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Conditional discriminations, symmetry, and semantic priming☆

Manish Vaidya[a,*], Caleb D. Hudgins[b], Daniele Ortu[a]

[a] The University of North Texas, United States
[b] Rutgers: The State University of New Jersey, United States

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ABSTRACT

Psychologists interested in the study of symbolic behavior have found that people are faster at reporting that two words are related to one another than they are in reporting that two words are not related – an effect called semantic priming. This phenomenon has largely been documented in the context of natural languages using real words as stimuli. The current study asked whether laboratory-generated stimulus–stimulus relations established between arbitrary geometrical shapes would also show the semantic priming effect. Participants learned six conditional relations using a one-to-many training structure (A1-B1, A1-C1, A1-D1, A2-B2, A2-C2, A2-D2) and demonstrated, via accurate performance on tests of derived symmetry, that the trained stimulus functions had become reversible. In a lexical decision task, subjects also demonstrated a priming effect as they displayed faster reaction times to target stimuli when the prime and target came from the same trained or derived conditional relations, compared to the condition in which the prime and target came from different trained or derived conditional relations. These data suggest that laboratory-generated equivalence relations may serve as useful analogues of symbolic behavior. However, the fact that conditional relations training and symmetry alone were sufficient to produce the effect suggests that semantic priming like effects may be the byproduct of simpler stimulus–stimulus relations.

1. Introduction

Stimulus equivalence refers to the observation that, after having learned a few overlapping conditional relations among stimuli, human subjects will demonstrate a number of other conditional relations among those stimuli without direct training or reinforcement (Sidman et al., 1989; Sidman and Tailby, 1982). For example, having learned to match the stimulus A1 to stimulus B1 (and not B2 or B3) and having learned to match stimulus B1 to stimulus C1 (and not C2 or C3), human participants will readily match B1 to A1, C1 to B1, A1 to C1, and C1 to A1 – without training or reinforcement.

Sets of stimuli for which the above description holds true are called stimulus equivalence classes because they satisfy the requirements of equivalence relations as described in mathematical set theory which states that a relation of equivalence obtains among members of a set if it can be shown that the elements are related via reflexivity, symmetry, and transitivity (cf. Sidman, 1994). Laboratory generated equivalence classes have a number of interesting characteristics that have led researchers to suggest that they may serve as effective analogues of linguistic and other complex human performances. Notice, first, that replacing the non-representative forms that are typically used in equivalence studies with everyday stimuli (the spoken word 'cat', a picture of a cat, the written word [cat], etc.) immediately transforms the conditional relations that define equivalence classes into linguistically relevant performances. For example, trials in which pictures serve as sample stimuli and the written or spoken word serve as comparison stimuli are good analogues of picture comprehension and trials in which the written word serves as the sample stimulus and the picture and spoken word serve as comparisons are good analogues of word comprehension and reading, respectively.

Furthermore, research has shown that stimulus functions established for one member of an equivalence class will extend to other members of the equivalence class without any training or contingencies supporting such extension (e.g.; Catania et al., 1989; Dougher et al., 1994). For example, Dougher et al. first directly trained two overlapping conditional discriminations and documented the existence of 2, four-member equivalence classes. The experimenters then established a conditioned-startle reflex with

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* Corresponding author at: Department of Behavior Analysis, University of North Texas, 1155 Union Circle, #310919, Denton, TX 76203, United States.
E-mail address: Vaidya@unt.edu (M. Vaidya).

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one element (B1) of the existing equivalence class and tested for the extension of that stimulus function to other class members (C1 and D1). They found that the conditioned-stimulus functions of B1 readily transferred to other members (C1 and D1) of the equivalence classes. This observed extension of function also mimics an important feature of natural languages, namely, the ability of a word (or a collection of words) to serve as a symbol for object or events (generically, referents) in the world. Laboratory-generated equivalence classes, then, may have properties that mimic certain aspects of linguistic functioning and may, therefore, serve as useful analogs for the laboratory study of such complex behavior.

These definitional and extra-definitional properties of laboratory-generated equivalence classes have led behavioral researchers to suggest that laboratory-generated stimulus equivalence relations and naturally developing and expanding semantic networks may be related (Barnes and Hampson, 1993; Cullinan et al., 1994; Fields, 1987; Hayes and Hayes, 1992; Reese, 1991; Sidman, 1986). It is important, however, to ascertain the extent to which laboratory-generated equivalence relations have the properties of more naturally occurring linguistic phenomena. One such phenomenon, of great interest to linguists and cognitive psychologists, is the semantic-priming effect.

