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Analogical priming via semantic relations

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Research on semantic memory has often tacitly treated semantic relations as simple conduits for spreading activation between associated object concepts, rather than as integral components of semantic organization. Yet conceptual relations, and the role bindings they impose on the objects they relate, are central to such cognitive tasks as discourse comprehension, inference, problem solving, and analogical reasoning. The present study addresses the question of whether semantic relations and their bindings can influence access to semantic memory. The experiments investigated whether, and under what conditions, presenting a prime pair of words linked by 1 of 10 common semantic relations would facilitate processing of a target pair of words linked by the same relation. No effect was observed when participants merely read the prime; however, relational priming was observed under instructions to note and use the semantic relations. Participants were faster at making a lexical decision or naming a word on a related pair of target words when that pair was primed with an analogously related pair of words than when the prime pair consisted of either two unrelated words or two words linked by some other relation. This evidence of analogical priming suggests that under an appropriate strategic set, lexical decisions and naming latencies can be influenced by a process akin to analogical mapping.

The metaphor of semantic memory as a rich network of associated concepts has become both an assumption and a tool of psychologists studying diverse cognitive processes. Many studies of semantic memory take advantage of the fact that concepts are associated; however, relatively little work has investigated the effects of the specific *content* of those associations, which are typically semantic relations. Yet such fundamental cognitive processes as discourse comprehension, inference, problem solving, and analogical reasoning depend on the human ability to represent and process the semantic relations between concepts.

Research has shown that people are able to decide quickly whether basic semantic relations, such as superordination, antonymy, and partonymy, hold between a pair of concepts (e.g., Chaffin & Herrmann, 1988; Collins & Quillian, 1969; Glass, Holyoak, & Kiger, 1979). However, there has been little investigation of the possible role of such relational decisions in promoting subsequent access to analogously related concepts (but see Chaffin & Herrmann, 1988). Standard network models of semantic memory depict object concepts as nodes and relations as links between these nodes. When one concept (typically corresponding to a noun) is activated, that activation is assumed to spread to linked concepts. In Quillian's (1968) original formulation, it was assumed that the semantic content of some links (typically corresponding to verbs) would also be activated, because those links were themselves concepts[1] (Collins & Loftus, 1975). Despite the extensive research on semantic priming since Quillian's proposal, little work has examined relational priming per se—that is, the role of links as structured semantic concepts, as opposed to simple conduits for activation. This gap is troublesome because of the general importance of relations and role bindings in cognition.

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Semantic Relations in Analogy

One cognitive process in which the ability to use specific semantic relations is fundamental is analogical reasoning. Semantic relations are important in the mapping of one analog to another, the retrieval of an analog from long-term memory, and the generation of an analog given a target problem. Analogical mapping involves finding correspondences between possibly dissimilar objects, such as the sun and an atomic nucleus or a planet and an electron, that play comparable roles with respect to similar relations (see, e.g., Gentner, 1983; Gick & Holyoak, 1980). People are generally successful at finding such relational correspondences (see Holyoak & Thagard, 1995, for a review).

Semantic relations also play an important role in the process of analog retrieval and generation. Although people often fail to be reminded of analogous problems involving dissimilar objects and *dissimilar* relations (Gick & Holyoak, 1980), *similar* relations do seem to facilitate memory access during problem solving (Gentner, Ratterman, & Forbus, 1993; Holyoak & Koh, 1987; Keane, 1988; Ross, 1987, 1989; Wharton et al., 1994; Wharton, Holyoak, & Lange, 1996) and may facilitate problem solving even without awareness of the analog in memory (Schunn & Dunbar, 1996). In fact, people seem to be able to use semantic relations to generate analogs that are superficially dissimilar to a familiar problem (Blanchette & Dunbar, 2000). Some computational models of analog retrieval assume that *structural consistency*—systematic correspondences between the role fillers associated with similar semantic relations—facilitates retrieval of structured material in memory (Hummel & Holyoak, 1997; Thagard, Holyoak, Nelson, & Gochfeld, 1990). In addition, all major models of analogical mapping treat structural consistency as an essential constraint (e.g., Falkenhainer, Forbus, & Gentner, 1989; Holyoak & Thagard, 1989; Hummel & Holyoak, 1997).

Sensitivity to structural consistency requires knowledge representations that capture the *bindings* of objects to the roles they play with respect to semantic relations. That is, rather than simply representing objects as associated via semantic relations, role bindings indicate *which* objects go together with a particular token of a relation, and *which role* each object plays with respect to that relation (see Dosher, 1983; Ratcliff & McKoon, 1989). The central question we address in the present paper is whether, and if so under what conditions, semantic relations and their role bindings provide a basis for memory access, as evidenced by semantic priming.

Implications of Semantic Links Being Concepts

If semantic links themselves are concepts, then priming such links should have consequences analogous to those that occur when object concepts are primed. When single-word object concepts are presented as primes and targets (e.g., Meyer & Schvaneveldt, 1971), participants can judge whether or not a target letter string is a word more quickly when the preceding prime word has direct semantic or associative relations to the target than when the prime word is unrelated to the target (see Neely, 1991, and McNamara, 1992a, for reviews of data and theories). In order to test priming of links, rather than nodes, the present study adapted the standard lexical decision and naming paradigms to present *pairs* of words as primes and *pairs* of words as targets.[2] In the experimental (i.e., analogous) condition, the individual words within the two pairs forming the prime and the target, respectively, were connected by a common semantic relation. For example, participants might be shown a prime pair of words exhibiting an implicit semantic relation, such as BIRD–NEST for the relation "lives in," and then make a lexical decision on a target pair exhibiting the same semantic relation, such as BEAR–CAVE. Facilitation was measured in comparison with control (i.e., nonanalogous) trials in which the prime consisted of mismatched words drawn from two different exemplars of the relation (e.g., the animal–habitat pairs BIRD–NEST and CAMEL–DESERT are "crossed" to form the prime BIRD–DESERT). These conditions are illustrated in the left column of Table 1. Thus control primes were chosen to equate for any "word-to-word" priming of object concepts (i.e., direct priming from individual words in the prime to individual words in the target) independent of the relation. If participants are able to identify BEAR–CAVE as words more quickly when preceded by BIRD–NEST, as opposed to BIRD–DESERT, then we can infer that priming has been conveyed by the implicit common relation, "lives in," which is shared by the analogous prime and target.

