Turner, M. L., and Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language 28*, 127–154.

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INTERFERENCE AND FORGETTING

Human long-term memory is characterized by a nearly limitless storage capacity. At any time, however, much of the information that exists in long-term memories (names, numbers, facts, procedures, events, and so forth) is not recallable. Why do people forget information that was once recallable? Because access to information in memory is subject to interference from competing information in memory. Before characterizing such interference processes in more detail, it is necessary to introduce some terminology.

The first concept is *transfer*. After some early point in life, people rarely, if ever, learn anything that is entirely new. Rather, people bring to any "new" learning of knowledge or skills an accumulation of related knowledge, skills, and habits from the past. Such prior learning influences the qualitative and quantitative character of the new learning process. Such transfer effects may be positive or negative, depending on whether prior experiences facilitate or impair the new learning process.

The second concept is *retroactive interference*. Whereas transfer refers to the effect of earlier learning on later learning, retroaction refers the impact of interpolated (intervening) learning experiences on one's memory for something teamed earlier. Once again, such effects may be positive or negative (retroactive facilitation and interference, respectively), depending on the similarity of the original and interpolated learning tasks. It is the negative case—where retroactive interference causes forgetting—that applies to this discussion. Thus, if one's ability to recall the maiden name of a woman friend is impaired by virtue of having learned her married name, one is suffering from retroactive interference.

The third concept is *proactive interference*. Something learned earlier may also impair one's ability to recall something learned more recently. If, for example, one is less able to recall a woman friend's married name by virtue of having learned her maiden name at an earlier time, one is suffering from proactive interference.

A Brief History of Research on Forgetting

Rigorous research on the possible causes of forgetting dates back to the turn of the twentieth century when two German researchers, Georg Elias Müller and A. Pilzecker, first demonstrated retroactive interference under controlled conditions. The history of that research interests contemporary scientists, partly because it is a case where intuition proved a poor guide to theorizing.

Early Theories That Proved Inadequate

Consolidation. Müller and Pilzecker (1900) found that subjects' memory for a series of nonsense syllables (consonant-vowel-consonant nonword syllables, such as DAX) was impaired by subsequent activity, such as learning a new series of nonsense syllables (compared with a condition where subjects simply rested for a similar period of time). They put forward a perseveration-consolidation hypothesis to explain their results. They argued that the changes in the nervous system that result in true learning are not complete by the end of training—that activity in the brain perseverates after learning, and that during that perseveration the memory traces corresponding to learning are consolidated. A subsequent activity, particularly if demanding and close in time to the original learning task, can disrupt the perseveration process, resulting in retroactive interference.

The consolidation idea seems plausible, especially given the evidence that certain traumas, such as electroconvulsive shock or a head injury, can produce retrograde amnesia (loss of memory for events occurring just prior to the injury), and that a period of sleep after a learning session produces less forgetting than does a comparable period of waking activity. The consolidation hypothesis proved unsatisfactory, however, because it does not provide an account for a variety of empirical phenomena. Long after the perseveration-consolidation process should be complete, for example, interpolated learning still produces substantial retroactive interference. Other problematic findings are that increasing the intensity of an unrelated interpolated activity results in little or no increase in forgetting, whereas increasing intertask similarity does play an important role in forgetting. A final blow for the theory is that it cannot explain proactive interference.

Decay. An explanation of forgetting that seems particularly plausible was put forth by Edward Thorndike (1914) as his so-called law of disuse. The thrust of his "law" is straightforward: Unless a person continues to access and use the memory representations corresponding to skills and information, those representations decay. Learning processes create memory representations; practice maintains those representations; but they fade with disuse.

The decay theory seems in general agreement with the average person's introspections as to how memories are formed and lost, but it proved entirely inadequate as a theory of forgetting. Thorndike's law was thoroughly discredited in a devastating critique by John McGeoch (1932). Among the problems with the theory are that forgetting is a function not simply of disuse across some retention interval but also of the nature of the activity in that interval, particularly its similarity to what is being remembered; information appears not to be lost from memory in some absolute sense, as implied by the theory, but, rather, becomes nonrecallable except under special circumstances; and it does not account for proactive interference.

The Emergence of Interference Theory

As an alternative to the consolidation and decay ideas, McGeoch (1932, 1942) put forth the initial version of what came to be called interference theory. That theoretical framework, as modified and refined over subsequent decades, constitutes the most significant and systematic theoretical formulation in the field of human learning and memory.