1.1. Semantic priming

In general, priming refers to a behavioral change in responding to a stimulus as a function of previous exposure to the same or related stimuli (Voss et al., 2010; Voss et al., 2010Voss et al., 2010; Schacter, 1987; Richardson-Klavehn and Bjork, 1988). "Semantic priming" refers to the observation of priming effects with words as stimuli in human participants. For instance, participants are faster in reporting that two words are related to each other than they are to report that two words are not related to each other (e.g., Meyer and Schvaneveldt, 1971). The task typically used to assess semantic priming is called the Lexical Decision Task (LDT). A typical trial begins with the presentation of a *prime* stimulus (usually a spoken or printed word) followed quickly by a *target* stimulus (also usually a spoken or printed word). The participant is then required to report whether the words are related or not by pressing one of two buttons to indicate a 'yes' or 'no' response. Two main measures fall out of this task. One is a measure of the participant's choices following the presentation of the *target* stimulus (e.g., whether the participant says "yes" or "no"). The second is a measure of the time the participant takes to make either response.

A common finding in these procedures is that participant's reaction times are systematically faster when they are accurately reporting "Yes" than when they are accurately reporting "No". For example, if asked whether two words go together (say 'YES') or not (say 'NO'), participants are faster to say "Yes" (or select Yes) when the words are "*animal*" and "*tiger*" than they are to say "No" (or select No) when the words are "*animal*" and "*coffee*". The faster reaction times for related words are said to be the result of more efficient retrieval dynamics resulting from generalized activation of the semantic network by the presentation of the prime stimulus (e.g., Meyer and Schvaneveldt, 1971).

If equivalence relations are to serve as viable analogues or models of naturally occurring semantic networks (Hayes and Hayes, 1992; Sidman, 1986), it is important to ascertain whether stimuli within equivalence classes are effective as primes and targets relative to stimuli not related via equivalence. The results of two studies (Hayes and Bisset, 1998; Barnes-Holmes et al., 2005) suggest that equivalence relations among otherwise unrelated stimuli are sufficient to produce the semantic priming effect. For example, Barnes-Holmes et al. trained the prerequisites for and documented the existence of two 4-member equivalence classes using nonsense words. After training and testing was complete, participants completed a LDT utilizing the stimuli comprising the equivalence classes as well as novel stimuli. Across the three experiments the researchers found priming effects for stimuli in equivalence classes. An important contribution of the Barnes-Holmes et al. study was their use of procedures that were typical of the conventional research on semantic priming which makes the task of comparing the effects of other variables of interest easier.

The current study sought to expand the conditions under which the relation between equivalence classes and semantic priming are investigated. Toward that end, the first change, relative to earlier studies, was the use of non-representative forms as stimuli. The use of nonsense words as stimuli leaves open the possibility that factors like stimulus generalization (from real words) may contribute to the observed effects in unknown ways. By contrast, a priming effect observed with nonverbal and non-representational stimuli would permit a stronger test of equivalence relations as being sufficient for the priming effect. Voss et al. (2010) have partially demonstrated a semantic priming effect with geometrical shapes, but only with stimuli rated as 'highly meaningful' by participants, and without intraexperimentally establishing the semantic relations of interest.

Along similar lines, this study attempted to more clearly isolate the role of conditional discrimination training and testing on semantic priming by conducting the LDT both before and after conditional discrimination training and prior to testing for emergent symmetry. Presenting the LDT prior to any exposure to the stimuli and training conditions allowed us to see if there was any naturally-occurring priming in the stimulus relations of interest. It was assumed that these data would allow for a cleaner interpretation of the role of the programmed training and testing contingencies on any observed priming.

A third change in the training conditions was also designed to reduce unknown sources of variability in the priming effects of interest in the study. Several studies have shown that linear training structures can potentially introduce associative distance between members of an equivalence class (Fields et al., 1984, 1995; cf. Imam, 2001, 2006) and the effects of associative distances may involve reaction times in addition to the accuracy of the response (Bentall et al., 1998; Spencer and Chase, 1996; cf. Imam, 2006). In the current study we avoided this potential confound by using a one-to-many training structure and a many-to-one testing structure in which only symmetry (associative distance = 0) was assayed.

2. Methods

2.1. Participants

Six young adults (4 women, 2 men) were recruited from the University of North Texas to participate. The participants were recruited via flyers posted around campus and were selected on the basis of their availability and naïveté with respect to the terms and concepts of the experimental analysis of behavior. Participants were instructed to "do as well as they could". All data collection for a participant occurred in a single meeting and each participant was given $10 for their involvement, regardless of their performance. Each experimental session lasted approximately 45 min depending on the number of trials required by individual participants to meet our training criterion.