Facilitation by analogical priming, if it can be demonstrated, would indicate that semantic access depends on knowledge representations that in some way solve the "binding problem." Simply stated, the binding problem requires an answer to the question: How do we know what goes with what (e.g., Hinton, McClelland, & Rumelhart, 1986)? For example, in visual perception, we need to know which features are associated with which object as objects move and change in the visual field (Treisman, 1988); in discourse comprehension, we need to know to whom various pronouns (such as *he* or *she*) refer in a passage involving many characters (see, e.g., Kintsch, 1987).

In the present context the binding problem is illustrated by the following question: Does the semantic retrieval system represent and use the fact that BIRD goes with NEST and CAMEL goes with DESERT? These pairs do not simply comprise one animal and one habitat; rather, they are animal–habitat pairs that *go together*. In an unconstrained system of spreading activation, presentation of any concept that fills the role of animal inhabitant (e.g., BIRD) paired with any concept that fills the role of a habitat (e.g., DESERT) would activate the relation "lives in," and hence trigger priming, just as well as would an animal–habitat pair bound to the same token of the relation (e.g., BIRD–NEST). Thus if semantic activation spread in such an unconstrained fashion, we would expect no

Table 1
Examples of Word Pairs Occurring in Each Condition in Each Experiment

Condition	Experiment 1A–C	Experiment 2 and 3A–B
Experimental (analogous)	Intact prime	Same relation prime
Prime	BIRD–NEST	BIRD–NEST
Target	BEAR–CAVE	BEAR–CAVE
Control (nonanalogous)	Split prime	"Different-relation" prime
Prime	BIRD–DESERT	WINDOW–GLASS
Target	BEAR–CAVE	BEAR–CAVE
		Neutral prime*
Prime		-----
Target		BEAR–CAVE

*Used only in Experiment 2.

benefit from priming by "intact" pairs such as BIRD–NEST rather than "split" pairs such as BIRD–DESERT.

Note that the fact that people obviously know that birds live in nests and camels in deserts, rather than in other possible animal–habitat combinations, does not by itself reveal whether or not binding information is used to guide semantic access. One possibility is that unconstrained spreading activation first allows all role fillers to activate relations regardless of bindings; postaccess mechanisms might subsequently weed out activated information in which appropriate bindings have been violated. An intermediate possibility is that the access system does not simply use or not use binding information in some automatic fashion. Rather, higher order strategic planning may influence whether or not the access process extracts and is guided by role bindings. Such strategic variations on access processes might parallel the apparent influence of strategies on whether or not relational structure influences similarity judgments (Markman & Gentner, 1993).

In addition to differing from previous studies involving only direct semantic or associative priming of object concepts, our study also differs from studies of mediated (or "second-order") semantic priming. Such studies tested whether one object concept can prime a seemingly unrelated concept via an implicit third concept (the "mediator") that is associated to both (e.g., BULL might be used as a prime for MILK, on the basis of associations from BULL to COW and from COW to MILK). Several early studies failed to find such mediated priming in lexical decision tasks (Balota & Lorch, 1986; de Groot, 1983), but later studies have shown facilitation under some presentation conditions (Balota & Paul, 1996; McNamara, 1992b; McNamara & Altarriba, 1988). However, McKoon and Ratcliff (1992; Ratcliff & McKoon, 1994) have argued that positive results are an artifact of the "mediated" pairs having a higher direct associative strength (as measured by cooccurrence) than control pairs. These investigators found no difference between the amount of priming obtained for items with and without obvious mediators when prime–target association strength was controlled (but see McNamara, 1992a, 1994, for replies).

Besides using word pairs rather than single words as primes and targets, our study differs from these previous studies of mediated priming in two important ways. First, in all previous studies the mediator was assumed to be an object concept (such as COW in the example just given), rather than a relational concept, such as "lives in." Second, in those studies the mediating concept was a strong associate of the prime and the target was a strong associate of the mediating concept. The mediating relational concepts used in the present study are not generally strong associates of either of the words in the prime pair; nor are the target words strong associates of the mediator. Evidence for analogical priming of the sort investigated here would suggest that lexical access can be influenced by a different type of mediated priming—one resembling analogical mapping, which depends on structured correspondences between the objects that serve as arguments of semantic relations.

Finally, the present study seeks to demonstrate that given an appropriate strategic set, even a single exposure to a prime containing an implicit relation, is sufficient to cause facilitation of a target pair of the same relation. McKoon and Ratcliff (1995) have demonstrated that relational priming can occur when participants are asked to perform lexical decision or naming on target words that follow related primes when the prime–target relation is consistent with the relations evident in other pairs of words in a block of trials. Specifically, they have shown that when participants read lists of pairs of words, where the majority of pairs exhibit the same relation, they are faster to respond to selected *same*–relation pairs than *different*–relation pairs. It is unclear from their study, however, whether this priming is due to some automatic process or rather to a strategic set developed by participants who have become aware of the dominant relation. The present study seeks to eliminate this uncertainty by making the manipulation of strategic set explicit.

