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SEMANTIC FALSE MEMORIES IN THE FORM OF DERIVED RELATIONAL INTRUSIONS FOLLOWING TRAINING

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Contemporary behavior analytic research is making headway in characterizing memory phenomena that typically have been characterized by cognitive models, and the current study extends this development by producing ''false memories'' in the form of functional equivalence responding. A match-to-sample training procedure was administered in order to encourage participants to treat groups of unrelated English words as being interchangeable. Following training, participants were presented with a list of words from within one of the groups for a free recall test and a recognition test. Results showed that participants were more likely to falsely recall and recognize words that had been assigned to the same group as the list words during prior training, relative to words not assigned to the same group and relative to words that co-occurred with list words. These results indicate that semantic relatedness can be experimentally manipulated in order to produce specific false memories.

Key words: false memory, equivalence, semantic, intrusions, word lists, free recall, recognition, humans

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Applied research on false memory phenomena has focused on settings in which unintentionally fictitious reports about past events can have severe negative consequences for individuals and society. Both eyewitness testimony (e.g., Loftus, 1975; Loftus & Palmer, 1974) and self-reports of childhood sexual abuse (e.g., Ceci & Friedman, 2000; Goodman & Clarke-Stewart, 1991; Lyon, 1995) have proven to be surprisingly fallible. Research in both of these domains has identified circumstances under which the accuracy of reporting is far below what would be expected based on everyday experience, suggesting that great care need be taken by police, therapists, or anyone who wishes to obtain accurate information without distorting the recollection of subjective experiences. More generally, false memory phenomena are of interest to some researchers who view these phenomena as being useful for modeling and exploring the properties of cognitive schema (e.g., Brewer & Treyens, 1981; Minsky, 1975; Schank & Abelson, 1977), thereby extending the body of research underlying a major branch of therapeutic intervention (i.e. cognitive therapy; Beck, 1976). On a more basic level, cognitive psychologists often study false memory phenomena in order to understand the relationship between semantic relatedness, associative strength, cognitive processes or structures, and apparent errors in the encoding, storage, or retrieval of informational representations (for reviews see Brainerd & Reyna, 2005; Gallo, 2006). The purpose of the current study is to develop a parallel behavior analytic conception of the relationship between semantic meaning, associative strength, learning history, and false memory phenomena.

Cognitive psychologists often use the Deese-Roediger-McDermott paradigm (DRM; Deese, 1959a, 1959b; Roediger & McDermott, 1995) to study the connection between semantic relatedness, associative strength, and false memories. During a DRM task, participants hear a list of study words that all have a strong association with a critical root word (e.g., the study words *bed*, *rest*, *awake*, *tired*, *dream*, *snore*, etc. are all strongly associated with the critical root word *sleep*). Following the study phase, participants perform a free recall task and often falsely recall (i.e., ''intrude'') the critical word even though it was never presented (e.g., Robinson & Roediger, 1997; Roediger & McDermott, 1995). Deese (1959a,1959b) found that across a variety of constructed lists, the probability that a given list's critical root word would be intruded was highly predictable from the list's mean backward associative strength, which was defined as the tendency

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of list words to elicit the critical root word in a free association test. In contrast, dense inter-item associative strength, or the tendency of list words to elicit other list words in a free association test, has been found to be predictive of greater levels of veridical recall and lower levels of false recall (Deese, 1959a, 1959b; McEvoy, Nelson, & Komatsu, 1999). Other research suggests that there is a stronger semantic relationship (as measured by Latent Semantic Analysis; see Landauer & Dumais, 1997) between intruded words and just-recalled words than there is between intruded words and remaining list words (Zaromb et al. 2006; see also Howard & Kahana, 1999). For example, given a particular study list for free recall (i.e., *keys, farmer, wall, book, moon, island,* etc.), a person who had just recalled the study word ''farmer'' may subsequently intrude the word ''rancher'' on the basis of semantic relatedness, even if this intrusion bears no strong semantic relation with the remaining study words. Semantic relatedness also predicts the order of veridical recall in episodic memory tasks (Romney, Brewer, & Batchelder, 1993; Steyvers, Shiffrin, & Nelson, 2005; Zaromb et al., 2006). Although cognitive factors besides semantic relatedness or associative strength may also come into play during memory retrieval (e.g., Roediger, Watson, McDermott, & Gallo, 2001), considerable data support the cognitive interpretation that semantic relatedness and associative strength play important roles in both true and false memory processes.

Given that semantic relatedness and associative strength are predictive of false memory phenomena, it is possible that that influencing these variables may, in turn, influence false memory phenomena. That is, insight into false memory phenomena may be garnered by treating semantic relatedness and associative strength as dependent variables rather than as independent variables (e.g., Barnes-Holmes et al., 2005; Dagenbach, Horst, & Carr, 1990; Davis, Geller, Rizzuto, & Kahana, 2008; Durgunoglu & Neely, 1987; Hayes & Bissett, 1998; McKoon & Ratcliff, 1979; Pecher & Raaijmakers, 1999). Before exploring the possibility of directly manipulating semantic relatedness and associative strength as a means of inducing false memories, it is important to distinguish between these two terms, and to consider the overarching issue of ''meaning'' as construed from the perspectives of cognitive psychology and behavior analysis.

Cognitive Construal of Meaning

Within the field of cognitive psychology, memory and meaning are defined in terms of a computer metaphor, in which informational representations, which have referents in the world, are stored in mental structures and retrieved by mental processes. There is, however, no single underlying cognitive theory regarding the nature of these hypothetical representations, structures, and processes. As such, the defining characteristics of semantic meaning (i.e., meaning in the context of language) varies according to which cognitive model one ascribes. Nevertheless, an overarching commonality of many cognitive models is the idea that informational representations can be thought of as ''nodes'' that are connected to each other in a cognitive network (Anderson, 1983; Collins & Loftus, 1975; Kawamoto, 1993; Masson, 1995; McNamara, 1992; Moss, Hare, Day, & Tyler, 1994; Plaut, 1995).

While a precise definition of semantic meaning depends on how one construes these cognitive networks, it is generally the case that the extent of connectivity between nodes is thought to arise from stimulus co-occurrence (see Hutchison, 2003). That is, the co-occurrence of stimuli leads to the simultaneous activation of their nodal representations, and simultaneous activation increases the degree of connectivity between the nodes. To the extent that the nodal representations of stimuli are interconnected, or to the extent that stimuli share nodal representations, they are said to be semantically related, or to ''mean the same thing.'' For example, it can be said that *cat* and *dog* are semantically related on the grounds that they share associations (or tend to co-occur) with a variety of other stimuli (e.g., *collars, veterinarians, allergies, fur, claws,* etc.). Stimulus co-occurrence is so central to cognitive conceptions of semantic meaning and associative strength that it has served as the foundation for meaning extraction in prominent formal modeling techniques such as Latent Semantic Analysis (Foltz, 1996; Landauer & Dumais, 1997; Landauer, Foltz, & Laham, 1998) and Hyperspace Analogue to Language (Burgess, 1998; Lund & Burgess, 1996; see also Spence & Owens, 1990).

The terms ''semantic relatedness'' and ''associative strength'' have various operational definitions, and their technical definitions also vary across cognitive models. For example, in holistic cognitive models (e.g., Anderson, 1983; Collins & Loftus, 1975; McNamara, 1992), the two terms are fairly interchangeable whereas in distributed cognitive models (e.g., e.g., Kawamoto, 1993; Masson, 1995; Moss, et al., 1994; Plaut, 1995) the term ''semantic relatedness'' is reserved for stimuli that share physical features. For present purposes, rather than ascribing associative strength to the definitions of any particular cognitive model, we can think of it as the degree of connectivity among nodes arising from direct stimulus co-occurrence, whereas semantic relatedness can be thought of as the degree of indirect connectivity among nodes that is mediated by other nodes within the network. For example, *lion* and *stripes* do not co-occur frequently and therefore are not highly associated. However, *lion* is associated with *tiger* and *tiger* is associated with *stripes*, so there is a semantic relationship between *lion* and *stripes* that is mediated by their common association with *tiger* (see Balota & Lorch, 1986). In contrast, *bread* and *butter* co-occur frequently through phrasal contiguity (see Fodor, 1983) and therefore are highly associated, and they are also semantically related through a variety of mediating associations (e.g., *toast, jam, breakfast,* etc.).

