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DERIVED STIMULUS RELATIONS PRODUCE MEDIATED AND EPISODIC PRIMING

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If derived stimulus relations can serve as a beginning behavioral model of semantic meaning, many of the cognitive findings shown with semantic relations should apply to derived stimulus relations. The present study examined whether priming in a lexical decision task occurs in equivalence relations. In the primary experiment, subjects were trained to form three 3-member equivalence classes of "word-like" nonsense words. Subjects were then given a battery of lexical recognition tasks that included previously trained equivalence class members. The priming effect for stimuli in an equivalence class, whether stimulus relations were directly trained or derived, was as strong as that previously reported for associated words. Control conditions show that these effects were due to derived stimulus relations, not to alternative sources of control. Priming through equivalence classes provides one of the more robust instances of what in the cognitive literature are termed "episodic priming" and "mediated priming." These results provide some additional support for the idea that derived stimulus relations are a useful preliminary behavioral model of semantic relations, and that they supply a useful procedure for research on priming more generally.

Derived stimulus relations are being widely used as a working behavioral model of basic semantic relations (Hayes & Hayes, 1989, 1992; Sidman, 1986; Wulfert & Hayes, 1988). For example, the basic bidirectionality of word-referent relations is paralleled in the symmetrical properties of equivalence relations.

The initial plausibility of the connection between derived stimulus relations and semantic meaning is supported by several findings. First, verbal abilities and the capacity to derive stimulus relations covary (Devany, Hayes, & Nelson, 1986; see other studies reviewed in Horne & Lowe, 1996), though the source of that covariation is still at issue. Second, it is known that derived stimulus relations develop in very early

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childhood (Lipkens, Hayes, & Hayes, 1993) and can be delayed by a lack of exposure to verbal training (Barnes, McCullagh, & Keenan, 1990). Third, derived stimulus relations are at least very difficult to produce and are arguably absent in nonhumans (Hayes & Hayes, 1992). Finally, equivalence, exclusion, and similar procedures have often been used as a means of establishing novel verbal performances (de Rose, de Souza, Rossito, & de Rose, 1988; Sidman, 1971).

Network theories of verbal meaning (Anderson, 1976, 1983; Anderson & Bower, 1973; Collins & Loftus, 1975; Kintsch, 1974; McClelland & Rumelhart, 1988) share similarities with the nature and behavioral impact of networks of stimulus relations as described in the behavioral literature (Barnes & Hampson, 1993; Cullinan, Barnes, Hampson, & Lyddy, 1994; Hayes & Hayes, 1992; Reese, 1991). If derived stimulus relations can serve as a useful working model of semantic meaning, then the kinds of findings that have been demonstrated using semantic stimuli should typically be found when using stimuli in equivalence or other derived relations (Branch, 1994). A particularly common method of assessing the relationship among semantic stimuli, priming, is examined in the present study (as was suggested by Branch, 1994).

The prototypical priming effect is shown when a subject more rapidly recognizes a word as a word when it is preceded by a related rather than an unrelated word. In this "lexical decision task" the first word is said to "prime" the faster response to the target word. The literature on priming is large and well documented, and it includes numerous variants such as semantic, associative, mediated, and episodic priming, as well as numerous experimental preparations utilized to demonstrate priming, such as lexical decision and pronunciation tasks (see Neely, 1991, for a review of the priming literature).

In "semantic priming" the words share a semantic association (*bread-cake*), while in "associative priming" the words are related by usage (*bread-butter*). In mediated priming word recognition is facilitated through a mediating stimulus; for example, *lion* primes *stripes* through the mediated link of *tiger*. In episodic priming words that are not preexperimentally associated become associated during the course of training in the experiment.