EXPERIMENT 1A

Experiment 1A tested whether merely having participants read a prime pair consisting of semantically related words would automatically facilitate a lexical decision about a target pair consisting of analogously related words.

Method

Participants

Participants were college undergraduates who served in the experiment in partial fulfillment of a course requirement in introductory psychology at the University of California, Los Angeles (UCLA). All were native English speakers. The data from 24 participants were used in the analyses; 4 participants who had more than 15% unusable trials (errors plus trials with reaction times [RTs] greater than 1,500 msec)[3] were replaced.

Materials and Design

The important unit of analysis for this experiment is *pairs* of words that exemplify a relation (e.g., the pair BIRD–NEST for the relation "lives in"). Ten common semantic relations were chosen: "is used to," "works in," "lives in," "is made of," "is kept in," "is the outside of," "is part of," verb antonym, subordinate, and superordinate. For each relation 18 or 24 pairs exemplifying the relation were found. Some superordinate and subordinate pairs were taken from Battig and Montague (1969). Other pairs were generated by the authors and by participants from an introductory psychology course, then normed for "goodness of relation" and checked for word familiarity by other participants from the same pool. The list of pairs was then edited so that no individual word appeared more than once. (The complete set of materials is available from the authors.)

Word trials. The 12 most highly rated exemplars of each relation were used to form the six prime pairs and six target pairs for the word trials. Two types of prime pairs were constructed for each relation: "intact" primes (such as BIRD–NEST for the relation "lives-in") formed an exemplar of a relation; "split" primes (such as BIRD–DESERT) consisted of mismatched words drawn from two different exemplars of the relation. (See the left column of Table 1.) Unlike prime pairs, which could be intact or split, the target pair was always an intact exemplar of the same semantic relation as the prime pair (e.g., BEAR–CAVE). Therefore, for each relation, three word trials were analogous (intact prime pair, intact target pair) and three word trials were not analogous (split prime pair, intact target pair).

Within-subjects counterbalancing. In order to obtain within-subjects measures on the same specific items, we had participants make lexical decisions on the same target pairs in a second block of trials, separated from the first block by an unrelated reasoning task. In the second block of trials, targets that had been preceded by intact primes in the first block were now preceded by split primes, and those that had been preceded by split primes were now preceded by intact ones. The words in the prime pairs were rearranged, so that no associative learning from the first block could carry over to the second block. Individual words that had been part of an intact prime pair in the first block became part of a split prime pair, and those that had been part of a split prime pair became part of an intact prime pair. In addition, if a word was part of the prime pair for a particular target in the first block, it would not be part of the prime pair for that same target in the second block. Thus, over all trials, the same individual words were used equally often in both intact and split primes, controlling for any effects of direct semantic links between individual prime and target words.

Between-subjects counterbalancing. In order to control for the effects of specific pairings of words, participants were rotated through 12 counterbalancing conditions. The first 12 participants in the experiment made lexical decisions on the same randomly selected set of target pairs. Six conditions ensured that each target was preceded by each of six different intact prime pairs and each of six different split prime pairs; the other six conditions presented the same pairings, but switched the block of presentation. The next 12 participants made decisions on a new random set of targets with similarly counterbalanced primes.

Nonword trials. The prime pairs for the nonword trials always consisted of two real words. The prime pairs were formed from the six next-best word pairs exemplifying each relation. As for the word trials, half of the prime pairs were intact and half were split. Also, in the second block, as for the word trials, individual words that had been part of an intact prime pair in the first block became part of a split prime pair, and those that had been part of a split prime pair became part of an intact prime pair.

The target pairs for the nonword trials always consisted of one word and one nonword. The nonword targets were created by taking unmatched pairs of words from the same semantic categories as the primes and changing one letter in either the first or the second word of the target to create a pronounceable nonword. For example, after a prime exemplifying the "lives in" relation, the first target string would be either the name of an animal or the name of an animal with one letter changed to form a pronounceable nonword; the second target string would be either the name of a habitat or the name of a habitat with one letter changed (e.g., TAGER–RIVER or TIGER–RINER). The nonword targets were slightly different in the two blocks: The two target letter strings remained together, but if the first letter string had been made into a nonword in Block 1, then the second letter string would be made into a nonword in Block 2.

Prime–target pairings in the nonword trials were the same for all participants.

Filler trials. The practice and filler trials consisted of both word and nonword trials and were indistinguishable from real trials.

Summary of design. These manipulations define (for the word trials) a 10 × 2 × 2 (relation × block × prime-type) within-subjects design. The dependent variable was the participant's average RT to the three trials in each condition. Only trials in which a correct decision followed another correct decision,[4] and in which the RT was shorter than 1,500 msec, were included in that average.

Each participant made a total of 240 lexical decisions (not including practice and filler trials). There were 120 word trials and 120 nonword trials. For the word trials, half had intact prime pairs (and were therefore analogous trials) and half had split prime pairs (and were therefore non-analogous trials); similarly, for the nonword trials, half had intact prime pairs and half had split prime pairs.