2.2. Setting and apparatus

Sessions were conducted in a small room (2 m by 3 m) equipped with a chair, desk, and a Macintosh^{TM} laptop computer (ibook Model A1005 running a G3/900 MHz processor with 256 MB of RAM). Participants interacted with a custom-written software package (MTS version 11.67, Dube and Hirris, 1991) which han-

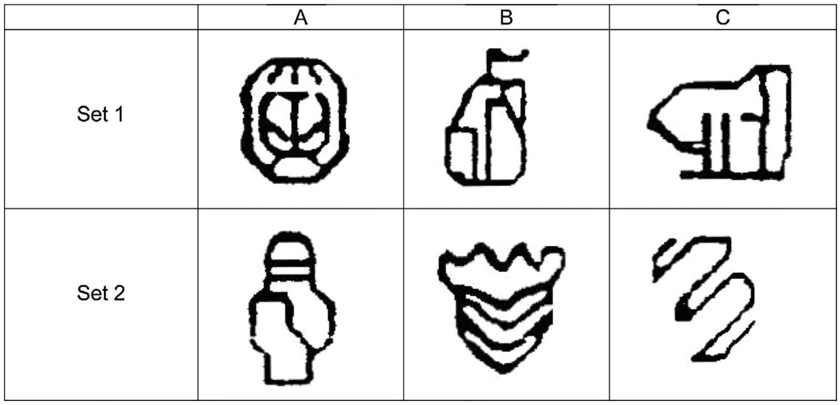

Fig. 1. An example of the geometric forms used as stimuli. Individual subjects were exposed to different configurations of stimuli.

dled all timing and contingencies, presented the LDT, carried out conditional discrimination training, and tested for the emergence of derived symmetrical relations between the trained stimuli. The stimuli were non-representative forms that had very little in common with real 3-d objects. These stimuli were arbitrarily selected from a bank of visual forms that came with MTS Version 11.67 (see Fig. 1 for example stimuli). Responses were made with either the computer mouse for conditional discrimination training and testing or the "J" and "L" keys on the computer keyboard for the LDT (described in detail below).

2.3. Procedure

All participants were introduced to the requirements of the LDT by first completing 96 trials of an LDT-familiarization task using pictures of everyday objects from commonly encountered categories. As this task was only meant to clarify the procedure, nothing further will be said about this familiarization task.

In the experiment proper, each participant completed an LDT with the non-representational stimuli described above. These same stimuli were then used in a matching-to-sample task to establish baseline conditional relations among stimuli. Participants were then re-exposed to the LDT with the same stimuli. Finally, participants completed the MTS task in which the emergence of derived symmetrical relations was assayed. Each of these conditions is described in detail below.

2.4. Lexical decision task

This task was derived from other lexical decision tasks in the semantic priming literature (e.g., Holcomb and Anderson, 1993). Each trial began with a fixation cross presented in the vertical and horizontal center of the screen. The cross remained on the screen for 250 ms followed by the presentation of the prime stimulus. The prime stimulus remained on the screen for 250 ms and was replaced by the target stimulus (250 ms stimulus onset asynchrony, SOA). The target stimulus was accompanied by the words "yes" and "no" and both target stimulus and the yes/no choices remained on the screen for 1500 ms (see Fig. 2). If the participant did not respond "yes" or "no" within 1500 ms, no response was recorded, all stimuli were removed from the display, and a 3000 ms inter-trial interval (ITI) was initiated. No feedback was provided to the participant in this task and the next trial began immediately following the ITI. A session consisted of 144 trials with a short break in the middle of the session.

All stimuli used in the study were presented an equal number of times as both primes and targets during the LDT. This created three distinguishable types of LDT trials. On Correct Prime (CP) trials, the

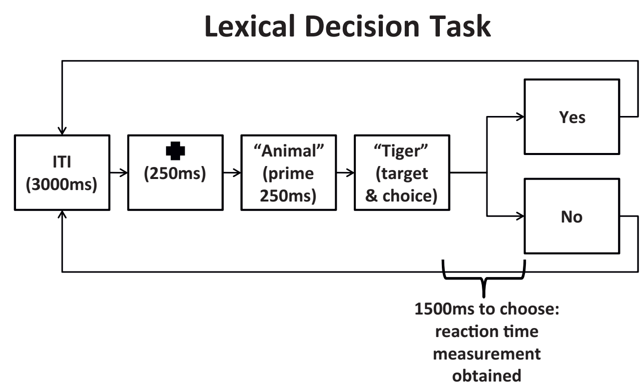

Fig. 2. A schematic representation of the lexical decision-making task.

prime and target stimuli both came from the same conditional relations (e.g., A1 presented as prime and D1 presented as target). On Incorrect Prime (IP) trials, the prime stimulus and the target stimulus came from different conditional relations (e.g., A2 presented as prime and C1 presented as target). Finally, on Irrelevant Prime (IRR) trials, the prime or the target stimuli came from a third set of stimuli which were never assigned to either set of conditional relations. Each type of trial was presented an equal number of times. See Table 1 for a layout of all stimulus combinations presented in the LDT.