If derived stimulus relations can reasonably be utilized as a working model of semantic relations, then priming should occur between stimuli that enter into derived stimulus relations more so than between stimuli that do not. In addition to supporting the connection between behavioral work on derived stimulus relations, and the larger issue of semantic relations, such a finding would have other implications. First, it would help provide a behavioral account of priming per se. Without the concept of derived stimulus relations, operant accounts of priming (e.g., Afari, 1996) can not readily account for priming among stimulus relations that are not based on direct training. Second, priming through derived stimulus relations, as studied in behavioral laboratories, would be an instance of "mediated priming" as studied in cognitive laboratories. To our knowledge, mediated priming has never been shown using "nonword" stimuli. Because of the need to rely on normal words, the study of mediated priming in cognitive laboratories has had to use stimuli with relatively poorly controlled histories. If mediated priming occurs through derived stimulus relations then these well developed behavioral preparations would give cognitive psychologists a more controlled way to study priming as such.

The following experiments examine the priming effect among stimuli participating in equivalence relations. Subjects were trained to form three 3-member equivalence classes using a matching-to-sample procedure and word-like nonwords as stimuli. Nonwords were utilized to eliminate some of the uncontrolled historical effects of specific language histories. When subjects derived the relevant equivalence relations, these stimuli were then used in a lexical decision task.

Method

Subjects

The subjects were 20 college student who received extra credit for participation. All subjects had English as their first language. Subjects were allowed to withdraw from the experiment at anytime. Six subjects never showed equivalence relations and either withdrew or were excused from further participation in the subsequent lexical decision task. Fourteen subjects completed the experiment.

Stimuli

The stimuli utilized in the matching-to-sample and priming phases were primarily from Massaro, Venezky, & Taylor (1979). The stimuli were permutations derived from the most frequent 150 six-letter English words in Kucera and Francis (1967) and which met the following criteria: (a) they were orthographically regular; (b) they were pronounceable; (c) they contained common vowel and consonant spellings; and (d) they had no more than three letters for a medial consonant cluster, if one occurred.

Apparatus

Sessions were conducted in a small room with subjects seated at a desk in front of a computer screen and a keyboard. The stimuli were presented on the screen, and all instructions and experimental tasks were presented and monitored via the computer.

Procedure

The procedure consisted of equivalence training, followed by a lexical decision task.

Equivalence training. Equivalence training consisted of a session of approximately 45 minutes in length. So that the subjects might plausibly identify stimuli as "words," a requirement of the lexical decision task, subjects were instructed that the word-like nonwords they were viewing were foreign words. The following instructions were given to the subjects at the start of the training session:

> During this phase of the experiment, you will be trained to match FOREIGN WORDS to other FOREIGN WORDS. ALL words in this phase will be TRUE FOREIGN WORDS. You will be asked to respond to them using the keys before you. Do this by striking one of three keys: "1" for the left box, "5" for the middle box, and "9" for the right box. While the box is blinking, you may confirm your choice by hitting "enter".
>
> You may change your choice by not entering it; and, when the box stops blinking, making a new choice. During some parts of the experiment, you may not receive any feedback. The relation between the foreign words is not already known to you. You will have to learn by trial and error. Remember, your task is to pick the foreign word on the bottom that goes with the one at the top.

In all trials, a sample stimulus (a "word") was presented in the center of the middle third of the monitor screen. After 2 sec, the "correct" response (a "word") was presented in random positions (left, center, or right) at the bottom of the screen, along with the two other "incorrect" responses, while the sample stimulus remained.

Pressing a "1," "5," or "9" key formed a blinking box around the left, middle, or right word, respectively. Pressing "enter" while the box was blinking selected the response inside the box. During the match-to-sample training phase, feedback ("correct" or "incorrect") was given. During testing for derived relations, no feedback was given. If subjects did not respond correctly on at least 90% of the trials, subjects cycled back to the beginning of the first phase for additional direct training. Only subjects meeting the 90% criterion on tests of derived relations moved on to the next phase, B, the lexical decision task.

Arbitrary matching-to-sample problems and probes are described using the following convention. The sample stimulus is given first, in brackets, followed by a set of comparisons separated by dashes. The reinforced comparison is emboldened. For example, the notation [A1] **B1**-B2-B3 indicates that in the presence of the sample stimulus "A1," selecting B1 was reinforced or "correct."