Procedure

Participants were tested individually on an IBM AT computer in a single session that lasted about 35 min. Instructions for the experiment were displayed on the computer screen. The participants were told that the experiment would consist of four parts: a word decision task on the computer, some simple problem solving, more of the word decision task, and then a memory test. Each participant was told that at the beginning of each trial an asterisk would appear in the center of the screen. After the asterisk disappeared, two words would then appear and quickly disappear. The participant was to read this pair because later the words (which would always be real English words) would be on the memory test. The participant was told that two strings of letters would appear on the screen and that the participant's task would be to decide whether both of those strings were real English words. The participants were told to make the lexical decision as quickly and accurately as possible. They did so by pressing one of the appropriate keys on the response box (the fingers of the right hand rested on five keys for "word"; the fingers of the left hand rested on five keys for "nonword").

The lexical decision task was then illustrated using the examples BOY–GIRL ("word"), BOT–GIRL ("nonword"), and BOY–GIRN ("nonword"). Nothing was said about the relation between the words or the pairs of words. Participants were told that that the first 10 trials would be practice.

On each trial, an asterisk appeared in the middle of the screen for 250 msec, after which the screen was blank for 250 msec. The prime pair appeared for 400 msec (stimulus onset asynchrony [SOA]) with the top word centered directly over where the asterisk had been and the bottom word centered directly below it. The target pair, which was centered on the same lines as the primes, appeared immediately after the primes disappeared. The target pair remained on until one of the response keys was depressed and the latency was recorded. If the response was incorrect, the message "wrong" appeared just below where the words had been; if the latency was greater than 1,500 msec, the message "too slow" appeared for 2,000 msec. After 250 msec, the next trial began. Whenever the participant made an incorrect response, the next trial was a filler trial.

Participants made 10 practice responses and then made lexical decisions on the 120 (plus filler) trials from Block 1. When they were done, they were given a booklet containing several logic and probability questions, which took 8–10 min to complete. Participants were then instructed that they would again be doing the same task on the computer and would be given several practice trials to begin the next set. They then completed the second block of trials. Participants were not given a memory test.

Results and Discussion

General Analyses (Experiments 1A–1C)

Only RTs from correct decisions following correct decisions were included in the analysis. In addition, RTs of greater than 1,500 msec were discarded. (See notes 3 and 4.) Results from all experiments are shown in Table 2.

A main effect of relation was consistently obtained, but because each relation necessarily was represented by different words, variations in overall RTs across relation are not of interest and are not reported. However, interactions involving relation are reported for each relevant experiment; overall priming by relation is reported in Table 3.

Priming Results (Experiment 1A)

Overall, no analogical priming was observed in Experiment 1A; that is, there was no difference between RTs for correct "word" decisions after intact primes (*M* =

Table 2
Mean Correct Reaction Times (RTs, in Milliseconds), Mean Percentage Error Rates (PEs) for Targets, and Standard Errors (*SE*s) as a Function of Prime Type, Target Type, and Experiment

	Lexical Decision Experiments																Naming Experiments							
	1A (Read Only + WM)				1B (Note Relation + RM)				1C (Note and Use Relation)				2 (Note and Use Relation)				3A (Read Only + WM)				3B (Note and Use Relation + RM)			
Condition	RT	*SE*	PE	*SE*	RT	*SE*	PE	*SE*	RT	*SE*	PE	*SE*	RT	*SE*	PE	*SE*	RT	*SE*	PE†	*SE*	RT	*SE*	PE†	*SE*
Word Targets																								
Exp. prime	816	6.6	2.9	.4	810	6.3	3.8	.6	761	5.1	2.5	.5	802	15.2	2.1	.7	766	23.6	2.2	.8	833	22.3	2.1	.8
Control prime	821	6.4	3.9	.5	812	6.1	3.6	.5	786	5.2	2.8	.5	829	14.5	2.7	.6	763	22.3	1.4	.5	847	23.2	2.6	.8
Neutral prime													848	17.8	5.0	1.0								
Nonword Targets	953	18.2	7.2	.6	933	17.5	6.9	.6	915	15.3	7.7	.6	997	15.6	12.1	1.1								
Priming Effect	5				2				25***				27**				−3				14*			

Note—Significant analogical priming is indicated by asterisks: *$p < .05$; **$p < .01$; ***$p < .0001$. WM = participants were told there would be a word memory test at the end of the experiment; RM = participants were told there would be a relation memory test at the end of the experiment. Note that the standard errors vary, in part, because the dependent variable is different across experiments. In Experiment 1, for the word targets, the standard errors are based on the means of 20 observations (10 relations × 2 blocks) per condition per participant. For the Experiment 1 nonword targets and for all conditions in Experiments 2 and 3, standard errors were computed on one mean score per condition per participant. (Thus they reflect between-subjects variability.) In Experiment 3, errors (†) represent machine errors in which the microphone did not pick up a response.

816 msec) versus split primes [$M = 821$ msec; $F(1,23) = .64$, n.s.; see Table 2]. This finding suggests that analogical priming is not obtained as an automatic consequence of reading the prime words.

Participants did become faster across blocks [$M = 862$ msec for Block 1; $M = 775$ msec for Block 2; $F(1,23) = 59.86$, $p < .0001$]; this effect did not interact with prime type [$F(1,23) = 1.50$, n.s.].

Relation did not interact with either block [$F(9,207) = .65$, n.s.] or prime type [$F(9,207) = 1.61$, n.s.]. The size of the priming effect for each relation is reported in Table 3 for Experiments 1 and 3. (The method of Experiment 2 precluded calculating priming effects of individual relations; see note to Table 3.)