The following instructions were presented on the screen immediately prior to the beginning of the first trial of the first session:"Your task in this part is to decide whether two pictures presented go together or not. Please focus your eyes on the cross in the middle of the computer screen and place your left and right index fingers on the letters "J" and "L" on the keyboard. You will see one picture appear on the screen followed by a different picture in the same location. Press the "J" key for "Yes" and the "L" key for

Table 1
Priming tests are within stimulus classes, across stimulus classes, and across irrelevant stimuli explicitly not trained as members in either class. Trials are presented with both the sample and comparisons as primes and targets.

Comparison as prime, sample as target						
Correct prime	B1A1	B2A2	C1A1	C2A2	D1A1	D2A2
Incorrect prime	B2A1	B1A2	C2A1	C1A2	D2A1	D1A2
Irrelevant prime	QA1	RA2	SA1	TA2	UA1	VA2
Sample as prime, comparison as target						
Correct prime	A1B1	A2B2	A1C1	A2C2	A1D1	A2D2
Incorrect prime	A1B2	A2B1	A1C2	A2C1	A1D2	A2D1
Irrelevant prime	A1Q	A2Q	A1S	A2T	A1U	A2V

Table 2
Stimuli with the same numeral designation are members of the same class.

Sample	Comparisons		
	Correct	Incorrect	Irrelevant
A1	B1	B2	Q
A2	B2	B1	R
A1	C1	C2	S
A2	C2	C1	T
A1	D1	D2	U
A2	D2	D1	V

Table 3
Stimuli with the same numeral designation are members of the same class.

Sample	Comparisons		
	Correct	Incorrect	Irrelevant
B1	A1	A2	Q
B2	A2	A1	R
C1	A1	A2	S
C2	A2	A1	T
D1	A1	A2	U
C2	A2	A1	V

"No". It is important to respond as quickly and accurately as you can in this task. Click on the word "Continue" to begin."

2.5. Matching to sample task – training

The training of the prerequisite baseline conditional relations was carried out in a matching to sample (MTS) task which began immediately after the LDT with experimental stimuli was completed. The following instructions were presented on the screen immediately prior to the beginning of the first trial of the MTS procedure:"Your task in this part is to decide which pictures go with each other. Click on the mouse to begin the trial and you will see a picture in the middle of the screen surrounded by other pictures in the corners of the screen. Match the center picture with one of the corner pictures; use the mouse to select your choice. You will receive feedback for your choices in this part of the task to help you learn what to do. Click on the word "Continue" to begin".

Each trial was initiated by the participant by pressing the space bar or clicking the mouse anywhere on the screen. This trial-initiation response was followed by the presentation of the sample stimulus in the horizontal and vertical center of the computer monitor and three comparison stimuli presented in the corners of the monitor. The locations of the 3 comparison choices were randomized such that each stimulus appeared in each of the four corners an equal number of times. Selection of the correct comparison stimulus produced a series of tones and the word "Correct" on the screen for 1 s while selection of the incorrect comparison stimuli produced the word "Wrong" for the same duration. Participants progressed from one training block to the next once performance accuracy exceeded 90% over the last 48 trials. During the second training block the trials were completely randomized.

Participants were taught eight conditional relations designed to yield two, 4-member equivalence classes. Specifically, participants learned to match comparison stimuli B1, C1, and D1 to sample stimulus A1 and comparison stimuli B2, C2, and D2 to sample stimulus A2. The training was expected to result in two equivalence classes – A1-B1-C1-D1 and A2-B2-C2-D2. For the purposes of a control trial type in the LDT, each MTS training trial presented three stimuli – one which was correct given the current sample (e.g., B1 given A1 as sample), one which was incorrect given the current sample (e.g., B2 given A1 as sample), and one which was always incorrect regardless of the sample stimulus presented (see Table 2 for a description of the particular trials). Training continued until the participant's performance accuracy was greater than 90% for the last block of 48 randomized trials.

2.6. Match to sample task – testing

The tests for emergent conditional relations were also carried out in the matching-to-sample procedure. All details were identical to the training conditions with a few exceptions. The stimuli that were presented as comparison stimuli during training now appeared as sample stimuli and stimuli presented as sample stimuli during training now appeared as comparison stimuli. These symmetry probe trials were randomly interspersed with baseline trials. Both symmetry and baseline trials were tested in extinction (no feedback). No accuracy criterion was imposed so each participant contacted exactly two blocks of 96 trials – 192 total (96 symmetry, 96 baseline) during testing. Table 3 presents the particular probe trials presented during the testing blocks. Symmetry was the only emergent relation assayed in this study.

3. Results

All participants completed the 96-trial LDT-familiarization task without any problems. No data were collected during the LDT-familiarization task and nothing further will be said about the subjects' performances during this task.

3.1. Conditional discrimination

Training: After the initial lexical decision task (LDT) all participants moved into conditional discrimination training. During the training blocks, the mastery criterion for baseline conditional relations was set at 90% or greater accuracy during the last 48 trials of the second block of training trials. All participants except one (Sp3) met the acquisition criterion with the first 48 randomized trials in the second block. Sp3 did not reach above 90% accuracy until 74 randomized training trials had been contacted.