The sequence of training is shown in Table 1. The individual phases were as follows: a block of A1 to B1 training (e.g., [A1] **B1**-B2-B3), a block of A2 to B2 training (e.g., [A2] B1-**B2**-B3), a block of A3 to B3 training (e.g., [A3] B1-B2-**B3**), a block of mixed A to B training, A1 to C1 training, A2 to C2 training, A3 to C3 training, a block of mixed A to C training, and a final block of mixed A to B and A to C training. Trained stimuli were then tested for derived relational responding using only equivalence relations (e.g., [C1] **B1**-B2-B3).

Equivalence provides a strong test of derived stimulus relations that logically entails symmetry in this case, because relations between B and

C were based on mutual relations to A. Furthermore, by not using formal tests of symmetry (e.g., [B1] **A1**-A2-A3), an additional control was provided. As previously discussed, priming can occur based on previous associations and direct history. If priming occurs for pairs related by symmetry as well as equivalence, even when symmetry has never been tested, then explicit pairing in testing will be weakened as an explanation for priming that is based on derived stimulus relations.

Table 1

Stimuli Composing Trials For Each Phase of Equivalence Training

Conditional Discrimination Training:	
Phase 1:	A1-B1 Relations (5 trials): [A1] **B1** B2 B3
Phase 2:	A2-B2 Relations (5 trials): [A2] B1 **B2** B3
Phase 3:	A3-B3 Relations (5 trials): [A3] B1 B2 **B3**
Phase 4:	Mixed A-B Relations (9 trials) using all A-B problems from Phases 1-3, randomly selected and presented.
Phase 5:	A1-C1 Relations (5 trials): [A1] **C1** C2 C3
Phase 6:	A2-C2 Relations (5 trials): [A2] C1 **C2** C3
Phase 7:	A3-C3 Relations (5 trials): [A3] C1 C2 **C3**
Phase 8:	Mixed A-C Relations (9 trials) using all A-C problems from Phases 5-7, randomly selected and presented.
Phase 9:	Grand Mix of A-B, A-C Relations (24 trials) using all A-B and A-C problems, from Phases 1-3 and 5-7, randomly selected and presented.
Test for Equivalence:	
Phase 10 (18 trials):	
	C-B Relations: [C1) **B1** B2 B3 [C2] B1 **B2** B3 [C3] B1 B2 **B3**
	B-C Relations: [B1] **C1** C2 C3 [B2] C1 **C2** C3 [B3] C1 C2 **C3**

Note. In all the problems below, the sample is in brackets, and the correct response is in boldface. The positions of the comparison stimuli were counterbalanced throughout the experiment.
In Phase 10, the six possible problems were randomly selected and presented.

The lexical decision task. The lexical decision task was scheduled immediately after equivalence training and testing, and lasted approximately 15 minutes. The procedures were closely modeled on Meyer and Schvaneveldt (1971), who first popularized the procedure. At the beginning of each trial, the word READY was presented on the screen for 3 sec as a warning signal. At the bottom of the screen was the instruction: "Work as fast as you can without making mistakes." Following this, two stimuli were displayed horizontally in white letters in the middle of the screen, with one string of letters centered above the other. At the bottom of the screen was the question "Are both of these foreign words?" If both strings were foreign words, the subject pressed the "y" key (for "yes"), otherwise pressing the "n" key (for "no"). Reaction time was measured from stimuli-onset to the response, which terminated the stimuli display. Subjects were informed of response correctness by the word "correct" or "incorrect" appearing in the middle of the screen for 2 sec immediately following their response.

Following a short practice session (24 trials) with English words, subjects received the following instructions:

> Now that you have had some practice, let's begin using FOREIGN and NONSENSE WORDS. During this phase of the experiment, you will be asked to respond to some words on the computer screen. SOME of these words will be the FOREIGN words you just learned. BUT, some of the words will be NONSENSE words.
>
> Two words will appear on the screen, one below the next. You will be asked: "ARE BOTH OF THESE FOREIGN WORDS?" Your task will be to hit the "y" key (for yes) if they are BOTH foreign words (that you were exposed to earlier) or the "n" key (for no) if one or both are NOT foreign words.