EXPERIMENT 1B

We were concerned that participants in Experiment 1A were not actually accessing the meaning of the relation in the prime pair. In a standard lexical decision paradigm, the way in which a prime is processed has been shown to affect the presence and amount of facilitation. Standard priming effects appear to require that participants access the meaning of the prime word. Facilitation *is* observed when participants are merely instructed to read the prime, but not, for example, when participants must perform a letter search on the prime (Smith, Theodor, & Franklin, 1983). Perhaps the task of merely reading the prime pair, under the instructions used in Experiment 1A, did not ensure that participants would access the meaning of the implicit relation. In order to guarantee that participants would access the meaning of the relation, instructions in Experiment 1B called participants' attention to the relations implicit in the primes.

Method

The method was the same as in Experiment 1A with the following exceptions.

Participants

Participants were undergraduates who met the criteria outlined for the previous experiment. None had participated in the earlier experiment. The data from 24 participants were used in the analyses; 6 participants who had more than 15% unusable trials were replaced.

Instructions

Rather than being told to read the prime pair because the *words* would be on a memory test, as in Experiment 1A, participants in Experiment 1B were told that the prime words might be related to each other, and that they should pay attention to that relation because there would be a memory test for the *relations*.

Results and Discussion

Overall, as shown in Table 2, the results of Experiment 1B were very similar to those of Experiment 1A. Again no analogical priming was observed; there was no difference between RTs after intact primes ($M = 810$ msec) versus split primes [$M = 812$ msec; $F(1,23) = .10$, n.s.]. These null findings suggest that not even instructions to

Table 3
Analogical Priming by Relation in Experiments 1 and 3 (in Milliseconds)

	Experiment				
	Lexical Decision			Naming	
Relation	1A (Read Only + WM)	1B (Note Relation + RM)	1C (Note and Use Relation)	3A (Read Only + WM)	3B (Note and Use Relation + WM)
Is used to	10	−8	−2	6	21
Works in	13	22	39	−22	46
Lives in	−18	9	8	−42	−18
Is made of	−18	−1	45	19	24
Verb opposites	13	−21	25	33	2
Is kept in	32	−11	28	−35	31
Is part of	11	18	40	1	3
Is the outside of	45	24	7	−17	15
Subordinates	−33	−2	52	19	14
Superordinates	0	−5	15	8	6
M	5	2	25	−3	14

Note—Scores are (RTs for split trials) − (RTs for intact trials); thus, positive scores are an indication of analogical priming. This analysis was not done for Experiment 2 because: (1) each participant has at most two usable responses to each relation in each condition, and (2) each participant responded to a different set of target pairs.

attend to the implicit relations linking prime words is sufficient to produce analogical priming of target pairs sharing those relations.

Participants did become faster across blocks [$M = 862$ msec for Block 1; $M = 760$ msec for Block 2; $F(1,23) = 32.87$, $p < .0001$]; this effect did not interact with prime type [$F(1,23) = .01$, n.s.].

Relation did not interact with either block [$F(9,207) = .75$, n.s.] or prime type [$F(9,207) = .85$, n.s.]; the size of the priming effect for each relation is reported in Table 3.

EXPERIMENT 1C

Although the results of Experiments 1A and 1B indicate that analogical priming is not automatic, it remains possible that it can be demonstrated under an appropriate strategic set. Accordingly, in Experiment 1C we not only directed participants' attention to the relations implicit in the primes, but we also told them of the possible connection between the relations implicit in the prime and target pairs.

Method

The method was the same as in Experiments 1A and 1B with the following exceptions.

Participants

Participants were undergraduates who met the criteria outlined for the previous experiments. None had participated in either of those experiments. The data from 24 participants were used in the analyses; 3 participants who had more than 15% unusable trials were replaced.

Instructions

The pretense of a later memory test was dropped. Participants were told that first they would see a pair of words that might be related (e.g., MAN–WOMAN), then they would have to make a lexical decision about a second pair of words, and sometimes the second pair would be related in the same way as the first (e.g., BOY– GIRL). The instructions continued: "That is why reading the first pair might help you with the decision you have to make about the second pair."

Results and Discussion

Significant analogical priming was observed in Experiment 1C. The magnitude of the effect was 25 msec: intact primes ($M = 761$ msec) led to shorter lexical decision times than did split primes [$M = 786$ msec; $F(1,23) = 36.54$, $p < .0001$]. No interactions involving prime type were significant, and the difference in the number of errors made in the prime conditions was not significant (2.5% for intact primes, 2.8% for control primes). These results provide the first evidence that when participants are encouraged to process the relations within the prime and target pairs, and also the relation between these relations, analogical priming can be demonstrated.

Participants responded more quickly across blocks [$M = 803$ msec for Block 1; $M = 745$ msec for Block 2; $F(1,23) = 41.70$, $p < .0001$]; this effect did not interact with prime type [$F(1,23) = .01$, n.s.].

Relation interacted with block [$F(9,207) = 2.20$, $p < .05$]; RTs were faster for all relations in Block 2, but the improvement ranged from 11 to 92 msec for different relations. Relation did not interact with prime type [$F(9,207) = 1.24$, n.s.]; the size of the priming effect for each relation is reported in Table 3. Note that for 9 of the 10 relations, RTs for intact pairs were faster than those for split pairs.

