and one- and two-node relations during Test 2

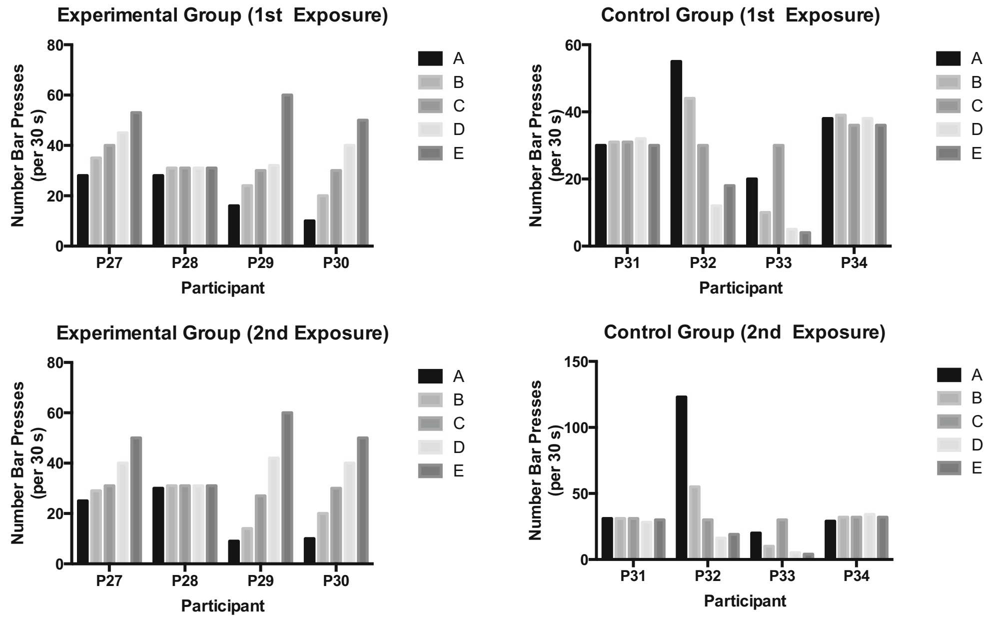

Fig. 5. The number of bar presses per 30 s to stimuli A, B, C, D and E for the four experimental (P27, P28, P29 and P30) and control participants (P31, P32, P33 and P34) in the bar press testing phase of Experiment 3. The upper figure refers to participants' responses during their first exposure to the transformation test phase, whereas the lower figure refers to responses during their second exposure to testing

the predicted patterns of performance when the test stimuli were presented in a fixed stimulus order, whereas three out of four participants in Experiment 3 did so (and on their first exposure), when given the transformation training and testing twice. Thus, it is unclear whether the fixed order of stimulus presentation was responsible or not for the successful performances observed in Experiment 3. Indeed, had participants in Experiment 2 been given an additional exposure it might have been possible to compare those participants with a fixed-order stimulus presentation with those that received the randomized order. As a result, we must therefore conclude that increasing exposures had no effect. Furthermore, the present study examined the transformation of discriminative functions to a five-member relational network, in contrast to the three-member network employed by Dougher et al. (2007). Thus, it remains to be seen whether different factors facilitate the transformation of discriminative functions to a three- and five-member arbitrary relational network. Further empirical work is warranted on this issue (see Munnelly, Dymond, & Hinton, 2010).