During the session, each subject was shown 24 pairs of equivalence class members: 8 that had been directly trained in the matching-to-sample procedure (e.g., A as the prime, B as the word to recognize), 8 related via symmetry (e.g., B — A), and 8 related via equivalence (e.g., B — C). Subjects were also shown 8 pairs of unrelated stimuli (an equivalence class member and member from another equivalence class), 16 pairs involving an equivalence class member and a novel nonword subjects had not seen in the matching-to-sample phase (termed here "nonsense" words), and 8 pairs of nonsense words.

Results and Discussion

Results of evaluation of the assumptions of normality of sampling distributions, linearity, and homogeneity of variance were satisfactory. Reaction times of 3 sec or greater (4.5% of responses) were eliminated from the results. Figure 1 shows the mean reaction times of correct responses and mean percentage of errors averaged over subjects for all types of stimuli pairs. Table 2 shows the comparisons among trials types. The specific comparisons are important to understanding the results because they provide the specific controls for explanations for priming based on factors other than derived stimulus relations.

Response Time

"Yes" responses were significantly faster for equivalent pairs than for nonequivalent pairs. This was true for pairs that had been directly trained [$F(1, 13) = 11.6$, $p = .004$] or derived through their symmetrical [$F(1, 13) = 6.1$, $p = .027$] or equivalence relationship [$F(1, 13) = 5.6$, $p = .033$]. The mean response time did not significantly differ by training history whether directly trained (1177 msec, $SE = 73$ msec) or derived through symmetry (1255 msec, $SE = 97$ msec) or equivalence (1266 msec, $SE = 85$ msec). Notably, no differences in the priming effect occurred for symmetrical pairs, which unlike the other stimuli had not been previously viewed during equivalence testing, and priming for equivalence relations,