EXPERIMENT 2

The results of Experiment 1C indicate that when participants are directed to attend to shared semantic relations, analogical priming is obtained. Since over the entire item set the same words were used in both intact and split primes, the advantage of the intact condition cannot be attributed to differential direct associations between individual words in the prime and target. However, it might be suggested that the apparent analogical priming was due to the greater ease of reading intact primes as opposed to split primes. That is, perhaps participants spent extra time trying to "make sense" of a split prime and hence delayed their processing of the target pair. This hypothesis predicts that split primes would also lead to slower responding on nonword trials. In fact, in all three experiments a slight nonsignificant advantage for intact prime trials was observed for nonwords (5–9 msec); however, (1) these trends were confounded with specific-item effects, and (2) the priming effect for word pairs in Experiment 1C was significantly greater than the trend observed for nonword pairs. The "differential prime processing" explanation thus cannot account for all of the priming obtained in Experiment 1C, nor for the difference between the positive priming obtained in Experiment 1C and the lack of priming in Experiments 1A and 1B. Nonetheless, Experiment 2 was performed to directly control for differential ease of processing intact versus split primes.

Method

The method for Experiment 2 was similar to that of Experiment 1.

Participants

Participants were undergraduates who met the criteria outlined for the previous experiments. None had participated in any of the earlier experiments. The data from 24 participants were used in the analyses; the data from 2 participants who had more than 15% unusable trials were discarded.

Materials

The same relations and items were used as in Experiments 1A–C. Three types of primes were constructed, as illustrated in the right column of Table 1. *Same-relation* primes were identical to the intact primes of the previous experiments; word pairs with the same implicit intra-pair relation as in the target pair. *Different-relation* primes also had a clear intra-pair relation, but one that differed from the relation within the target pair. Thus unlike the two prime types used in Experiments 1A–C, there was no basis for any difference in processing time for same- and different-relation primes (given that assignment of pairs as same- and different-relation pairs was counterbalanced). In addition, a third prime type, the neutral "---------" was also employed (but see Jonides & Mack, 1984, for discussion of the problems involved in defining a truly "neutral" prime). As in the earlier experiments, target pairs were always semantically related.

Participants saw only one block of 120 trials (not including practice and filler trials), which consisted of 60 word and 60 nonword trials, 20 of each with each type of prime. The assignments of pairs to be primes or targets, of particular prime pairs to be same- or different-relation primes, and of particular target pairs to the three prime conditions, were completely randomized across participants, as was the order of presentation. The orienting instructions to participants were identical to those used in Experiment 1C except that (1) participants were told about the neutral prime condition, and (2) participants were told that all, rather than some, of the prime word pairs would have an intra-pair relation.

Design

The sole independent variable (for the word condition) was the type of prime (same-relation, different-relation, neutral). The dependent variable was the participant's average RT for the 20 trials in each condition.

Procedure

The procedure was identical to that of Experiments 1A–C except that participants received 18 practice trials before starting and the experiment was run in a single block.

Results and Discussion

Experiment 2 also demonstrated analogical priming. An analysis of variance revealed that RTs for word targets differed significantly across the three prime conditions [$F(2,46) = 5.70$, $p < .01$]. A planned comparison revealed that participants were significantly faster at making lexical decisions to word targets after same-relation primes ($M = 802$ msec) than after different-relation primes [$M = 829$ msec; $F(1,23) = 9.09$, $p < .01$].

Performance in the neutral condition was relatively slow and erratic, suggesting that the neutral condition was not truly "neutral" (Jonides & Mack, 1984). A Newman–Keuls test revealed that the neutral condition ($M = 848$ msec) was significantly slower than the same-relation condition, although not significantly slower than the different-relation condition. Variability was substantially higher in the neutral condition than in either of the other conditions (Table 2); in addition, the frequency of errors in the neutral condition (5%) was significantly higher than in the average of the other two conditions [2.4%; $F(1,23) = 4.57$, $p < .05$].

The results of Experiment 2 thus confirm and extend the results of Experiment 1C, demonstrating analogical priming that cannot be ascribed to differential processing time for same-relation primes. The intact and split primes used in Experiment 1 were constructed to equate for any direct priming between individual words in the prime and target; however, this control is not possible for same- and different-relation primes (because the words in the pair are always presented together). If word-to-word priming contributed in any way to the results of Experiment 2 (and Experiment 3), we would expect to find a larger advantage for the same-relation over the different-relation conditions for more specific relations. For example, one might expect more word-to-word priming for the relatively specific "lives in" relation (e.g., given prime BIRD–NEST and target BEAR–CAVE, there might be more word-to-word priming from BIRD to BEAR and from NEST to CAVE) than for the highly general superordinate relation (e.g., given prime HAMMER–TOOL and target CARROT–VEGETABLE, we would expect little priming from HAMMER to CARROT and from TOOL to VEGETABLE). We therefore wanted to compare priming for the relations for which word-to-word priming might be expected ("lives in" and "works in") to priming for relations for which such priming would not be expected ("is part of," verb opposites, superordinates, and subordinates).

The design of Experiment 2, in which (1) each participant gave at most two usable responses to each relation in each condition, and (2) each participant responded to a different set of target pairs, precludes an analysis by individual relations. However, the data in Table 3 show that in Experiment 1 the relations more likely to involve word-to-word priming (works in, lives in) did not tend to show any more priming than did the more general relations (is part of, verb opposites, subordinates, superordinates).

In addition, previous evidence has suggested that automatic word-to-word priming typically occurs only when the prime and target are highly associated (e.g., Lupker, 1984; McRae & Boisvert, 1998; Shelton & Martin, 1992). Thus, it is unlikely that the weak associations from BIRD to BEAR and NEST to CAVE would contribute significantly to the observed priming effect. The results of Experiment 2 thus provide further evidence for analogical priming that cannot be attributed to differential word-to-word priming.