Behavior Analytic Construal of Meaning

Behavior analysts ground meaning, not in mental representations, but rather in the conditions under which behavior occurs (Day, 1969; Leigland, 2007; Skinner, 1953, 1957). Sometimes the use of a particular word is dictated by direct training, as when a child is reinforced for pointing to the printed word *cat* in the presence of a picture of a cat. Other times the use of a word involves a derived relationship that has not been directly trained (see Hayes, Barnes-Homes, & Roche, 2001; Sidman, 1994). For example, a child who has been directly reinforced for picking the printed word *cat* in the presence of a picture of a cat could also be directly reinforced for picking the word *gato* in the presence of a picture of a cat. The child may then derive that *cat* ''means the same thing as'' *gato,* as would be evident if the child went on to pick the printed word *gato* in the presence of the word *cat* without any prior history of reinforcement for such a behavior. While physical stimulus features play a role in many behaviors (e.g., generalized responding to perceptually similar stimuli), a principal characteristic of derived relationships is that they can occur between stimuli that bear no necessary physical relationship to each other (e.g., words and pictures; words and other words; words and sounds; tastes and sounds; etc.). Thus, two stimuli can ''mean the same thing'' not because they refer to common physical features, but rather because they are functionally interchangeable and thereby produce comparable effects (Hayes, et al., 2001; Sidman, 1994; Sidman & Tailby, 1982).

In the laboratory, behavior analysts may establish semantic relations using match-to-sample (MTS; Barnes-Holmes et al., 2005; Hayes & Bissett, 1998; Sidman, 1994; Sidman & Tailby, 1982). On a given MTS training trial, a sample stimulus is presented along with two or more comparison stimuli. Basic research typically employs arbitrary, unrelated stimuli during MTS training, but for purposes of illustration we will focus on stimuli that most readers will recognize as being related. Imagine that the sample on a given trial is a picture of a cat, and the comparison stimuli are the printed words *cat, perro,* and *dog.* Only one of these comparison stimuli ''matches'' the sample, in the sense that its selection produces a reinforcer (e.g., selection of the printed word *cat* in the presence of the picture of the cat produces food, or praise, or the word ''CORRECT''). On the next trial, the sample stimulus remains a picture of a cat, but the comparison items now are the printed words *gato, perro,* and *dog*; in this instance the selection of the printed word *gato* is reinforced. Later trials may include different samples (e.g., a picture of a dog) and different comparisons (e.g., the printed words *dog, gato,* and *cat*), whereupon different sample–comparison selections are reinforced (e.g., the selection of the printed word *dog* in the presence of the picture of the dog would be reinforced).

Following this kind of MTS training, an important behavioral phenomenon known as stimulus equivalence can emerge in which a person derives symmetric and transitive relationships (Sidman, 1994; Sidman & Tailby, 1982). In the example described above, in the presence of a picture of a cat (A) picking the printed word *cat* (B) is reinforced; this training arrangement can be denoted as A→B. The A and B stimuli are said to be symmetrically related if, without any further training, the individual can select a picture of a cat in the presence of the printed word *cat* (B→A). Similarly, direct training in which picking the printed word *gato* (C) in the presence of a picture of a cat (A) is reinforced (A→C) may produce the emergent symmetric relationship C→A. Moreover, direct training of A→B and A→C may also yield the emergent transitive relationships B→C and C→B (these derived relations are technically labeled as *combined symmetry and transitivity*, but for the sake of brevity we refer to them simply as transitive relationships). When symmetric and transitive responding are exhibited with respect to a set of stimuli, the stimuli are said to participate in a stimulus equivalence class (Sidman, 1994; Sidman & Tailby, 1982). To the extent that they are now functionally interchangeable, these physically dissimilar and formerly unrelated stimuli now ''mean the same thing.''

Our central assumption is that transitive relations reflect the mediated semantic relations described in the cognitive literature (Barnes-Holmes et al., 2005; Hayes & Bissett, 1998). For example, recall that *lion* and *stripes* infrequently co-occur in natural language, yet they are related through the mediating item *tiger*, as evidenced by findings that *lion* and *stripes* prime each other (e.g., Balota & Lorch 1986). Likewise, B and C stimuli never co-occur during MTS training, yet they can come to be functionally equivalent through their directly trained relations with A. This functional equivalence reflects semantic relatedness, as evidenced by findings that B stimuli and C stimuli prime each other (Barnes-Holmes et al.; Hayes & Bissett). Thus, MTS training can be used to establish semantic relations among stimuli while holding their unmediated associative strength relatively constant.

Origins of False Memories in Equivalence Classes

An interesting characteristic of stimulus equivalence classes (i.e., stimuli that mean the same thing, are functionally interchangeable, or participate in a ''relational frame of coordination''; see Hayes et al., 2001) is transfer of stimulus function, in which a new function is directly acquired by one class member and then indirectly acquired by remaining members (Barnes, 1994; Donahoe & Palmer, 2004; Dougher & Markham, 1994, 1996; Goldiamond, 1962, 1966; Hayes, 1991; Sidman, 1994). For example, suppose that via MTS training the words *cat* and *gato* become members of a common stimulus equivalence class (first row of Figure 1). Subsequently, suppose that the presentation of the word *cat* is paired with an electric shock, such that this word directly acquires a fear-eliciting function. Given that *cat* and *gato* are members of a common stimulus equivalence class, the eliciting function that had been directly acquired by the word *cat* is likely to be indirectly acquired by the word *gato*, such that the presentation of the word *gato* would elicit a fear response even though the word *gato* was never directly paired with an electric shock. Following such a pattern of responding, it would be said that the words *cat* and *gato* are members of a ''functional equivalence class'' with respect to fear elicitation (see Donahoe & Palmer, 2004; Dougher & Markham, 1994, 1996; Goldiamond, 1962, 1966).

We propose that certain semantic false memory phenomena can be accounted for in terms of functional equivalence responding. Just as an eliciting function can transfer between the words *cat* and *gato*, a ''remembering'' function may transfer between study words and nonstudy words that are functionally equivalent to study words. That is, the functions of study words are altered by the instruction to remember them, and nonstudy words that are functionally-equivalent to study words may likewise undergo function alteration and be remembered (see Discussion). For example, the DRM list word *rest* may be functionally equivalent to the critical root word *sleep* for English-speaking participants, most likely because of a variety of learning experiences that have accumulated during multiple interactions within an English-speaking community (see the second row of Figure 1). Should the DRM list words come to acquire a remembering function via instruction (e.g., as manifest by correct recall and correct recognition of the word *rest* on subsequent memory tests), functionally equivalent words that were not presented for study also may acquire this function (e.g., as manifest by the false recall and false recogni-

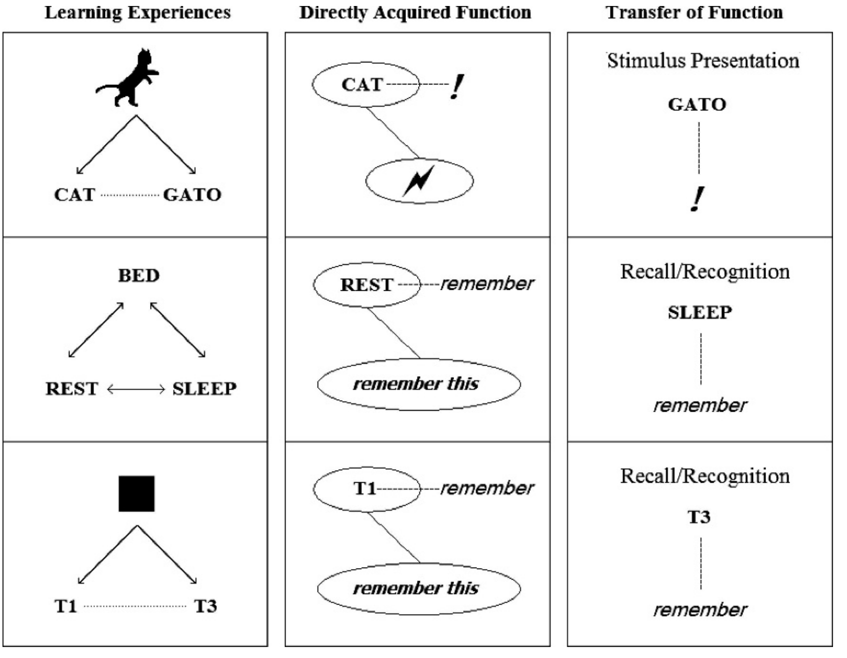

Fig. 1. Three plausible equivalence classes. Top row: An example from the text involving the words *cat* and *gato* and a picture of a cat. Middle row: An example from the DRM paradigm, which is commonly used to study false memory in cognitive research. Bottom row: An illustration of the DRIFT paradigm. In all cases, see text for explanation.