Testing: The top panel of Fig. 3 presents each participant's accuracy on the baseline conditional discrimination trials during testing. These trials were identical to the trials presented during training except that no feedback was provided. This figure shows that participants' accuracy ranged between 86 and 100%. All participants except one (Sp3) maintained criterion-level accuracy on the baseline trials.

All participants were also exposed to symmetry testing trials following the second presentation of the LDT. The bottom panel of Fig. 3 presents each participant's accuracy on trial types assessing symmetry. The left-most bars present the mean accuracy for all subjects with the error bars representing the standard error of the mean. The remaining bars present data from the individual participants. The figure shows that five of the six participants showed evidence of symmetrical relations among the stimuli. For these participants, accuracy on symmetry tests exceeded 85% correct. Sp3 was again the exception. Of the five, only one (Sp1) was less than 90% accurate on trials with derived symmetrical relations. For Sp1, the errors on symmetry test trials involved the same stimuli that were incorrectly responded to on baseline testing trials. No such pattern was identifiable for Sp3.

3.2. Lexical decision task

Fig. 4 presents a summary of "Yes" and "No" responses on the LDT. Prior to establishment of baseline relations, the average proportion of "No" responses was undifferentiated across trial types. Individual proportions of responses varied widely across participants. Notice that, for the first presentation of the LDT, there

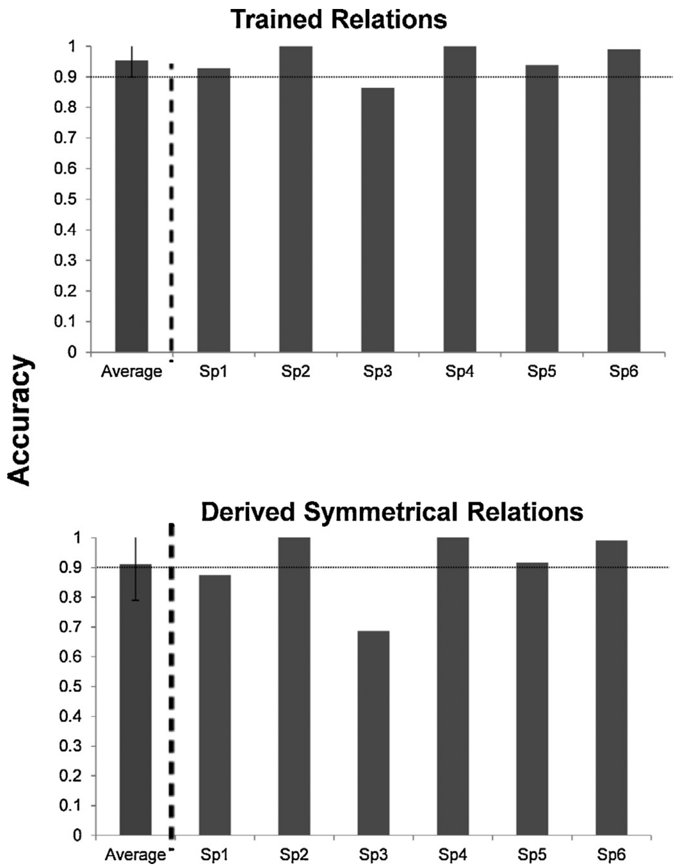

Fig. 3. Conditional discrimination testing accuracy for trained (top panel) and derived (bottom panel) symmetrical relations. Error bars indicate standard error of the mean. The dotted line separates group and individual accuracies.