EXPERIMENT 3A

In addition to lexical decision tasks, naming latencies have been widely used to study lexical access. Although these two approaches frequently yield similar results, differences do exist, particularly in complex paradigms (Balota & Lorch, 1986; see Neely, 1991, for a review). Thus, to better characterize the phenomenon of analogical priming we designed a naming version of the experiment (based on comparing same- and different-relation primes, as in Experiment 2).

We also reinstated the instructions that told participants there would be a memory test at the end of the experiment. One possible description of our previous experiments is that we had not found analogical priming when there was a concurrent memory load (Experiments 1A and 1B) and had found analogical priming when there was no concurrent memory load (Experiments 1C and 2). In Experiment 3A, as in Experiment 1A, people were not told about the relations that were present.

Method

Participants

Participants were 32 undergraduates who met the criteria outlined for the previous experiments. None had participated in any of the earlier experiments.

Materials

The same relations and items were used as in Experiment 2 except that two filler items (DEER–FOREST; GOLF–SPORT) were substituted for target pairs (CAMEL–DESERT; PIE–DESSERT) due to frequent mispronunciation errors in a pilot study. In addition, the highly variable neutral condition was dropped. The two types of primes are illustrated in the right column of Table 1. Participants saw 60 trials (not including practice and filler trials) consisting of 30 same- and 30 different-relation trials. All targets were word pairs; there were no nonword targets in the naming experiments. Each of the 10 relations was equally represented across conditions. Four versions of the experiment were created so that each word pair served as both a prime pair and target pair in both same- and different-relation conditions across the four versions. (Note: this procedure was therefore more controlled that that of Experiment 2, in which primes and targets were randomized for each participant.)

Procedure

Participants were tested individually on a Macintosh computer with a 15-in. monitor in a single session that lasted about 30 min. Participants were asked to put on a microphone that clipped around their ears and to adjust the microphone so that it was 1 in. from their mouths.

Instructions for the experiment were displayed on the computer. Participants were told that at the beginning of each trial an asterisk would appear in the center of the screen. After the asterisk disappeared, a pair of words would appear and quickly disappear. Participants were told to read the words silently. When those words disappeared, two more words would appear. Participants were told to read the first word silently and then to say aloud the second word, which would appear in all capital letters, as quickly and accurately as possible. They were told to pay attention to the words that they saw because there would be a memory test for the words. The naming task was then illustrated using an example: BOY–MAN, GIRL–WOMAN. Participants were reminded that their voices were being recorded, so they should speak loudly.

On each trial an asterisk appeared in the middle of the screen for 1 sec, after which the prime pair appeared for 400 msec (SOA) with the top word centered directly over where the asterisk had been and the bottom word centered directly below it. After the primes disappeared, the first word of the target pair appeared for 250 msec, after which it was joined by the second word of the target pair, shown in all capital letters. This order of presentation was used to ensure that participants read both words of the target pair prior to naming the second word. The target pair remained on for 1,500 msec. Naming latency was recorded by the computer from the time of onset of the target to be named—that is, from the time that the second word in all capital letters joined the first word of the target. If no response was recorded during this period, the message "speak up" appeared just below where the words had been. The next trial began immediately.

Participants made 10 practice responses, after which they were asked if they had any questions and were queried about whether they had seen the "speak up" warning. Participants were then reminded that their voices were being recorded, after which the experimenter would start an audiotape to record the verbal content of the trials and begin the experiment. They then completed three blocks of 20 trials. Each block began with a filler trial. Trials in each block were presented in random order for each participant. There was a 30-sec rest period between each block. When they were done, participants participated in a second unrelated experiment, after which they were debriefed and released. No memory test was administered.

Results and Discussion

In Experiment 3A, the dependent variable was the participant's average naming latency for the 30 trials in each condition. As in Experiments 1A and 1B, no analogical priming was observed; there was no difference between RTs after same-relation primes (M = 766 msec) versus different-relation primes [M = 763 msec; $F(1,31) = .14$, n.s.]. These null findings suggest that, as in lexical decision, analogical priming in naming is not automatic.

EXPERIMENT 3B

In order to discover whether analogical priming in naming responds to the same conditions as in lexical decision, the instructions given in Experiment 3A were modified. In Experiment 3B participants were given the same instructions to attend to and use the relations as in Experiments 1C and 2 and also given the same memory test instructions as in Experiment 1B (which asked them to remember the relations). Thus, this experiment was the first to have both the full instructions on how to use the relations and a memory load.

Method

The method was the same as in Experiment 3A with the following exceptions.

Participants

Participants were 28 undergraduates who met the criteria outlined for the previous experiments. None had participated in any of the earlier experiments.

Instructions

Instructions were similar to those in Experiment 3A except that participants were told that the first pair of words would be related. Participants were told to read the words silently and think about the relation connecting them. They were told that the second pair of words would also be related, sometimes in the same way as the first pair. They were also told that it was important to pay attention to how the words were related because at the end of the experiment there would be a memory test for the relations. As in Experiment 3A, the naming task was illustrated using an example: BOY–MAN, GIRL–WOMAN.

Results and Discussion

In Experiment 3B, the dependent variable was again the participant's average naming latency for the 30 trials in each condition. Participants showed analogical priming; they were significantly faster at naming targets after *same-relation* primes (M = 833 msec) than after *different-relation* primes [M = 847 msec; $F(1,27) = 4.45$, $p < .05$].

Thus, as in the lexical decision task, instructions to note and use the relational information in naming produced significant analogical priming. In addition, analogical priming occurred even with memory instructions, so memory load cannot explain the failures to find priming in Experiments 1A, 1B, and 3A. As in Experiment 2, there was no evidence that word-to-word priming contributed to the same-relation priming advantage because there was no significant difference in the size of the priming effect across the different kinds of relations [$F(9,110) = .70$, n.s.; the size of the priming effect for each relation is reported in Table 3]. Note that for 9 of the 10 relations, RTs for same-relation pairs were faster than those for different-relation pairs.