tion of the word *sleep*). Theoretically, a remembering function could transfer from study words to nonstudy words if there has been a learning history that promotes the transfer of function between the study words and nonstudy words, including a learning history sufficient for the formation of derived relationships (see the third row of Figure 1 and Method). In order to test this possibility, we developed the Derived Relational Intrusions Following Training (DRIFT) paradigm.

Our primary objective in developing the DRIFT paradigm was to manipulate specific environmental variables in order to produce specific false memory phenomena. Specifically, we sought to use MTS training to influence semantic false memory phenomena by creating derived semantic relations. We wished to examine if stimuli assigned to the same class as study list words (i.e., words assigned to be semantically related to study list words) would be intruded or falsely recognized at greater rates relative to words that had not been assigned to the same class. Furthermore, since comparison stimuli are simultaneously presented during MTS training, a co-occurrence that could conceivably influence word associations and hence influence associative false memory, we introduced a possible secondary source of intrusions and false positive recognitions. Thus, the DRIFT paradigm was designed to demonstrate the effects of MTS training on semantic false memory phenomena while permitting exploratory analyses of semantic (i.e., derived or mediated) versus associative (i.e., co-occurrence) effects.

METHOD

Participants

Sixty-six undergraduate psychology students who were recruited through a departmental web advertisement volunteered for the study in exchange for course credit. Data are omitted for 9 individuals who were affected by equipment failure ($n = 4$), did not comply with instructions ($n = 4$), or generated outcomes that could not be categorized according to our nomothetic data analysis scheme ($n = 1$), leaving $N = 57$ participants.

Setting, Apparatus, and Materials

Participants completed the study in a quiet 2 m × 2 m laboratory in the Psychology

Department at the University of New Mexico. The room contained a chair, a desk, and a standard desktop computer equipped with a mouse for making responses and a 43.2-cm (17-inch) monitor on which stimuli were presented. The computer program for collecting responses and presenting stimuli was written by the first author and is available upon request. A total of 72 English words were chosen (from Wilson, 1988) as experimental stimuli on the basis that there was no obvious semantic theme uniting them; the words were concrete nouns five to eight letters in length (see Figure 2). While word norms are typically crucial for an understanding of semantic and associative effects, our MTS training procedure involved the random assignment of words to conditions for each participant, thereby statistically neutralizing preexperimental semantic relations or associations. That is, barring extreme statistical improbabilities, *differential* dependent false memory effects across experimental conditions would be the product of the independent manipulation of MTS learning history and could not be attributed to stimulus properties established prior to experimentation.

Procedure

After meeting the experimenter and signing statements of informed consent, participants began the study with a computerized MTS training procedure. This training was intended to establish three 24-member equivalence classes and consisted of an arbitrary, three-comparison, MTS task. Training followed a one-to-many format, with colored shapes (a red square, blue circle, or green pentagon) always serving as samples and the words as comparisons. Participants read the following instructions on the computer screen:

> Welcome to the experiment! For this first part of the experiment, you will be solving several problems. For each problem, you will be shown a sample item on the top third of the screen and three selection items on the bottom third of the screen. Your job is to learn to consistently pick the correct selection items, but we can't tell you much about how to go about doing this. What we can tell you is that the sample is important, and that for each problem you will be shown a happy face if you make a correct selection or you will be shown a sad face if you make an incorrect selection. To solve the problems, you can make your selection choices by using the 1, 2, or 3 key on the keypad. To pick the item on the left, press the 1 key. To pick the item in the middle, press the 2 key. To pick the item on the right, press the 3 key. After you pick an item and receive feedback, you can move on to the next problem by pressing the [SPACE BAR]. After you have been through all of the regular problems once, you will be given some ''Bonus Problems.'' Even though the Bonus Problems have correct answers, you will not be given feedback after you answer them! If you do not answer the Bonus Problems correctly, you will go through all of the regular problems again. You only have a limited number of chances to try to beat the Bonus Problems. This process will repeat until you are able to answer the Bonus Problems correctly or until you run out of chances, at which point you will move on to the second part of the experiment. The person who can beat the Bonus Problems with the fewest number of errors will win $100. Feel free to take a break at any time, but please let the experimenter know if you need to leave the room. Pace yourself, use a good strategy, be patient with yourself, and try your best to beat the Bonus Problems! Once you have finished reading this, please ask the experimenter any questions you may have, or otherwise let the experimenter know that you are ready to begin.

For each participant, a red square, a blue circle, and a green pentagon were randomly assigned as stimulus samples that are designated here as Shape 1 (S1), Shape 2 (S2), and Shape 3 (S3). For each participant, the 72 stimulus comparison words were randomly assigned to one of five Types, designated here as T1, T2, T3, T4 and T5 (see Figure 2). T1 words were presented for study during the memory test in the second phase of the experiment, and they were consistently paired with T2 words as comparison stimuli during MTS training (e.g., *ANIMAL* and *GARDEN* always co-occurred as comparison stimuli across training blocks, as did *ARTIST* and *GRAPH, etc.*). Defined in terms of the frequency of experimental co-occurrence, the T2 words were therefore strong associates of T1 words. However, the T2 words were not semantically related to T1 words because they were assigned to a different class. T3 words were semantically related to T1 words in the sense that they were assigned to the same class as T1 words during MTS training; T3 words

	Shape 1 (S1) Words		Shape 2 (S2) Words			Shape 3 (S3) Words		
T1	ANIMAL	$T1^{1}$	$T2^{1}$	GARDEN	T2	OFFICE	$T5^{1}$	T5
	ARTIST	$T1^{2}$	$T2^{2}$	GRAPH		PAINT	$T5^{2}$	
	AVENUE	$T1^{3}$	$T2^{3}$	HONEY		PEPPER	$T5^{3}$	
	BALLOON	$T1^{4}$	$T2^{4}$	HORSE		POCKET	$T5^{4}$	
	BEARD	$T1^{5}$	$T2^{5}$	HOUSE		PRINCESS	$T5^{5}$	
	BOTTLE	$T1^{6}$	$T2^{6}$	HUSBAND		QUARTER	$T5^{6}$	
	BRANCH	$T1^{7}$	$T2^{7}$	INSECT		RABBIT	$T5^{7}$	
	BRICK	$T1^{8}$	$T2^{8}$	ISLAND		RADIO	$T5^{8}$	
	BUBBLE	$T1^{9}$	$T2^{9}$	IVORY		RIVER	$T5^{9}$	
	CAMERA	$T1^{10}$	$T2^{10}$	JACKET		SHOWER	$T5^{10}$	
	CARPET	$T1^{11}$	$T2^{11}$	JUDGE		SLEEVE	$T5^{11}$	
	CIGAR	$T1^{12}$	$T2^{12}$	JUICE		SMILE	$T5^{12}$	
T3	CLOUD	$T3^{1}$	$T4^{1}$	KNIFE	T4	SUGAR	$T5^{13}$	
	DOCTOR	$T3^{2}$	$T4^{2}$	LEMON		TABLE	$T5^{14}$	
	DOLLAR	$T3^{3}$	$T4^{3}$	LETTER		THREAD	$T5^{15}$	
	DRAIN	$T3^{4}$	$T4^{4}$	LIQUID		TOAST	$T5^{16}$	
	DRESS	$T3^{5}$	$T4^{5}$	LUNCH		TRAIN	$T5^{17}$	
	ELBOW	$T3^{6}$	$T4^{6}$	MAGAZINE		TUNNEL	$T5^{18}$	
	ENGINE	$T3^{7}$	$T4^{7}$	MIRROR		VALLEY	$T5^{19}$	
	ENVELOPE	$T3^{8}$	$T4^{8}$	MOTOR		VEHICLE	$T5^{20}$	
	FACTORY	$T3^{9}$	$T4^{9}$	MUSIC		VILLAGE	$T5^{21}$	
	FENCE	$T3^{10}$	$T4^{10}$	NEEDLE		WALNUT	$T5^{22}$	
	FLOWER	$T3^{11}$	$T4^{11}$	NOVEL		WEDDING	$T5^{13}$	
	FRUIT	$T3^{12}$	$T4^{12}$	OCEAN		WINDOW	$T5^{24}$	