Reproductive Inhibition. McGeoch argued that human memory is fundamentally associative—that recall is guided by cues or stimuli to which items in memory are associated. As a consequence of a given individual's various experiences, however, multiple items in memory (responses) may become associated to the same cue. The recall of a given target response to a given cue, then, can suffer competition from other responses associated to that cue. Such competition, according to McGeoch, produces forgetting through reproductive inhibition: Recall of the target response is blocked or inhibited by the retrieval of other responses associated to that cue. Those other responses may have been learned before or after the response in question (proactive and retroactive interference, respectively), and such interference should be a function of intertask similarity across learning episodes.

Another factor in forgetting, according to McGeoch, is that the stimulus conditions existing at the time recall is tested will differ from the conditions that existed during training. Such differences are likely to increase as the interval from training to test grows longer; and to the degree the stimulus conditions at test do differ they will become less effective as cues for the response that was the target of training.

Unlearning and Spontaneous Recovery. In a pivotal study, Arthur W. Melton and J. M. Irwin (1940) took issue with McGeoch's analysis of retroactive interference. In their experiment, subjects learned two similar lists of verbal items and then were asked to relearn the first list. They found that the retroactive interference caused by the second list was, as predicted, an increasing function of the number of learning trials on the second list, but that the frequency of overt intrusions of second-list items during the relearning of the first list actually decreased with high levels of training on the second list. They argued that response competition could not, therefore, be the sole factor contributing to retroactive interference, because such intrusions are a straightforward measure of such competition. They proposed a second factor: unlearning of first-list responses during second-list learning. Their idea, which must have seemed somewhat bizarre, is analogous to a basic result in the animal-learning literature: Learned responses are gradually extinguished when no longer reinforced by a reward of some kind. From that perspective, intrusions of first-list responses during second-list learning constitute unreinforced errors.

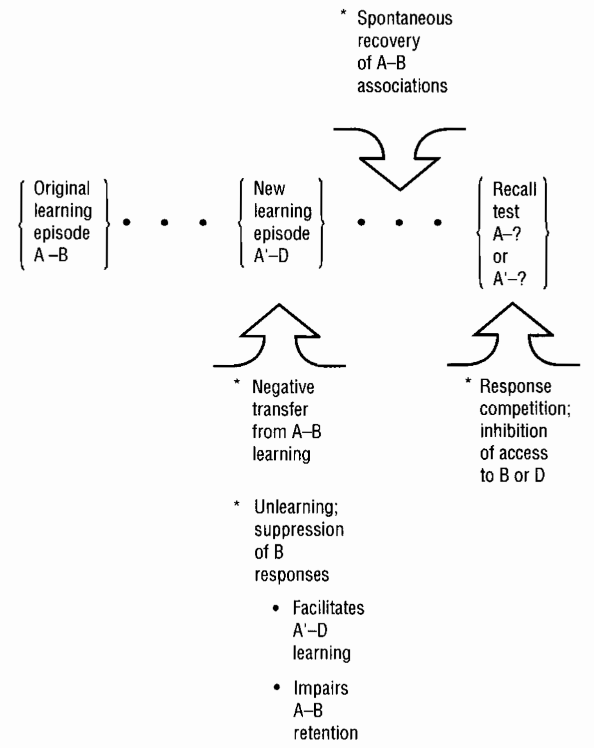
As if the unlearning idea were not strange enough by itself, it had an additional counterintuitive implication: If unlearning is analogous to experimental extinction, then—as in animal-learning research—the unlearned responses should show spontaneous recovery over time. That is, the unlearned responses should recover—become more available in memory—as time passes following the retroactive learning episode. Such an implication seems to violate a law or first principle of memory—namely, that items in memory become less available with time. However unintuitive the unlearning/spontaneous recovery idea may seem, research carried out over the twenty years or so following the Melton and Irwin (1940) paper provided unambiguous support for the basic idea (see Barnes and Underwood, 1959; Briggs, 1954; Underwood, 1957).

By the late 1960s the basic interplay of proactive and retroactive interference had become clear. The dynamics of that interplay are summarized in the next section of this entry. More complete versions of the history and final state of "classical" research on interference and forgetting are available in Roberta Klatzky (1980), Gordon Bower and E. Hilgard (1981), Robert Crowder (1976), and Leo Postman (1971).

The Dynamics of Interference and Forgetting

Figure 1 summarizes the dynamics of interference and forgetting. Assume that the original learning episode involves learning to associate each member, B, of a set of responses with a particular member, A, of a set of stimuli. Assume further that the new (interpolated) learning episode involves associating each member, D, of a different set of responses with a particular member, A', of a set of stimuli that may vary from being only generally similar to the A stimuli to being essentially identical. At the time memory is tested, assume that a given member of stimulus set A or A' is presented as a cue for the associated B or D response.