The present set of experiments aimed to address two potential limitations with Dougher et al.'s (2007) findings. For example, it was noted in the Introduction that results from the bar-press test phase in the Dougher et al. study may in fact have been reflective of transformation of functions in accordance with nonarbitrary relations. Second, it was argued that the derivation of relations in that study was limited to derived "more-than" relations. Both of these potential limitations were considered important with respect to modeling the basic effects of transformation of functions and modeling human language processes. For example, the training and testing protocols employed in the present study were considered to be representative of those typically used to examine derived comparative responding (e.g., Dymond & Barnes, 1995; Munnelly et al., 2010; Munnelly et al., 2013; Reilly, Whelan, & Barnes-Holmes, 2005; Whelan et al., 2006). That is, in the present study, the contextual functions of "more-than" and "less-than" were first established for two arbitrary stimuli, where responding to the nonarbitrary relation between stimuli was reinforced. Next, the two arbitrary contextual cue stimuli, which had been established as "more-than" and "less-than," were used to establish an arbitrary comparative relational network among five stimuli (A–B–C–D–E). Members of the arbitrary comparative network were then employed during the transformation of functions training and test phases. In contrast, in Experiment 1 of Dougher et al., the functions of particular arbitrary stimuli were first established by relating them directly to nonarbitrary features of comparison stimuli (i.e., the relative size of the comparisons). These arbitrary stimuli were then used as the relational network through which transformation of functions was said to have occurred. Despite this difference, the present study did provide a demonstration of the transformation of discriminative functions through the (five-member) comparative relational network involved, thus extending the results of Dougher et al. At the same time, the results of this study show a less reliable (i.e., across participants) pattern of transformation of functions than in Dougher et al. and it is possible that this outcome may be a function of the differences involved.

One such difference might be the effect of nonarbitrary relations but perhaps this is not the only one. It might be argued for instance that during the present preparation, the cues for more-than or less-than may have been established in the opposite fashion from what was intended. For example, perhaps during the nonarbitrary training the contextual cues might have functioned as either more-than or less-than depending on the direction in which the participant read their response. So, for instance, perhaps the ostensibly "more-than" cue could for some participants have come to function as "less-than" if they read from right to left instead from left to right. This would have had a minimal bearing on performance during the initial stages as the direction of the network was relative but when the networks were used in the transformation test, the directional difference would then have been apparent. The counterargument to this however is that participants would have a long history of reading from left to right, which would have made right–left reading very unlikely. In addition, the nonarbitrary phase deliberately reinforced this sequence of responding in the experimental context also (i.e., based on the order in which participants had to insert stimuli into the blank boxes), so it seems unlikely that participants would have responded contrary to both their own history and the pattern reinforced during the experiment. Nevertheless, perhaps future work might test people before the transformation test to ensure maintenance of appropriate contextual control.

The second potential limitation of Dougher et al. (2007) that the present study attempted to address concerned the range of derived relations examined. For example, it was argued that in the Dougher et al. study, the authors only examined responding in accordance with derived "more-than." This was considered important given that, according to RFT, the ability to derive multiple relations is a key feature of language and, in turn, the transformation of functions. For example, when derived stimulus relations are established, stimulus functions are altered (Torneke, 2010). In research on the transformation of functions, stimuli that were previously considered neutral may acquire new functions and the functions of other stimuli may then be changed based on the derived relation between the stimuli. In order to examine the transformation of functions as comprehensively as possible though, all patterns of derivation should be tested, in case of functional differences. For example, previous research by Reilly et al. (2005) showed that "more-than" and "less-than" relations may in fact be functionally distinct in terms of the ease with which they are acquired and the resulting patterns of derivation. Reilly et al. proposed this may be due to differences in contingencies within the verbal community such that "more-than" relations emerge earlier in the behavioral repertoires of young children, and in turn, responding to "more-than" relations may be at greater strength than responding to "less-than" relations at adulthood (Barnes-Holmes, Barnes-Holmes, Smeets, Strand, & Friman, 2004; Munnelly et al., 2010). Given this potential difference in repertoires, it was considered important in the present study to demonstrate and investigate transformation of functions for both derived less than as well as more than relations and to examine possible differences between these relational repertoires. Our combined results show that participants given either All-More or All-Less training were equally likely to derive the resulting network of comparative relations (that is, apart from P20 in Experiment 2, who was given All-More training and failed to complete the study). Only half of the participants across the experiments conducted demonstrated the predicted transformation of functions, but this was not a function of the use of more versus less relational training. As such, we did not detect any differences in the strengths of these relational repertoires across groups in the context of this procedure.