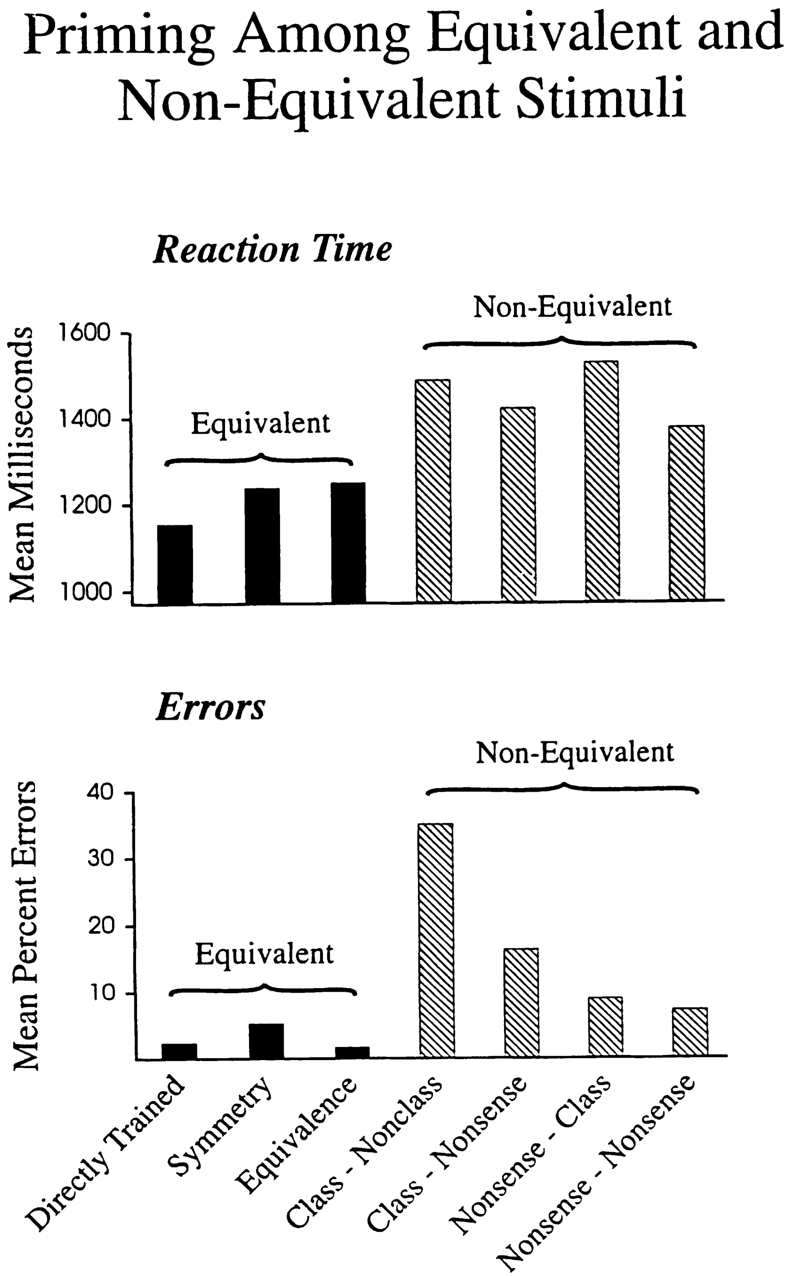

Figure 1. Priming, as measured by reaction time and percentage of errors, for equivalent and nonequivalent stimuli. Priming is indicated by lower scores in each case.

Table 2

Priming Through Derived Stimulus Relations

Stimuli Presented: Top String	Stimuli Presented: Bottom String	Correct response	Proportion of trials	RT (Msec) Mean	RT (Msec) Std. Error.	% of Errors Mean	% of Errors Std. Error
Equivalent pairs:							
1. Directly-trained	Directly trained	yes	.143	1,177	73	2.5	1.3
2. Derived (symmetry)	Derived (symmetry)	yes	.143	1,255	97	5.4	1.8
3. Derived (transitivity)	Derived (transitivity)	yes	.143	1,266	85	1.8	1.2
Nonequivalent pairs:							
4. Equivalence class member	Nonmember	yes	.143	1,503	94	35.8	4.9
5. Equivalence class member	Nonsense word	no	.143	1,437	67	16.7	3.7
6. Nonsense word	Equivalence class member	no	.143	1,538	106	9.1	2.9
7. Nonsense word	Nonsense word	no	.143	1,388	95	7.1	3.5

Planned comparisons	Statistical significance: Response time	Statistical significance: % of errors
Equivalent (direct) vs. nonequivalent (1. vs. 4.)	.004*	.000*
Equivalent (symmetry) vs. nonequivalent (2. vs. 4.)	.027*	.000*
Equivalent (transitive) vs. nonequivalent (3. vs. 4.)	.033*	.000*
Direct vs. symmetrical (1. vs. 2)	.142	.140
Direct vs. equivalence (1. vs. 3.)	.060	.654
Symmetrical vs. equivalence pairs (2. vs. 3.)	.805	.043*
Nonequivalent (5.) vs. nonequivalent (6.)	.115	.028*
Nonequivalent (6.) vs. nonequivalent (7.)	.014*	.619

which had been previously tested. It is important to note also that the comparisons made rule out the possibility that subjects showed priming because all the stimuli were lumped into a class of "foreign words." In the critical comparisons, stimuli within equivalence classes primed words relative to other stimuli that were used in the matching-to-sample procedure but that were in other equivalence classes (see specific comparisons in Table 2).