Figure 1



SOURCE: Courtesy of Robert A. Bjork.

Summary of the processes underlying proactive and retroactive interference; A-B and A'-D denote associative learning tasks in which A and A' are similar or identical stimuli and B and D are different responses.

The A-B, A'-D notation is meant to be interpreted quite broadly. A given stimulus might be a person's face and the response that person's name, for example, and the number of A-B and A'-D pairings to be learned might vary from one of each to some large number (as in the case of a grade-school teacher learning the names of the students in each year's class). In certain cases the stimulus might actually correspond to a configuration of stimuli and the response might be a coordinated set of verbal or motor responses (A-B and A'-D, e.g., could refer to learning to operate two different automobiles, the first in the United States and the second in England). The time course of the A-B and A'-D learning episodes might vary from brief to very extended (as would be the case if A-B denotes learning to label objects in a first language and A'-D denotes learning to label those same objects in a second language).

Unlearning

During the new learning episode (A'-D), competing responses from the original learning episode (A-B) are gradually suppressed or extinguished. Such suppression facilitates A'-D learning by reducing the negative transfer from competing B responses, but it also impairs any subsequent efforts to recall B responses. On the basis of a considerable body of research (particularly McGovern, 1964; Postman et al., 1968), it appears that—depending on the relationship of the stimulus-response pairings in the two learning episodes—one or more of three distinct types of unlearning may take place. Forward associations (from A to B) can be unlearned (which facilitates A'-D learning), backward associations (from B to A) can be unlearned (which would, for example, facilitate C-B learning, where C denotes stimuli that are not similar to A), and the entire set of B responses can be suppressed (which would aid A'-D or C-D learning).

Spontaneous Recovery

During the retention interval following A'-D learning (typically filled with other real-world activities on the part of the learner) the A-B associations that were suppressed during A'-D learning gradually recover in strength. Any other preexperimental associations to a given A or A' stimulus that may have been learned prior to A-B or A'-D learning will recover in strength as well.

Thus, at the end of A'-D learning, the D responses will be highly accessible in memory and the B responses will be relatively inaccessible (the exact ratio of B and D strengths will depend, of course, on the initial levels of A-B and A'-D learning, and on the overlap of the A and A' stimuli). As the retention interval from the end of A'-D learning increases, however, the pattern changes: The D responses become less recallable as the interval increases, and the B responses become relatively or absolutely more recallable. Whether the B responses themselves become more recallable in absolute terms appears to depend on whether those responses are also in competition with other (recovering) responses learned prior to the A-B episode. If a given A-B association is itself subject to proactive interference from one or more prior associations (A-E, A-F, and so forth), recall of the B response will tend to decrease, not increase, as the retention interval increases.

As the B responses (and any other prior associations to a given A' stimulus) recover, recall of the D responses will suffer increasing proactive interference. One implication of such recovery is that the rate of forgetting of D responses after A'-D training should be a function of the number of preceding similar lists a subject has learned. In an analysis of the results of many experiments reported in the literature, Underwood (1957) found striking support for that prediction.

Response Competition

At the time a given A or A' stimulus is presented as a cue for recall of the appropriate B or D response learned earlier, that target response will be in competition with any other responses associated to that stimulus. The impact of that competition is to inhibit access to the target response in memory. In general, recall of a given target response will decrease as the number and strength of competing responses increases. That generalization, in more modern terms, is the cue-overload principle (Watkins and Watkins, 1975). In the analysis of such response competition, however, an important distinction is relevant. It is the functional stimulus, not the nominal stimulus, that cues the retrieval of items in memory. Thus, A and A' may be nominally identical or highly similar stimuli, but if the learning episodes involving those stimuli differ substantially—in terms of the environmental, temporal, or social context, or even in terms of the learner's emotional or physical state—the functional encoding of those stimuli may differ markedly. Thus, any stimulus, together with the context in which it is embedded, offers the learner a variety of aspects that may be "sampled" (Estes, 1955) or attended to, and that process determines the functional encoding of a given stimulus.

Consistent with the foregoing analysis, the degree to which different learning episodes result in later response competition depends on how discriminable—on one basis or another—those episodes are from each other at the time of test. The more such episodes are separated from each other temporally, for example, the less they will interfere with each other (Underwood and Ekstrand, 1967).

Retrieval as a Memory Modifier

The results of research conducted in the late twentieth century add to the body of research. There is abundant evidence that the recall process alters the relative accessibility of items in memory. The act of recall is itself a learning event in the sense that an item recalled in response to a given cue becomes more recallable in the future. One consequence of such response-produced strengthening of future access to recalled items, however, is that other items associated with that cue may become less recallable. That is, the recall process can alter the pattern of relative access strengths across the set of items associated to a given cue.