Fig. 2. The 72 words used in the study. Although shown in alphabetical order here, the words were randomly assigned to one of five Types (T1–T5) for each participant. Superscripts denote specific randomly assigned words of a given Type, and can be cross-referenced with Table 1. See text for details.

and T1 words never co-occurred (except during tests of transitivity) and therefore were not associated during MTS training trials. T4 words were consistently paired with T3 words as comparison stimuli during MTS training (e.g., *CLOUD* and *KNIFE* always co-occurred as comparison stimuli across training blocks, as did *DOCTOR* and *LEMON*, etc.). T4 words were weak associates of the T1 words in the sense that they were never paired with T1 words during MTS training. T5 words were randomly presented as third comparison stimuli along with T1–T2 and T3–T4 pairs; the particular comparison triplet that a T5 word participated in was randomly determined at the beginning of each block of trials. For example, a comparison triplet might consist of the words *ANIMAL*, *GARDEN* and *PAINT* during the first block of training, but the triplet might instead consist of the words *ANIMAL*, *GARDEN*, and *WINDOW* during the second block of training. As such, T5 words were moderate associates of T1 words, in the sense that they were inconsistently paired with T1 words as comparison stimuli during MTS training trials.

Training ("Regular Problems"). On each MTS training trial (see Figure 3), a sample shape (i.e., a red square, blue circle, or green pentagon) appeared at the top of the computer screen and three comparison words appeared below the sample (i.e., a T1–T2 pair with a random T5 word, or a T3–T4 pair with a random T5 word). Participants were required to select one comparison using the 1, 2, or 3 key on the computer keypad, at which point a line appeared under the selected word. Correct responses were followed by the presentation of a happy face beneath the selected comparison and a pleasant chime sound, whereas incorrect responses were followed by the presentation of a sad face beneath the selected comparison and an unpleasant buzz sound. A correct response was scored if the

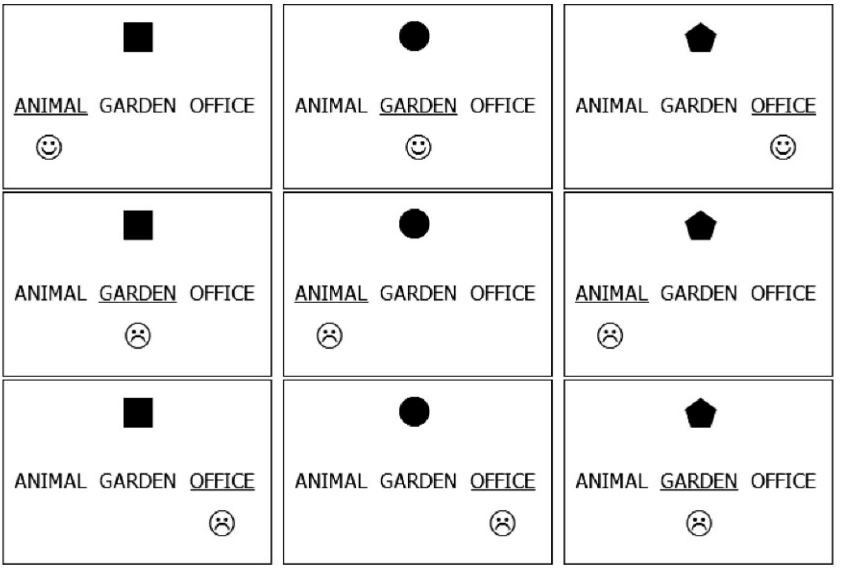

Fig. 3. Examples of MTS training feedback following the selection of comparison stimuli. Left column: A square serves as the sample (S1) with *animal* as the correct comparison. Middle column: A circle serves as the sample (S2) with *garden* as the correct comparison. Right column: A pentagon serves as the sample (S3) with *office* as the correct comparison. NOTE: Actual assignments of shapes and words were randomized for each participant and hence different for each participant. See text for further explanation.

participant selected an S1 (T1 or T3) word in the presence of an S1 sample, an S2 (T2 or T4) word in the presence of an S2 sample, or an S3 (T5) word in the presence of an S3 sample. An incorrect response was scored if the participant's selection did not match the sample. Following each comparison-stimulus selection, the visual feedback remained on the screen until the participant pressed the space bar, at which point a new problem was presented.

Each MTS training block consisted of 24 trial sets of three trials each, corresponding to the 24 possible word triplets within a block (i.e., $T1^1$, $T2^1$, and $T5^x$; $T1^2$, $T2^2$, and $T5^x$; … $T3^{12}$, $T4^{12}$, and $T5^x$). Each trial set consisted of an S1 sample problem, an S2 sample problem, and an S3 sample problem, with the same word triplet (i.e., comparison stimuli) across the set of trials. Thus, each training block consisted of 72 individual trials. The order of trial set presentation and the assignment of T5 words to comparison triplets were randomly determined at the beginning of each block, the order of problem type presentation within a set (i.e., S1, S2, and S3) was randomly determined at the beginning of each set, and the left–middle–right positions of the comparison stimuli were randomly determined at the beginning of each trial.

Equivalence testing (“Bonus Problems”). Every MTS training block of Regular Problems was followed by a round of ‘‘Bonus Problems,’’ which consisted of six symmetry trials and then six transitivity trials (see Table 1), presented in a random order and in a format that resembled the Regular Problems but without feedback. On symmetry trials, the sample was an experimental word and the comparisons were the three shapes. On transitivity trials, the sample and comparisons all were experimental words. Incorrect comparisons during transitivity testing consisted of other stimuli specific to that round of Bonus Problems, and one of the two possible incorrect comparisons from each nonmatching class was randomly selected to be presented as comparison stimuli (designated by ‘‘or’’ in Table 1). Participants completed MTS training if they were able to achieve 100% accuracy on a round of these ‘‘Bonus Problems.’’ New symmetry and transitivity trials were administered following every block, such that participants were never tested on the same stimuli twice. Aside from this trial novelty, participants could not predict which random

Table 1

Sample and Comparison Stimuli Used to Test Symmetry and Transitivity.