GENERAL DISCUSSION

The present study identified a new phenomenon—priming of lexical decisions and naming mediated by a single shared semantic relation—and clarified boundary conditions on that phenomenon. In the lexical decision experiments, we did not find analogical priming in our first two studies, in which participants were told to attend to the words (Experiment 1A) or individual relations (Experiment 1B) for a later memory test; however, we did find analogical priming in our second two studies, in which participants were told to attend to the relation between the relations (Experiments 1C and 2). Similarly, in the naming experiments, no analogical priming was found when participants were told to attend to the words (Experiment 3A); however, analogical priming was found when participants were told to attend to the relation between the relations (Experiment 3B)—even with the addition of memory test instructions.

In summary, analogical priming was obtained only when instructions directed participants to attend to the possible intra-pair relation shared by the prime and target pairs. This boundary condition indicates that analogical priming is not fully automatic (Posner & Snyder, 1975). On the other hand, the 400-msec delay between prime and target pairs used in the present experiments is somewhat shorter (especially given the dual- rather than single-string decision task we used) than the delay typically required to obtain apparent trial-by-trial variations in strategic processing within lexical decision tasks (Neely, 1977, 1991). Thus the kind of processing required to produce analogical priming seems to be neither fully automatic nor fully strategic. Rather, it may reflect a general attentional strategy set up for the entire task, which in turn initiates a relatively automatic form of relational processing on each trial. Some proposals for attentional modulation within connectionist networks (e.g., Cohen, Dunbar, & McClelland, 1990) suggest mechanisms with this mixed automatic/strategic character. Spellman (1991) reported evidence for relational priming in an intentional memory task when relations are incidentally processed, providing evidence that relational priming need not require conscious strategy selection.

That analogical priming might need more of a "boost" than semantic priming is not surprising in light of some results from the similarity and analogy literature. Analogical priming involves not just using the relations between pairs of objects, but also using a higher order relation (i.e., sameness of relation) that holds between the two similarly related pairs of objects. The ability to use relations between relations, rather than simple relations between objects, takes more processing time for adults (Gentner & Markman, 1997), develops relatively later in children (Gentner & Rattermann, 1991) and may be possible only for species that can use an external symbol system (i.e., humans and trained chimps; see Holyoak & Thagard, 1995).

Thus, our general hypothesis is that analogical priming is the product of an analogical mapping (e.g., Falkenhainer et al., 1989; Holyoak & Thagard, 1989; Hummel & Holyoak, 1997), since people attempt to identify structured correspondences between the roles played by the concepts that comprise the prime and the target pairs. That is, people using a mapping strategy may identify the target as a word pair if a good mapping is detected. As in tasks involving judgments of similarity, use of a mapping strategy may itself depend on the overall strategic set that the participant invokes (Markman & Gentner, 1993). In order to use such a mapping strategy, semantic relations between pairs of words must be generated and evaluated, and the systematicity of the bindings of object concepts into appropriately linked relational roles must be considered. Thus, semantic processing done under this strategic set differs from what would be expected by automatic spreading activation or the use of compound cues. Neither of those theories explicitly takes structure into account. Spreading activation theory would predict that activation would spread indiscriminately from one animal–habitat pair that goes together to all random pairings of animals and habitats—not more specifically to other animal–habitat pairs that go together. Compound-cue theory (Ratcliff & McKoon, 1988, 1994) would predict that there should be more priming for more specific relations (because they form more familiar cues but not due to structure per se)—a result we did not obtain. Whereas many retrieval models do not represent role bindings (see Ratcliff & McKoon, 1989, for a brief review), some models of analogical retrieval do represent role bindings (e.g., Hummel & Holyoak, 1997), and therefore could potentially account for analogical priming.

The crucial role of orienting instructions (to attend to the relation between relations) in producing the analogical priming effect thus needs to be further explored. Although the full set of conditions under which analogical priming may occur remains unclear, we have shown the importance of instructions when facilitation is achieved by a single *intact*-relation (or *same*-relation) pair of words. McKoon and Ratcliff (1995) have demonstrated a similar effect through the context of target words. The version of the effect obtained in their study may be the result of an implicit strategic set similar to that produced by instructions in the present study.

Although many questions about the nature of analogical priming remain unanswered, the phenomenon may prove central in providing theoretical linkage between basic mechanisms for accessing semantic memory and mechanisms for comprehension and reasoning.

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NOTES

1. More accurately, such links correspond to *tokens* that derive meaning from pointers to their corresponding concept *types*.

2. Of course, Meyer and Schvaneveldt (1971) and others have presented pairs of words to be judged at the same time, which is what participants did with the target pairs in our lexical decision experiments.

3. Note that our dependent variable was the average of the correct (at most three) RTs for the target pairs in each condition in each relation in each block. To maximize the stability of that measure, we wanted (1) to make sure participants contributed the greatest number of correct responses possible and (2) to eliminate outlier responses. The cutoff of 1,500 msec was chosen because pilot participants had shown mean RTs (in the word condition) ranging from about 650 to 1,000 msec with a mean standard deviation of about 200 msec. The cutoff therefore was about 3 *SD* above the mean RT in the word condition.

4. Pilot testing revealed that after receiving the feedback "wrong" for an incorrect answer, participants had longer latencies on the next trial. Thus, filler trials were inserted after incorrect trials and were not analyzed.

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