Output Interference and Part-List Cuing

Consistent with the foregoing argument, there is evidence that recall is a "self-limiting process" (Roediger, 1978). Attempts to recall the members of a category or list of items occasion difficulty in recalling all the items in that set that exist in memory because the early items recalled impede the recall of subsequent items; having been recalled, the early items become more accessible in memory and block access to yet-to-be-recalled items.

Similar dynamics are probably at work in the inhibitory consequences of part-list cuing. When some members of a list or category of items are presented to subjects as cues to aid their recall of the remaining items, the recall of those remaining items is typically hindered rather than helped. Such inhibitory effects, considered an "enigma" in memory research (Nickerson, 1984), are at least in part a consequence of the cued items becoming too available in memory.

Retrieval-Induced Forgetting

The negative consequences of retrieval have been examined more explicitly via a retrieval-practice paradigm introduced by M. C. Anderson, R. A. Bjork, and E. L. Bjork (1994). The procedure includes an initial study phase, during which a number of category-exemplar pairs (such as Fruit-*Orange*) are presented. Typically, about forty-eight pairs are presented, which might be composed, for instance, of six exemplars of each of eight categories. There is then a retrieval-practice phase, during which participants are cued to recall, in response to cues such as Fruit-*Or*____, half of the exemplars of half of the studied categories multiple times. Finally, after a retention interval of twenty minutes or so, a surprise test is administered during which participants are presented each of the category names and asked to recall all of the exemplars they can remember having been paired with that name during the study phase.

Not surprisingly, the practiced members of practiced categories are recalled better on the final test than are corresponding unpracticed members of unpracticed categories. In contrast, the unpracticed members of practiced categories are actually recalled worse than are corresponding unpracticed members of unpracticed categories. That is, there seems to be retrieval-induced forgetting of exemplars that are in the same category as the practiced exemplars, but are not themselves practiced.

The findings obtained with various versions of the retrieval-practice paradigm suggest that retrieval-induced forgetting is a consequence of suppression of not-to-be-recalled exemplars during the retrieval-practice phase. Thus, correctly recalling "Orange" in response to a cue such as Fruit-*Or*____ requires not only selecting from among the studied items the fruit that fits "*Or*____," but also not recalling (suppressing) other studied exemplars in the fruit category, such as "Banana." M. C. Anderson and B. A. Spellman (1995) have suggested that such selection-suppression processes are simiar to those known to categorize human attention and that retrieving targeted information from memory requires a type of conceptually focused attention, one consequence of which is retrieval-induced forgetting of unselected items.

Conclusion

Interference and transfer are fundamental to human learning, memory, and performance. After a period of almost twenty years, from roughly 1970 to 1990, during which research on interference and forgetting was not a dominant theme in experimental psychology, there has been a resurgence of interest in such phenomena. Several contributing factors in that resurgence can be mentioned. First, there is renewed evidence of and appreciation for the role inhibitory processes play in human cognition. Second, in certain applied fields, such as research on memory factors in advertising and witness testimony, there is a need to understand how successive inputs to memory compete and interact. In research on witness memory, for example, an issue of intense concern is how memory representations are modified by misleading postevent information. Third, among researchers who are working to implement and test various types of mathematical and computer models of human memory there is a growing realization that any plausible model must account for the basic patterns of proactive and retroactive interference (Mensink and Raaijmakers, 1988).

Forgetting is not simply a failure or weakness of the memory system. In terms of the ovreall functioning of the system, there must be some means of restricting what is retrieved in response to a given cue: Information that is out of date or inappropriate needs to be suppressed, segregated, or eliminated. During the attempt to recall one's home phone number, or where one left the car, for example, it is not useful to retrieve one's prior home phone number, or where one left the car yesterday or a week ago. In short, in terms of speed and accuracy of the recall process, one does not want everything that exists in one's memory to be accessible, especially given the essentially unlimited capacity of human memory.

There are clearly some adaptive functions of the interference mechanisms that underlie forgetting. As a person continues to learn and continues to use new information, for example, access to the out-of-date information it replaces is inhibited. Such retrieval inhibition has several advantages over the kind of destructive updating of memory characteristic of computers (Bjork, 1989). Because the old information is inhibited, it tends not to interfere with the recall of the new information, but because that information still exists in memory—in contrast to overwritten items in a computer's memory—it tends to be recognizable and readily relearned should the need arise. Finally, should one stop using the new information (e.g., how to drive in Britain), there will be some recovery of the old information (e.g., how to drive in the United States), which will often be adaptive as well.