		Sample	(Correct) Comparison 1	(Incorrect) Comparison 2	(Incorrect) Comparison 3
Block 1 Bonus Problems					
	Symmetry 1	$T1^{1}$	S1	S2	S3
	Symmetry 2	$T3^{1}$	S1	S2	S3
	Symmetry 3	$T2^{1}$	S2	S1	S3
	Symmetry 4	$T4^{1}$	S2	S1	S3
	Symmetry 5	$T5^{1}$	S3	S1	S2
	Symmetry 6	$T5^{13}$	S3	S1	S2
	Transitivity 1	$T1^{1}$	$T3^{1}$	$T2^{1}$ or $T4^{1}$	$T5^{1}$ or $T5^{13}$
	Transitivity 2	$T3^{1}$	$T1^{1}$	$T2^{1}$ or $T4^{1}$	$T5^{1}$ or $T5^{13}$
	Transitivity 3	$T2^{1}$	$T4^{1}$	$T1^{1}$ or $T3^{1}$	$T5^{1}$ or $T5^{13}$
	Transitivity 4	$T4^{1}$	$T2^{1}$	$T1^{1}$ or $T3^{1}$	$T5^{1}$ or $T5^{13}$
	Transitivity 5	$T5^{1}$	$T5^{13}$	$T1^{1}$ or $T3^{1}$	$T2^{1}$ or $T4^{1}$
	Transitivity 6	$T5^{13}$	$T5^{1}$	$T1^{1}$ or $T3^{1}$	$T2^{1}$ or $T4^{1}$
Block 2 Bonus Problems					
	Symmetry 1	$T1^{2}$	S1	S2	S3
	Symmetry 2	$T3^{2}$	S1	S2	S3
	Symmetry 3	$T2^{2}$	S2	S1	S3
	Symmetry 4	$T4^{2}$	S2	S1	S3
	Symmetry 5	$T5^{2}$	S3	S1	S2
	Symmetry 6	$T5^{14}$	S3	S1	S2
	Transitivity 1	$T1^{2}$	$T3^{2}$	$T2^{2}$ or $T4^{2}$	$T5^{2}$ or $T5^{14}$
	Transitivity 2	$T3^{2}$	$T1^{2}$	$T2^{2}$ or $T4^{2}$	$T5^{2}$ or $T5^{14}$
	Transitivity 3	$T2^{2}$	$T4^{2}$	$T1^{2}$ or $T3^{2}$	$T5^{2}$ or $T5^{14}$
	Transitivity 4	$T4^{2}$	$T2^{2}$	$T1^{2}$ or $T3^{2}$	$T5^{2}$ or $T5^{14}$
	Transitivity 5	$T5^{2}$	$T5^{14}$	$T1^{2}$ or $T3^{2}$	$T2^{2}$ or $T4^{2}$
	Transitivity 6	$T5^{14}$	$T5^{2}$	$T1^{2}$ or $T3^{2}$	$T2^{2}$ or $T4^{2}$
Block 3 Bonus Problems					
	Symmetry 1	$T1^{3}$	S1	S2	S3
	Symmetry 2	$T3^{3}$	S1	S2	S3
	Symmetry 3	$T2^{3}$	S2	S1	S3
	Symmetry 4	$T4^{3}$	S2	S1	S3
	Symmetry 5	$T5^{3}$	S3	S1	S2
	Symmetry 6	$T5^{15}$	S3	S1	S2
	Transitivity 1	$T1^{3}$	$T3^{3}$	$T2^{3}$ or $T4^{3}$	$T5^{3}$ or $T5^{15}$
	Transitivity 2	$T3^{3}$	$T1^{3}$	$T2^{3}$ or $T4^{3}$	$T5^{3}$ or $T5^{15}$
	Transitivity 3	$T2^{3}$	$T4^{3}$	$T1^{3}$ or $T3^{3}$	$T5^{3}$ or $T5^{15}$
	Transitivity 4	$T4^{3}$	$T2^{3}$	$T1^{3}$ or $T3^{3}$	$T5^{3}$ or $T5^{15}$
	Transitivity 5	$T5^{3}$	$T5^{15}$	$T1^{3}$ or $T3^{3}$	$T2^{3}$ or $T4^{3}$
	Transitivity 6	$T5^{15}$	$T5^{3}$	$T1^{3}$ or $T3^{3}$	$T2^{3}$ or $T4^{3}$
Blocks 4–12 Bonus Problems (Pattern Continues)		...	...	...	...

Note. Superscripts refer to specific individual words of a given Type, and can be cross-referenced with Figure 2.

relations would be tested during administration of the Bonus Problems. Participants had 12 chances (i.e., up to 12 training blocks) to meet criterion on the Bonus Problems.

Study-list presentation and memory testing. After exhausting their 12 chances to pass a round of Bonus Problems or after passing a round of Bonus Problems with 100% accuracy, participants were required to leave the laboratory and take a break for approximately 5 min (participants actually returned 4 to10 min later). Once participants returned, they were told that they were entering a new phase of the experiment, and were given the following instructions for the free recall task:

> For the next part of the experiment, we will show you some words that we want you to remember for a later memory test. The words will automatically appear one at a time on the screen, so you don't need to press any keys. Even though all of the words that you are about to see will be familiar to you, when we later ask you to remember the MEMORY TEST WORDS, just remember the words that you are

Table 2

Demographic, MTS Training, and Memory Test Means (SDs) by Achievement Groups and for the Total Sample.

	Achievement Group			
	Failed	Partial	Full	Total
Age	19.85 (2.38)	19.73 (2.96)	19.34 (2.53)	19.56 (2.58)
Males (*n*)	6	2	14	22
Females (*n*)	7	13	15	35
Education	13.00 (0.91)	12.73 (1.49)	12.72 (0.92)	12.79 (1.08)
MTS Blocks	12.00 (0.00)	12.00 (0.00)	7.03 (2.68)	9.47 (3.14)
MTS Total Errors	497.31 (53.96)	307.67 (98.06)	191.07 (72.13)	291.60 (144.07)
MTS Final Accuracy	44.38 (14.98)	83.68 (11.66)	83.76 (7.67)	74.76 (19.72)
Delay Time in Seconds	96.70 (21.89)	103.29 (24.51)	118.92 (39.69)	109.74 (33.68)
T1 Correct Recall	3.92 (2.36)	5.60 (2.53)	6.83 (2.16)	5.84 (2.55)
T1 Correct Recognitions	6.62 (2.29)	7.73 (3.08)	9.79 (1.80)	8.53 (2.64)

Notes. MTS Total Errors does not include errors on the Bonus Problems. MTS Final Accuracy refers to the percent of correct trials on participants' last MTS training block. Delay time refers to how long it took participants to read the short story between study list presentation and free recall.

about to see. Please ask the experimenter if you have any questions.

Once the experimenter had answered any questions, the 12 T1 study list words were presented on the computer screen one at a time, below a presentation of the S1 stimulus, for 2 s each with a 2-s interstimulus interval. Following presentation of the list items, participants were shown a reminder screen instructing them to ‘‘Remember the MEMORY TEST words! Please press the [SPACE BAR] now to continue…’’ Upon pressing the space bar, participants were presented with the instructions ‘‘Please read the following short story’’ along with a transcript of the American Indian short story *War of the Ghosts* (from Bartlett, 1932). It took participants approximately 2 min to read the short story (see Table 2). At the conclusion of the story, the instruction ‘‘Please let the experimenter know that you have finished reading the story’’ was printed on the screen. Once prompted, the experimenter handed the participants a blank sheet of paper and a pen and asked the participants to write down as many of the memory test words as they could remember in the next 4 min. The experimenter then pressed a button on the computer that advanced the screen to show these same instructions, along with a timer that counted down from 240 s. After the time expired, a chime sounded and the experimenter collected the participants' recalled words. After participants left at the end of the experiment, the experimenter manually entered the recalled words into the computer for scoring, making corrections for misspellings. Following administration of the free recall test, participants were administered a recognition test beginning with the presentation of the following instructions:

> For the next part of the experiment, you will see a word come up on the screen. If this word is a MEMORY TEST word, click on the left mouse button (YES). If the word you see is not a MEMORY TEST word, click on the right mouse button (NO). Once you make your response, a new word will appear for you to judge. Even though all of the words that you are about to see will be familiar to you, only choose (YES) if the current word is a memory test word. On average, only one out of every five words will be a memory test word. We would like you to make your selection as quickly as possible—we will be recording your reaction time. However, you should also be as accurate as you can! Please ask the experimenter if you have any questions before you begin. The test will begin by pressing the [SPACE BAR].

The specific instructions that were presented to each participant reflected a random counterbalancing of the left/right side to which the YES and NO responses were assigned, and the words YES and NO were presented on either side of the bottom of the screen throughout the recognition task in accordance with this counterbalancing. A total of 60 recognition trials were given in a random order, corresponding to each of the T1, T2, T3, and T4 words, along with half (randomly selected) of the T5 words. On each trial, a randomly selected experimental word appeared on the center of the screen and remained until the participant made a response. After a response was made, the word disappeared and a new word appeared on the next trial 1 s later. Participants did not receive feedback regarding the accuracy or speed of their recognition responses. After the last recognition word was judged, participants were debriefed and thanked for their participation. Depending on participant performance, the entire experimental procedure lasted no longer than 2 hr.