Error Rate

Similar results were found for error rates, which were significantly less for equivalent pairs than for nonequivalent pairs. Again, this was true for directly trained pairs [$F(1, 13)$ 34.2, p = .000], or derived symmetry [$F(1, 13) = 33.7$, $p = .000$] or equivalence [$F(1, 13) = 40.0$, $p =$ .000] relationships. However, unlike the response time results, error rates differed by training history within equivalence classes. As is shown in Table 2, the error rate for symmetrically related pairs (5.4%, SE = 1.8%) was significantly greater than for pairs derived through equivalence (1.8%, SE = 1.2%), but no different from directly trained pairs (2.5%, SE = 1.3%). Directly trained and equivalence pairs also did not differ significantly (see Table 2). This difference between symmetrical and equivalence pairs may have been caused by subjects receiving less exposure to the symmetrical stimuli, which had not been included in the previous test for equivalence. However, it is not clear why this account would be salient for error rate results, but not for response rate results. The relatively high between-subject variability associated with the error rate data (see Table 2) indicate that caution be exercised in any comparison of error rates, particularly vis-à-vis response times.

Taken together, these results show priming effects can be obtained through derived stimulus relations. The priming effect for "nonwords" participating in an equivalence relation is as strong as that of associated words reported by Meyer and Schvaneveldt (1971). The effect is present for all equivalence class members, whether directly trained or derived.

The priming effects demonstrated in our study are particularly intriguing in that they are achieved without the benefit of learned semantic content (stimuli were nonwords without a history) and sometimes without direct association (in the case of derived equivalence class members). To the extent that priming is a semantic process, derived stimulus relations act like semantic relations. To the extent that priming is an "associative" process, derived stimulus relations act like direct associations.

There is a technical barrier that might prevent the application of these data to the cognitive literature, however. The Meyer and Schvaneveldt (1971) priming study differed from the present study in that it did not use the experimental arrangements typically used in research on derived stimulus relations (i.e., the use of computer presented stimuli). To assess the importance of these differences, we replicated the Meyer and Schvaneveldt study, using the same apparatus and lexical recognition procedure as was used in this present study but with the stimuli in their original experiment.

Table 3 summarizes the mean reaction times of correct responses and mean percentages of errors averaged over subjects. Our response latencies were approximately 400 to 600 msec longer than those of Meyer

Table 3

Replication of Meyer and Schvaneveldt

Stimuli Presented Top String - Bottom String	Correct response	Proportion of trials	Mean RT (msec)	Mean % of errors
1. word - associated word	yes	.25	1,226	3.0
2. word - unassociated word	yes	.25	1,335	15.5
3. word - nonword	no	.167	1,650	14.0
4. nonword - word	no	.167	1,585	13.8
5. nonword - nonword	no	.167	1,481	2.6

Planned comparisons, mean response time (RT):	*p*
associated vs. unassociated words (#1 vs. #2)	.017*
word/nonword vs. nonword/word (#3 vs. #4)	.395
nonword/word vs. nonword/nonword (#4 vs. #5)	.083
Planned comparisons, mean percentage of errors:	
associated vs. unassociated words (#1 vs. #2)	.000*
word/nonword vs. nonword/word (#3 vs. #4)	.972
nonword/word vs. nonword/nonword (#4 vs. #5)	.051

and Schvaneveldt, probably caused by the differences in equipment used. As in Meyer and Schvaneveldt, priming was obtained as is indicated by the difference in reaction times between pairs of related words compared to pairs of nonrelated words. In addition, unlike the original study, we also obtained significantly fewer errors for pairs of related than nonrelated words. Thus, the priming effect using the present apparatus, if anything, was stronger than in the original study. The key point is that our procedure and apparatus produce priming as studied in the traditional cognitive literature, not just as shown in the main experiment.

General Discussion

The etiology of priming is not well understood. Many cognitive theories have been proposed to account for the phenomenon, including automatic spreading activation (Anderson, 1976; Collins & Loftus, 1975; Collins & Quillian, 1969; Neely, 1977), expectancy-base priming (Anderson, 1983; Becker, 1980, 1985; Posner & Snyder, 1975), plausibility-checking (Norris, 1986), cue-combination (Ratcliff & McKoon, 1988), and retrospective semantic-matching (Neely & Keefe, 1989). All of these assume a network nodal structure, wherein each word is represented in memory as an individual node. A competing notion, connectionist parallel distributed processing (PDP) (McClelland, Rumelhart, & the PDP Research Group, 1986; Rumelhart, McClelland, & the PDP Research Group, 1986), dispenses with the concept of word nodes and substitutes a set of interconnected distributed features representing orthographic, phonological, or semantic information. All these theories, however, agree in pointing to semantic relations as particularly powerful sources of priming.