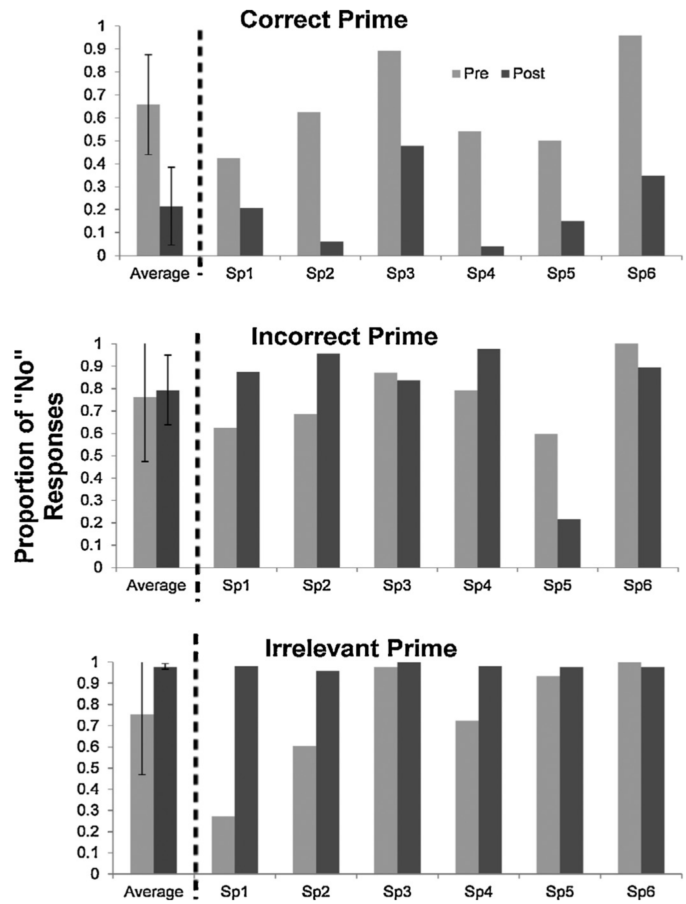

Fig. 4. Proportion of "No" responses in the lexical decision task pre and post training across the three trial types. Error bars indicate standard error of the mean. The group data is separated by a dotted line.

was no basis for the participants to report "yes" and "no" – their responses were arbitrary because the prime and target stimuli were unassigned to stimulus classes at that time. After conditional discrimination training, the stimuli were putatively grouped into either one of two separate four-member equivalence classes or a set of untrained stimuli as described above. As described above, the particular details of the training conditions allowed us to categorize each LDT trial into three trial types. The correct prime (CP) presented stimuli within established classes (e.g., A1-B1, A2-B2, etc.). The incorrect prime (IP) trial type involved a prime from one class and a target from the other class of stimuli (e.g., A1-B2, A2-B1). The irrelevant prime (IRR) trial type contained untrained stimuli as target or prime (e.g., A1-R, R-A1). This set of stimuli functioned as controls for assessing reaction times across the different trial types. That is, responding on irrelevant and incorrect prime trials should both be biased toward "No" responses after training because participants had histories with incorrect stimuli that established their membership in separate classes ("No" response is expected) and had histories with irrelevant stimuli such that they were not in any equivalence classes ("No" response also expected). This allowed us to compare reaction times for "No" responses for the class-inconsistent and class-irrelevant trials. The irrelevant prime trials also served as a control in that they constituted test stimuli to which participants had an equal amount of exposure as the stimuli tested for symmetry but no explicit history of participating in particular conditional relations. During the second exposure to the LDT (following baseline MTS training) the proportion of "No" responses for the correct prime trial decreased post training for all 6 participants. For 5 of 6 participants, the likelihood of reporting "No" on incorrect and irrelevant prime trials increased (Sp1, Sp2, and Sp4) or remained high (Sp3 and Sp6). Sp5 was the only exception for whom the likelihood of reporting 'No' on irrelevant prime trials decreased relative to the pre-training exposure to the LDT (see Fig. 4). Group averages are separated by the dotted line and the error bars are the standard error of the mean.

Fig. 5 shows mean reaction times before and after establishment of baseline relations after logarithmic transformation of the raw data that ensured meeting the normality assumption for the group analysis (Ratcliff, 1993). For the post-training LDT

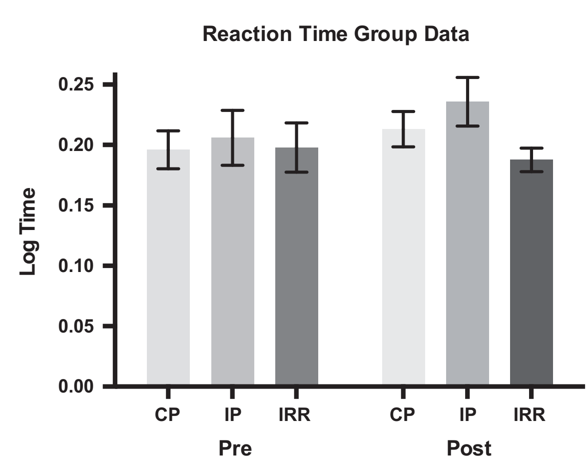

Fig. 5. Pre and Post-training log time mean reaction time data at the group level for each trial type. Error bars indicate SEM.