Post Hoc Separation into Groups

Because in most published studies false memory phenomena are quite variable across participants, we chose to employ nomothetic analyses and to analyze data from participants who achieved different levels of success in training. This approach was consistent with our view of semantic relatedness being a function of experience. From this perspective, false-memory effects should be heavily dependent on training outcomes. Participants thus were sorted by their MTS training and Bonus Problems performances in order to assign them to one of three groups, and data from all three groups were analyzed.

The first (*Failed*) group (n = 13) included participants who had achieved less than 66% accuracy on their last block of MTS trials and did not pass a set of random Bonus Problems with 100% accuracy. The training experiences of these individuals were not expected to contribute to semantic relatedness or, therefore, the emergence of false memory effects. The second (*Partial Achievement*) group (n = 15) included participants who achieved limited success during training, meaning greater than 66% accuracy on their last block of MTS trials and failure to pass a set of random Bonus Problems with 100% accuracy. The training experiences of these individuals were expected to spawn some false memory effects. Finally, the third (*Full Achievement*) group (n = 29) included those participants who had achieved greater than 66% accuracy on their last block of MTS trials and passed a set of random Bonus Problems with 100% accuracy. The training experiences of these individuals were expected to reliably spawn false memory effects.

Demographic characteristics of the three groups and the total sample can be found in Table 2. According to one-way between-subjects ANOVAs (critical alpha = .05), the groups did not differ significantly in terms of age, $F(2, 54) = 0.21$, $p = .812$, $\eta^2 = .01$, gender ratio, $F(2, 54) = 2.88$, $p = .065$, $\eta^2 = .10$, or years of education, $F(2, 54) = 0.31$, $p = .734$, $\eta^2 = .01$.

RESULTS

MTS Performance Analyses

Table 2 shows performance summary data for the three groups and for the total sample. A series of one-way between-subjects ANOVAs with post-hoc pairwise comparisons (critical alpha = .05) were conducted to evaluate possible differences among the three groups in terms of MTS performance variables. The groups differed significantly in mean number of MTS training blocks completed, $F(2, 54) = 47.19$, $p < .001$, $\eta^2 = .64$. Specifically, participants in the full achievement group were able to pass the Bonus Problems before exhausting their 12 chances and therefore required fewer MTS training blocks than the other two groups; participants who failed training or with partial achievement did not pass the Bonus Problems and therefore were exposed to exactly 12 MTS training blocks. There was also a significant difference among the three groups in mean total number of errors (i.e., incorrect responses) made during MTS training trials, $F(2, 54) = 72.55$, $p < .001$, $\eta^2 = .73$, with significant differences among all three groups reflecting a combination of differential error rates and a differential number of training blocks; error rates decreased with increasing achievement. There was a significant difference among the three groups in mean trial accuracy on the final block of MTS training trials, $F(2, 54) = 67.17$, $p < .001$, $\eta^2 = .71$. Participants who failed training tended to achieve lower trial accuracy on their final MTS training block than did participants in the partial and full achievement groups; the partial and full achievement groups were equated for mean trial accuracy on their final MTS training block by the experimenters.

Memory Analyses

There were no significant differences among the three groups in mean amount of time required to read the short story during the delay period, $F(2, 54) = 2.45$, $p = .096$, $\eta^2 = .08$. There was a significant difference among the three groups in mean number of correctly recalled T1 study list words during free recall, $F(2, 54) = 7.25$, $p = .002$, $\eta^2 = .21$, with participants in the full achievement group having significantly greater mean correct recall than participants who failed training. Similarly, participants in the full achievement group had significantly greater mean correct recognition of T1 words than participants who failed training, $F(2, 54) = 9.74$, $p < .001$, $\eta^2 = .27$. These differences could reflect a facilitating effect of full achievement, or perhaps participants who were predisposed to full achievement were also predisposed to correctly recall and recognize more words.

Free recall analyses. Perfect performance on the free recall task would require participants to recall all 12 of the T1 words without intruding any T2, T3, T4, or T5 words, indicating that a remembering function was acquired by all of the T1 words with no indirect acquisition of the remembering function by any other words. We anticipated that semantically related T3 words would be the most likely to be intruded, on the grounds that these words had been assigned to the same class as the T1 study list words during MTS training and thereby would be most likely to indirectly acquire the remembering function. We also anticipated a relatively high probability of intrusions among T2 strong associates, since these words had consistently co-occurred with T1 words throughout MTS training. The lowest levels of intrusions were anticipated for T5 moderate associates and then for T4 weak associates. In addition, we anticipated that these effects would be most pronounced among participants in the full achievement group and least pronounced among participants who failed training. In order to correct for the greater number of T5 words available for intruding, analyses were conducted after first dividing the observed number of T5 intrusions in half for each participant; the intrusion means in Figure 4 reflect this T5/2 adjustment.

A 3 × 4 (group by word Type) mixed-design ANOVA with a Greenhouse-Geisser correction

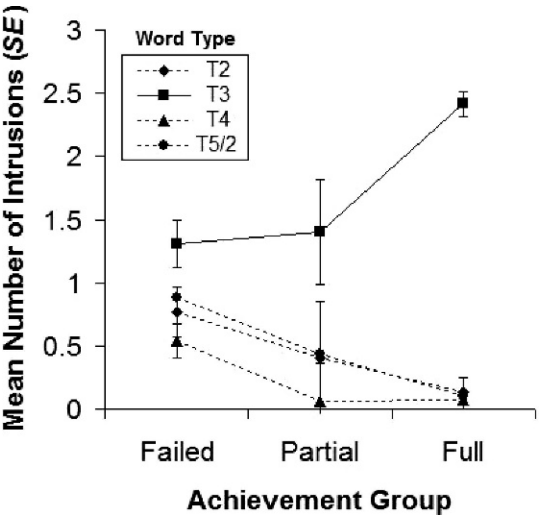

Fig. 4. Mean number of intrusions for each word Type for the three MTS training achievement groups during the free recall phase of the experiment. Error bars convey standard error.

for sphericity indicated a nonsignificant main effect of group, $F(2, 54) = 1.15$, $p = .33$, partial $\eta^2 = .04$, and a significant main effect of word Type, $F(1.49, 80.25) = 27.20$, $p < .001$, partial $\eta^2 = .34$. However, these main effects must be interpreted in light of a significant interaction between group and word Type, $F(2.97, 80.25) = 4.90$, $p = .004$, partial $\eta^2 = .15$. Post hoc analyses of the simple main effect of word Type at each level of achievement group were conducted using pairwise comparisons, a Bonferroni correction, and a critical alpha of .05. Among those participants who failed training, there were no significant differences in mean number of T2, T3, T4, and T5/2 intrusions. Among those participants in the partial achievement group, the mean number of T3 intrusions was significantly greater than the mean number of T4 intrusions, but there were no significant differences among the mean number of T2, T4, and T5/2 intrusions. Among those participants in the full achievement group, the mean number of T3 intrusions was significantly greater than the mean number of T2, T4, and T5/2 intrusions, which did not significantly differ from each other. The significant interaction suggests that successful MTS training may have produced both a semantic relatedness effect as well as a "semantic suppression" effect. That is, it appears that not only did participants with partial and full achievement tend to treat the T3 words as if these words were "the same as" T1 words, they also tended to treat the T2, T4, and T5 words as if these words were not the same as T1 words.

To summarize, differential word co-occurrence during MTS training did not produce differential frequencies of T2, T4, or T5/2 associative intrusions (with a possible exception of infrequent T4 intruding among participants in the partial achievement group). However, the results do indicate that semantically-related T3 words were most likely to indirectly acquire the T1 remembering function, at least among those participants in the partial and full achievement groups. Thus, at higher levels of MTS training achievement, the MTS training procedure was able to produce specific semantic false memory phenomena in the form of elevated T3 intrusions.

Recognition analyses. Perfect performance on the recognition task would require participants to correctly recognize all 12 of the T1 words without making any T2, T3, T4, or T5 false positive recognitions, indicating that a remembering function was acquired by all of the T1 words with no indirect acquisition of the remembering function by any other words. We expected the results of the recognition test to run parallel to those of the free recall test. Since 12 words of each Type were presented during the recognition task, no adjustments were made to T5 means for recognition analyses. Figure 5 shows the mean number of T2, T3, T4, and T5 false positive recognitions for each group.