An issue arising from the current experimental work is that it may be necessary for future studies to examine the respondent and eliciting functions associated with stimuli from a five-member relational network, using procedures similar to those employed by Dougher et al. (2007). For example, in the Dougher et al. study, following the bar-press training and testing phase, participants were exposed to a respondent conditioning phase in which the middle ranking stimulus B, was paired with a mild electric shock. Testing then involved the presentation of stimuli A and C, and changes in skin conductance were recorded as the dependent measure. Findings from Experiments 1 of Dougher et al. showed that participants displayed higher changes in skin conductance to C and lower levels to A, than to B, even though they had never directly experienced shock associated with these stimuli. Thus, Dougher et al. (2007) propose that the behavioral processes involved in the transformation of functions may provide an alternative account to the proposed cognitive models of the clinical symptoms observed in anxiety and fear reactions (Dymond & Roche, 2009). That is, the current behavioral account may have the potential to account for how individuals come to arbitrarily relate symbols and events in their environments, and thus engage in certain avoidant behavioral patterns, even though they have never directly received reinforcement for doing so. However, if the current approach is to provide a viable alternative to cognitive models of clinically significant behaviors, then further research from an RFT perspective is warranted (Dymond, Roche, & Bennett, 2013; Dymond et al., 2018).

A potential criticism of the present study centers on the length of the arbitrary relational test phases that small samples of participants were exposed to before transformation training and testing. For example, across all experiments, participants were exposed to two test phases, in which probes for the properties of mutual entailment were presented first, followed by probes for one- and two-node combinatorial entailment. In addition, during these test phases, participants were required to make a minimum of three out of four (i.e., 75% accuracy) correct responses on all test trials. Furthermore, if this criterion was not met initially, participants were reexposed to the entire experimental task up to three further times. A potential problem with both the mastery criterion and additional training and testing phases is that this may have inadvertently affected performances during tests for the transformation of discriminative functions. Indeed, the present method of presenting test blocks involving mutually entailed relations before probes for combinatorial entailment was previously employed to examine the prerequisites necessary for the emergence of relational reasoning abilities (transitive inference) in adult participants. Therefore, although it is necessary that accurate responding to the five-member relational network is firmly established before participants are exposed to transformation tests, it may be beneficial for future studies to present both mutually and combinatorially entailed relations within the same test block, where participants are required to meet an averaged mastery criterion across all test relations, and with larger sample sizes. This in turn may help to circumvent potential problems associated with fatigue and inattention, which may affect performances during transformation tests.

Another potential limitation was that we did not adopt a predetermined mastery criterion to assess the transformation of functions. Gil, Luciano, Ruiz, and Valdivia-Salas (2012) examined the transformation of functions through hierarchical relations and adopted a mastery criterion of six out of seven correct responses during their transformation testing phase. If participants failed to meet this criterion, they were reexposed to training and testing of the stimulus functions. Gil et al. (2012) found that four out of five participants who initially failed to pass transformation tests, did so, following retraining. Thus, it may have been beneficial in the current study if we had adopted a predetermined mastery criterion for the transformation test, which, if not met, resulted in reexposure to the bar press training and test phase for a predetermined number of times.

To conclude, the present experiments demonstrated that a number of participants were successful in demonstrating the symbolic generalization or transformation of discriminative functions in accordance with a five-member comparative relational network. In addition, the present findings have overcome two potential limitations with the Dougher et al. (2007) study and extended the examination of this pattern of responding from a three- to five-member network. However, because there was considerable variation in participant responding across all experiments, further research is needed to determine the factors affecting the emergence of this behavior. In addition, it may be beneficial for future studies to examine the respondent and eliciting functions associated with stimuli from the five-member relational network employed in the present study, using procedures similar to those employed by Dougher et al. (2007).

Compliance with Ethical Standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Conflict of Interest The authors declare that they have no conflict of interest.

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