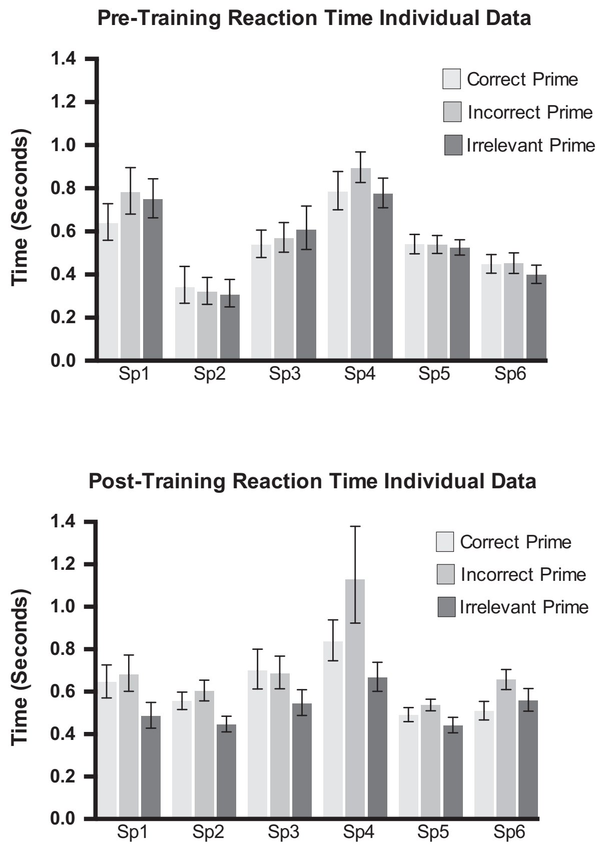

Fig. 6. Pre (top panel) and post (bottom panel) training geometric mean reaction time data in seconds for individual participants. Error bars indicate 95% confidence interval.

only reaction times on correct trials were included in the analysis. The mean number of trials (and standard deviation) across trial types, pre and post training, included in the following analyses were Correct Prime Pre-Training 38.83(10.68); Incorrect Prime Pre-Training 39.83(11.2); Irrelevant Prime Pre-Training 39(11.35); Correct Prime Post-Training 35.66(8.37); Incorrect Prime Post-Training 35.5(13.18); Irrelevant Prime Post-Training 46(1.73).

For the reaction time data, we ran a two-way repeated measures ANOVA with a factor of Training (pre, post), and a factor of Trial Type (Correct Prime, Incorrect Prime, Irrelevant Prime) with individual subjects as the repeated measure. The ANOVA yielded a significant main effect of Trial Type $F(2,10) = 8.711$; $p = 0.0064$ and a significant Training × Trial Type interaction $F(2,10) = 5.640$; $p = 0.0229$. Following up the significant interaction we ran post-hoc comparisons (corrected for multiple comparisons; Holm-Sidak's multiple comparisons test) revealing that prior to training reaction times to the three trial types were undifferentiated (all p values >0.6), while all trial types differed from each other after conditional discrimination training (all p values <0.03).

Additionally, we investigated individual trends for each trial type by running a one way Kruskal–Wallis ANOVA for each participant, pre and post conditional discrimination training. In these analyses incorrect trials were still excluded but the raw reaction time data was not logarithmically transformed because the transformation did not lead to meeting the assumption of normality for five participants out of six. Fig. 6 shows geometric means (preferable to arithmetic means when describing non-normally distributed data) and 95% confidence intervals for each individual participant, pre and post conditional discrimination training. In the post training phase for all participants except for Sp3, mean reaction times on incorrect prime trials were slower than on correct prime trials. For Sp5 and Sp6 this difference was statistically significant. Moreover, for all participants except for Sp6, reaction times were fastest for the irrelevant prime trial though not all differences were statistically significant. Importantly, for all subjects reaction times were significantly different between IRR and IP trial types demonstrating that reaction time differences are consistent even when the same response ("No") is selected. All statistical outcomes, including post-hoc comparisons (corrected for multiple comparisons using Dunn's test) are presented in detail in Table 4.

4. Discussion

Our primary question in this study was to see if laboratory-generated stimulus classes consisting of non-representational stimuli would show a priming effect. The *semantic* priming effect is a robust and reliable phenomenon mainly documented with words from natural languages used as stimuli. If the development of laboratory-generated stimulus classes and the development and expansion of naturally-occurring semantic networks are allied phenomena, it should be possible to relate the characteristics measures of one kind of performance with characteristic measures of another kind of performance.

The results of the study suggest the answer may be affirmative: group analyses showed that reaction time measures on the first exposure to the LDT with experimental stimuli were undifferentiated. This was expected given that these stimuli were completely novel for the participants and there was no known basis on which response allocation differences or reaction time differences could be based. It was not until participants contacted conditional discrimination training that statistically significant reaction time differences emerged across all trial types. In addition, results show that mere exposure to the stimuli in the context of conditional discrimination training was not sufficient to produce the priming effect. Within individual participants, the priming effects seen were isolated to trials in which the prime and target stimuli were drawn from the same putative class. Five of the six participants were relatively slower to report "no" when the prime and target stimuli were drawn from different classes.