A 3 × 4 (group by word Type) mixed-design ANOVA with a Greenhouse-Geisser correction for sphericity indicated a significant main effect of group, $F(2, 54) = 6.32$, $p = .003$, partial $\eta^2 = .19$, and a significant main effect of word Type, $F(1.46, 78.84) = 25.57$, $p < .001$, partial $\eta^2 = .32$. However, these main effects must be interpreted in light of a significant interaction between group and word Type, $F(2.92, 78.84) = 6.27$, $p = .001$, partial $\eta^2 = .19$. Post hoc analyses of the simple main effect of word Type at each level of group were conducted using pairwise comparisons, a Bonferroni correction, and a critical alpha of .05. Among those participants who failed training, there were no significant differences in mean number of T2, T3, T4, and T5 false positive recognitions. Among those participants in the partial and full achievement groups, the mean number of T3 intrusions was significantly greater than the mean number of T2, T4, and T5 intrusions, which did not significantly differ from each other. The recognition results were therefore similar to the free recall results.

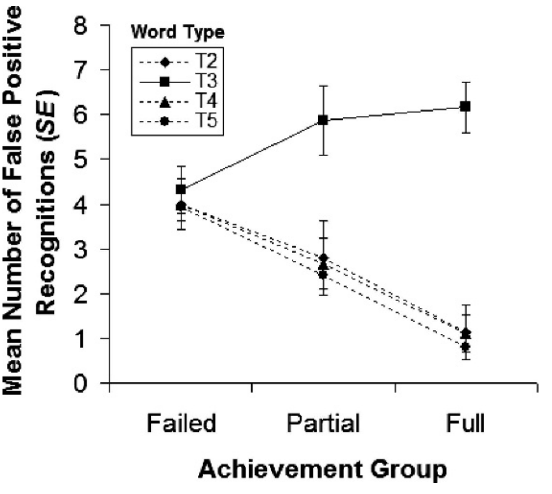

Fig. 5. Mean number of false positive recognitions for each word Type for the three MTS training achievement groups during the recognition phase of the experiment. Error bars convey standard error.

DISCUSSION

Many previous studies show that semantic relatedness predicts the likelihood of memory intrusions (e.g., Deese, 1959a, 1959b; McEvoy, et al., 1999; Roediger & McDermott, 1995; Zaromb et al., 2006). Most research on false memory, however, has relied upon preexisting semantic relatedness that was presumably based in preexperimental linguistic experiences. By contrast, in the present investigation, semantic relatedness was built from the ground up through MTS training, which established derived semantic relations and permitted the transfer of stimulus functions. By treating semantic relatedness as a dependent variable rather than an independent variable, we were able to manipulate specific environmental variables in order to produce specific false memories.

Running parallel to naturalistic learning histories, the results of this study indicate that MTS training can be used as a tool to engineer semantic relationships that distort recall and recognition of subsequent events: words assigned to the same class as study list words were more likely to be intruded and more likely to be falsely recognized than other types of words. While there are undoubtedly many MTS training arrangements that would not produce this effect and other experimental or naturalistic arrangements that would produce this effect, our findings demonstrate that semantic false memory effects can be engineered through the manipulation of environmental variables. As depicted in the third row of Figure 1, we first used MTS training to establish a group of T1 words and a group of T3 words as being equivalent and therefore semantically related, as demonstrated by tests of symmetry and transitivity. In the next phase of the experiment, participants were shown the T1 words and were asked to remember them for a later memory test. As evidenced by correct T1 recall and correct T1 recognitions, these instructions interacted with participants' learning histories to establish a remembering function for the T1 words. Furthermore, because T1 words and T3 words had been assigned to the same class during prior MTS training, the remembering function was acquired indirectly and differentially by semantically-related T3 words. Specifically, relative to words that had not been assigned to the same class as T1 words during prior MTS training (i.e., T2, T4, and T5 words), more T3 words were intruded and falsely recognized. Thus, our results replicate previous findings that semantic relations are predictive of false memories (see Brainerd & Reyna, 2005; Gallo, 2006). Moreover, we influenced semantic relations and thereby influenced false memories.

However, the differential co-occurrence of words during MTS training did not result in differential levels of associative intruding or false recognition. Specifically, T2 words and T5 words frequently co-occurred with T1 words during MTS comparison presentations, yet these words were no more likely to be intruded or falsely recognized than T4 words, which never co-occurred with T1 words. These findings were unexpected, given that stimulus co-occurrence is thought to increase associative strength (Burgess, 1998; Fodor, 1983; Landauer & Dumais, 1997), and associative strength is thought to increase the probability of intrusion and false recognition (e.g., Deese, 1959a, 1959b; McEvoy et al., 1999; Robinson & Roediger, 1997; Roediger & McDermott, 1995).

Implications for Understanding False Memory

Our MTS training procedure produced semantic behaviors that can be interpreted to reflect conceptual mediation (Balota & Lorch, 1986), which is a central phenomenon supporting holistic models of semantic memory (see Hutchison, 2003). From a cognitive perspective, the experimental procedure appears to have established mediated semantic relations (i.e., T1↔S1↔T3), similar to naturally occurring mediated semantic relations (e.g., *lion↔tiger↔stripes*). Thus, a semantic effect was demonstrated despite the fact that the T1 and T3 words do not refer to common physical features, which would not be predicted from a distributed model of semantic memory based in physical feature overlap (e.g., Kawamoto, 1993; Masson, 1995; Moss et al., 1994; Plaut, 1995; see Hutchison, 2003). Of course, it remains possible that other false memory phenomena may involve the physical characteristics of stimuli, but the current false memory phenomena would appear to be based in derived, functional semantic relations rather than referential feature overlap.

While the results of the current behavior analytic investigation are consistent with cognitive explanations involving conceptual mediation within holistic semantic networks, they do not support the notion that associative strength is the product of stimulus co-occurrence (e.g., Burgess, 1988; Fodor, 1983; Landauer & Dumais, 1997). For participants in the full achievement group, the mean total number of direct (T1–T3) and mediated (S1–T1 and S1–T3) co-occurrences among the T1 and T3 words (Observed M = 182.78) was smaller than the mean number of co-occurrences between T1 and T2 words (Minimum frequency M = 253.08), yet the vast majority of intrusions and false positive recognitions were T3 words. That is, among participants in the full achievement group, the semantic relationship between T1 and T3 words reflected a more powerful effect than would be expected on the basis of their relative associative strength alone. We are aware of no cognitive model predicting a negative relationship between level of co-occurrence and magnitude of semantic or associative effects. Thus, though formal models based in stimulus co-occurrence can be globally predictive of semantic and associative behaviors (e.g., Burgess, 1998; Landauer & Dumais, 1997), contingency factors other than stimulus co-occurrence could play important roles in the formation of organic semantic relations and associations. In particular, the present results indicate that the functional relationship between stimuli is a more important factor in determining semantic false memory phenomena than is stimulus co-occurrence.

In a related vein, Hutchison (2003) has identified several different topographies of stimulus associations, such as synonyms, antonyms, category members, perceptually similar items, and phrasal associates. The task of characterizing these and other relations within cognitive models could be facilitated by analyses of the environmental histories responsible for the formation of various forms of relatedness and association. For example, the DRIFT paradigm can be thought of as a procedure for producing synonyms; variations of this procedure could help illuminate the nature of conceptual mediation. To the extent that different cognitive models make different predictions with respect to stimuli that vary in stimulus functions, associations, and features, procedures designed to experimentally manipulate these variables may constitute useful technologies for cognitive researchers (see also Carroll & Kirsner, 1982; Dagenbach et al., 1990; Davis et al., 2008; Durgunoglu & Neely, 1987; McKoon & Ratcliff, 1979; Neely & Durgunoglu, 1985). Conversely, there are a variety of semantic effects that are reliably predicted using cognitive models (e.g., see Brainerd & Reyna, 2005; Gallo, 2006; Hutchison, 2003), but have yet to be fully characterized in terms of environmental manipulations and derived relationships. The success of the DRIFT paradigm in producing specific semantic false memory phenomena represents an advance in this direction, and suggests that many other avenues of research are available for exploration that can be mutually informed by cognitive and behavior analytic perspectives.