Priming may also be analyzed from a behavioral operant perspective (Afari, 1996). In this account the prime is conceptualized as a discriminative stimulus in the presence of which there is a history of reinforcement for responding to the target stimulus. In this account, the quantity of prior responding explains the facilitative effects of the prime: the longer the history, the greater the facilitation. A straight-forward operant model of this kind can not account for priming among stimulus relations that are not based on direct training, but an operant model does quite well if two concepts from the behavioral literature are added: derived stimulus relations and the transformation of stimulus functions through derived stimulus relations. In this model, in addition to a direct discriminative relation, the more there is a mutual stimulus relation between two events, and the more that functions of one stimulus transfer to the other in accord with that relation, the more one stimulus will prime another.

For example, if a subject is trained to pick B in the presence of A, A will "prime" B by direct training, as in the operant account above. The stimulus B will prime A because stimulus equivalence produces symmetry, in which B controls the selection of A. Because this symmetrical response occurs also during the lexical recognition task, the subject is prepared to recognize and select A when B is presented as a prime. The present study provides considerable support for the view that stimulus equivalence is a sufficient condition to observe priming among stimuli.

The more general concept of "derived stimulus relations" seems to be needed, however, rather than merely "stimulus equivalence" because many of the semantic relations that show priming are not obviously equivalence relations. "Hot" will prime "cold," for example, or "bread" will prime "butter." A behavioral theory of priming would have to deal with more flexible relations of this kind. The importance of multiple stimulus relations has been particularly emphasized by relational frame theory (Barnes & Holmes, 1991; Hayes, 1991; Hayes & Hayes, 1989, 1992). Relational frame theory would predict that priming will be observed between strongly related stimuli across a wide variety of specific kinds of trained and derived relations. Future research should examine priming in both equivalence relations and other kinds of derived stimulus relations to see if the effect seen in the present study is unique to equivalence or is a more general phenomena.

It is interesting that the matching-to-sample procedure used in this study established such robust priming. Priming across equivalence relations is a clear example of what cognitive psychologists call "mediated priming," in the sense that the effect depends upon the mutual relations between each of two stimuli and another stimulus (e.g., B primes C based on their mutual relation to A). To our knowledge, the present study is the first demonstration of mediated priming that did not utilize real words.

Heretofore, mediated priming has not been easily demonstrated. For example, when the experimental preparation consisted of a lexical decision task in the form of a single prime subsequently followed by a target, mediated priming was not found (Balota & Lorch, 1986; De Groot, 1983), except by way of additional changes in the experimental procedure (i.e., having subjects respond to word targets and withhold responses to nonword targets). McNamara and Altaribba (1988) demonstrated mediated priming using the same lexical decision procedure utilized by Meyer and Schvaneveldt (1971) and this study (i.e., simultaneous presentation of the prime and target). However, mediated priming did not occur within a battery of trials that included word pairs that were associatively related by common usage.

There are benefits to the matching-to-sample procedure as a method of studying priming. Semantic priming results are often explained by the history of associations that these words commonly share. A benefit of the matching-to-sample preparation is that prior learning histories may be precisely controlled. By controlling the training history of the elements in a stimulus network, the present study demonstrated that priming is dependent upon that specific history.

The present study shows that some of the methods used in the cognitive literature to assess the relationship among semantic stimuli apply with equal or even greater force to derived stimulus relations. If priming did not occur through derived equivalence relations, this would have delivered a severe blow to the idea that derived stimulus relations are a good working model of semantic meaning. When theories are not falsified, however, that does not necessarily mean that they will ultimately prove useful. The present study thus does not prove the ultimate viability of a model of semantic meaning based on derived stimulus relations, but it makes that model incrementally more plausible.

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