Finally, the results of the study suggest that the priming effects observed are related to the classes created by virtue of the conditional discrimination training. For all participants, the reaction times on IRR trials (for which "no" was the correct report) were significantly faster than on IP trials (for which "no" was also the correct report). These results were most likely due to the fact that the IRR trials included 'irrelevant' stimuli which may have primed the "no" response even before the target stimulus was presented. These data suggest that the "Yes" and "No" choices themselves do not account for the reaction time differences. Instead, the consistently slower reaction times seen on IP relative to CP trials are due to the prime and target stimuli being drawn from different classes. Taken together, these data show that the priming effect (faster reaction times for class-consistent prime-target pairings) was related to the conditional relations established among stimuli in the laboratory. Given the results' similarity to the *semantic* priming effect, these results provide support for the idea that laboratory generated derived relations and naturally developing and expanding semantic relations are related phenomena.

These data contribute to the existing literature on the relation between derived stimulus–stimulus relations and the semantic priming effect by expanding the range of stimuli with which the effect has been documented. The occurrence of the priming effect with non-representational forms suggests that it was the training contingencies themselves and not some artifact of an idiosyncratic history with the stimuli that was responsible for the priming effect observed. Also, the addition of a baseline LDT task allowed us to take

Table 4
Results of statistical analyses carried out for each individual participant pre and post conditional discrimination training. The first two columns on the left represent results for the non parametric Kruskal–Wallis ANOVAs ran pre and post training. The remaining columns represent post-hoc comparisons (*p* values adjusted for multiple comparisons using Dunn's test) for all trial types. Significant *p* values are presented in bold font.

Subject	Pre ANOVA	Post ANOVA	Pre CP-IP	Post CP-IP	Pre CP-IRR	Post CP-IRR	Pre IP-IRR	Post IP-IRR
1	**0.0499***	**0.0002***	0.0728	>0.9999	0.1543	**0.0110***	>0.9999	**0.0005***
2	0.3398	**<0.0001***	0.6038	0.4965	0.6156	**0.0018***	>0.9999	**<0.0001***
3	0.6267	**0.0008***	>0.9999	>0.9999	>0.9999	**0.0109***	>0.9999	**0.0026***
4	**0.0401***	**0.0002***	0.1590	0.0860	>0.9999	**0.0309***	0.0537	**0.0005***
5	0.9460	**0.0004***	>0.9999	**0.0313***	>0.9999	0.5737	>0.9999	**0.0003***
6	0.1042	**<0.0001***	>0.9999	**<0.0001***	0.3231	0.4037	0.1343	**0.0050***

pre-training reaction time differences into account which allowed a more precise specification of the changes that resulted from the training of baseline conditional relations and the development of derived symmetrical relations. Finally, the use of an OTM training structure combined with an MTO testing structure ensured that the nodal (or associative) distance for all tested relations was zero thus minimizing its potential influence on the reaction time differences observed.

The results of the study also contribute by suggesting that trained conditional relations and derived symmetrical relations alone may be sufficient to produce the oft-documented priming effects. However, limitations in the procedure along at least two dimensions preclude any strong conclusions regarding this issue. First, although we did not assess equivalence relations (B–C, C–D, or B–D relations) in either the MTS or LDT preparations, the training conditions had established the pre-requisites for relational responses among those stimuli to be pre-potent. The potential role of such relations, though not instantiated in the directly assayed responses of the participant, remains unmeasured and unexplored in the current study. In other words, the full complement of equivalence relations were possible in our study and may have served an important, albeit unexamined, role in the priming effects observed. Future research should attempt to better isolate the precise roles of all of the conditional relations that define equivalence classes in the semantic priming effect.

Alternatively, the results of the study raise the possibility that the priming effects observed are actually the result of much simpler behavioral processes, perhaps just involving conditional discriminations among stimuli. Recall that, in the current study, the post-training LDT tests were presented prior to the tests for symmetry. Strictly speaking, then, the priming effects were observed before any symmetrical responding was instantiated but after the conditional relations had been established to a high degree of accuracy. These data raise the intriguing possibility that the establishment of the conditional relations alone was sufficient to give rise to two outcomes – priming effects for within class prime-target pairs in the LDT and symmetrical relational responses in the MTS probes. The use of detailed instructions, however, raises the possibility that more complex (e.g., equivalence-like) relations had been potentiated. Future studies should attempt to isolate whether conditional relations alone are sufficient to give rise to priming-like effects.

These results suggest the possibility that the semantic relatedness of words which produces the "automatic" priming effect is, at least in part, due to the associative history of the semantic forms (Hutchison, 2003; Ortu et al., 2013). While other conceptualizations of the semantic priming effect exist, there is evidence suggesting that associative histories may also contribute to the development and size of the semantic priming effect. Ortu and colleagues, for example, found a relatively greater N400 effect given violations of more commonly used two-word expressions (stronger history of associative pairing) than less commonly used two-word expressions (relatively weaker history of associative pairing). Prior research shows that the development of equivalence relations among stimuli can influence the development of simpler analytic units (Vaidya & Brackney, 2014). Future studies should attempt to more precisely control the instantiation of associative and non-associative (e.g., equivalence) relations among stimuli to more precisely identify the conditions necessary and sufficient for the semantic-priming effect.

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