Methodological Issues

It could be construed that the current study was not truly experimental because participants were not randomly assigned to experimental and control groups. That is, rather than providing an experimental group with training and withholding this training from a control group, all participants received training and participant groups were formed post hoc (i.e., participants were assigned to groups based on their training achievement). However, it can also be construed that the study was indeed experimental because stimuli were randomly assigned to conditions. That is, participants had differential learning histories with respect to different groups of words, and these differential histories comprised experimental and control conditions within subjects. While it would not be difficult for future researchers to provide between-subjects experimental and control conditions, this approach may not be especially informative. To illustrate, including a between-subjects control condition would involve withholding training from participants in the control group, presenting them with a list of random study words, and then seeing how many of their recalled words matched a different list of random nonstudy words; one would expect the resulting number of matching words to be fairly constant at about zero. Rather than providing a between-subjects control condition of this sort, resources may be better allocated in determining those factors that influence training achievement.

The current design does not rule out the possibility that stimulus co-occurrence can influence semantic relatedness, associative strength, or false memory phenomena. For example, verbally competent adults can form equivalence classes of simultaneously presented stimuli even in the absence of ongoing reinforcement for this behavior (Barnes, Smeets, & Leader, 1996; Leader, Barnes, & Smeets, 1996). One would expect that stimulus co-occurrence could influence behavior to the extent that there has been phylogenetic or ontogenetic selection for such a relationship (see also Mitchell, De Houwer & Lovibond, 2009), but neither of these variables was manipulated in the current design. Instead, we attempted to see if uncontrolled preexperimental histories of selection would interact with experimental manipulations of stimulus co-occurrence to produce differential false memory phenomena. However, we found no such effect. The null effect could have been the result of an insufficient preexperimental history of selection for responding to stimulus co-occurrence, a lack of contextual cues for such responding, or could have resulted from a manipulation failure (i.e., a wider range of differential co-occurrences would be necessary to detect an effect). Alternatively, it may have been the case that there was a floor effect for association reflecting the observed semantic suppression effect. While it would be difficult to manipulate phylogenetic selection, future investigations could provide differential (or contextually controlled) experimental learning histories with respect to responding to stimulus co-occurrence, include conditions with higher frequencies of stimulus co-occurrence, and include conditions for which stimulus co-occurrence is not confounded by derived relations or differential class membership (see also Leader & Barnes-Holmes, 2001).

A more serious concern regarding the current design was the inclusion of tests of symmetry and transitivity prior to the administration of memory tests. While stimulus equivalence is of great interest to many behavior analysts, tests for stimulus equivalence introduced an experimental source of direct stimulus co-occurrence. Even though passing these tests required the derivation of stimulus relations, it is possible that the false memory effects were directly mediated via the tests, which may have created linked, mediated functional classes without requiring that the false memory performances be derived. However, this interpretation seems improbable, given that equivalence tests involved co-occurring presentations of matching as well as nonmatching comparisons and no feedback was provided during equivalence testing; one could not distinguish between classes on the basis of co-occurrence alone. Furthermore, a number of studies have shown that MTS relational training procedures without tests of stimulus equivalence are sufficient for the derived transfer or transformation of stimulus functions (see Barnes 1994; Barnes & Roche, 1996; Barnes-Holmes, Barnes-Holmes, Smeets, Cullinan, & Leader, 2004), suggesting that equivalence testing was not a necessary component for the production of false memory phenomena in the current study (though it may have catalyzed such responding). Indeed, we have conducted other studies, to be reported elsewhere, using modified versions of the DRIFT paradigm that indicate that stimulus equivalence testing is not necessary for the production of false memory phenomena following MTS training. Thus, the essential training characteristics of the DRIFT paradigm appear to be those that permit the transfer of stimulus function, whether through linked classes or through derived relationships.

Behavior Analytic Interpretation

While the MTS training procedure resulted in false memory performances that satisfy the definition of functional equivalence (see Donahoe & Palmer, 2004; Dougher & Markham, 1994; Dougher & Markham, 1996; Goldiamond, 1962, 1966), it also resulted in derived symmetry and transitivity performances that satisfy the definition of stimulus equivalence (see Sidman, 1971; Sidman, 1994; Sidman & Tailby 1982). However, this is not meant to imply that functional equivalence was caused by prior stimulus equivalence (see McIlvane & Dube, 1990). Rather, both types of responding were dependent behavioral variables that were due to the MTS training, and both involved the transfer of function. For functional equivalence, the function that transferred to the T3 words during free recall and recognition was a remembering function. For stimulus equivalence, the functions that transferred during tests of symmetry and transitivity were the respective conditional and discriminative functions that had been directly trained during MTS training (Hayes, 1994; Sidman & Tailby, 1982). To further clarify, the false memory phenomena exhibited in the current study were not themselves instances of stimulus equivalence responding, since the free recall and recognition memory tests were not tests of symmetry and transitivity.

In line with Donahoe and Palmer (2004) and Skinner (1953; 1957), we assume that the experimenter's request to recall and recognize the memory test words occasioned whatever precurrent, covert operants the individual participants used to enhance recall and recognition and, thereby, satisfy the implicit experimental contingency. In the absence of an appropriate experimental analysis, it is not possible to stipulate the actual covert repertoires used by the individual participants to enhance recall and recognition, so it is difficult to specify the exact nature of the function that was acquired by the T1 study list words. We have therefore opted to use the general term ''remembering function'' to refer to the functions that differentially transferred from T1 words to T3 words during recall and recognition, though the exact functions that transferred may have varied according to individual repertoires and according to type of remembering task.

In the case of the recognition task, the T1 words functioned conditionally for the discriminative function of YES, while the T2–T5 words functioned conditionally for the discriminative function of NO. The fact that the T3 words evoked significantly more false positive recognitions (i.e., YES responses) than any of the other stimuli suggests that MTS training facilitated transfer of the conditional T1 function to same-class T3 words. Again, while false recognitions may well have been mediated by private operant behaviors that have not been elaborated in this account, the pattern of responding demonstrates the formation of a functional equivalence class consisting of T1 and T3 words.

Our failure to find any differential associative influence of T2, T4, or T5 co-occurrence on intrusions or false positive recognitions is somewhat surprising in light of previous findings that temporal contiguity influences intrusion (e.g., Zaromb et al. 2006) and demonstrations that concurrent pairing can lead to stimulus equivalence responding (Barnes et al., 1996; Leader et al., 1996; Tonneau, Arreola, & Martinez, 2006). The lack of associative effects (and presence of a semantic suppression effect) may be related to the nature of the experimental procedure, which may have resulted in three different functional equivalence classes (i.e., S1, S2, and S3 words). This may have placed the three classes in a relation of nonequivalence or distinction (e.g., see Hayes et al., 2001), and that may have overridden the effects of co-occurrence. Specifically, across MTS training trials, one comparison item was the correct answer and the others were, by definition, wrong, and this might have served to ''separate'' these items functionally. Consistent with this possibility, it was not uncommon in postexperimental conversation for participants to relate that they had considered writing down a word during the memory test, but then decided not to write it because they realized that the word they were considering was a S2 or S3 word. Because the relations among the three potential classes were not specifically assessed, this account of the null associative findings is speculative and awaits further research.

Our results contribute to the ongoing development of a satisfactory behavioral account of semantic meaning and extend this account to the domain of false memory phenomena. Following the precedents of Hayes and Bissett (1998) and Barnes-Holmes et al. (2005), this study represents a further increment towards establishing the viability of a model of semantic meaning based on derived stimulus relations. While their results indicate that learning histories leading to equivalence relations can also produce semantic priming effects, our results similarly indicate that such histories can produce false memory effects. These studies suggest that behavioral explorations of traditionally cognitive phenomena may be fruitful. It is our hope that this line of research engenders an optimistic appreciation of the interplay between behavioral and cognitive perspectives on learning, memory, and meaning.

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