In general, it appears that differences in accessibility across the vast number of items in memory acts as a kind of filter. The information and skills most readily accessible in human memories will tend to be those people have been using in the recent past. On a statistical basis, those are the same skills and knowledge people will tend to need in the near future

See also: FORGETTING; MCGEOCH, JOHN A.; MEMORY CONSOLIDATION: PROLONGED PROCESS OF REORGANIZATION; MÜLLER, GEORG ELIAS; RECONSTRUCTIVE MEMORY; THORNDIKE, EDWARD

Bibliography

Anderson, M. C., Bjork, R. A., and Bjork, E. L. (1994). Remembering can cause forgetting: Retrieval dynamics in long-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition 20,* 1,063–1,087.

Anderson, M. C., and Spellman, B. A. (1995). On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychological Review 102,* 68–100.

Barnes, J. M., and Underwood, B. J. (1959). Fate of first-list associations in transfer theory. *Journal of Experimental Psychology 58,* 97–105.

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger and F. I. M. Craik, eds., *Varieties of memory and consciousness: Essays in honour of Endel Tulving.* Hillsdale, NJ: Erlbaum.

Bower, G. H., and Hilgard, E. R. (1981). *Theories of learning,* 5th edition. Englewood Cliffs, NJ: Prentice-Hall.

Briggs, G. E. (1954). Acquisition, extinction and recovery functions in retroactive inhibition. *Journal of Experimental Psychology 47,* 285–293.

Crowder, R. G. (1976). *Principles of learning and memory.* Hillsdale, NJ: Erlbaum.

Estes, W. K. (1955). Statistical theory of spontaneous recovery and regression. *Psychological Review 62,* 145–154.

Klatzky, R. L. (1980). *Human memory: Structures and processes,* 2nd edition. San Francisco: Freeman.

McGeoch, J. A. (1932). Forgetting and the law of disuse. *Psychological Review 39,* 352–370.

——— (1942). *The psychology of human learning.* New York: Longmans, Green.

McGovern, J. B. (1964). Extinction of associations in four transfer paradigms. *Psychological Monographs 78* (16, whole no. 593).

Melton, A. W., and Irwin, J. M. (1940). The influence of degree of interpolated learning on retroactive inhibition and the overt transfer of specific responses. *American Journal of Psychology 53,* 173–203.

Mensink, G. J., and Raaijmakers, J. G. W. (1988). A model for interference and forgetting. *Psychological Review 93,* 434–455.

Müller, G. E., and Pilzecker, A. (1900). Experimentelle Beiträge zur Lehre von Gedächtnis. *Zeitschrift für Psychologie 1,* 1–300.

Nickerson, R. S. (1984). Retrieval inhibition from partlist cuing: A persisting enigma in memory research. *Memory & Cognition 12,* 531–552.

Postman, L. (1971). Transfer, interference, and forgetting. In J. W. Kling and L. A. Riggs, eds., *Woodworth and Schlosberg's experimental psychology*, 3rd edition. New York: Holt, Rinehart and Winston.

Postman, L., Stark, K., and Fraser, J. (1968). Temporal changes in interference. *Journal of Verbal Learning and Verbal Behavior 7*, 672–694.

Roediger, H. L. (1978). Recall as a self-limiting process. *Memory & Cognition 6*, 54–63.

Thorndike, E. L. (1914). *The psychology of learning*. New York: Teachers College Press.

Underwood, B. J. (1957). Interference and forgetting. *Psychological Review 64*, 49–60.

Underwood, B. J., and Ekstrand, B. R. (1967). Studies of distributed practice: XXIV: Differentiation and proactive inhibition. *Journal of Experimental Psychology 74*, 574–580.

Watkins, O. C., and Watkins, M. J. (1975). Buildup of proactive inhibition as a cue-overload effect. *Journal of Experimental Psychology: Human Learning and Memory 104*, 442–452.

Robert A. Bjork

INVERTEBRATE LEARNING

[*Invertebrates are particularly useful for analyzing the neural and molecular events underlying learning and memory. The nervous systems of many invertebrates contain only several thousand cells (compared with the billions of cells in the vertebrate nervous system). Despite the small number of cells, an invertebrate ganglion can control a variety of behaviors. A given behavior may, therefore, be mediated by 100 or fewer neurons, and this small size of the circuit makes complete description easier. Moreover, many neurons are relatively large and can be repeatedly identified as unique individuals, permitting one to examine the functional properties to a specific behavior mediated by the cell. Changes in cellular properties that occur when a behavior is modified by learning can then be related to specific changes in behavior. Molecular and biophysical events underlying the changes in cellular properties can then be determined. This approach has been particularly successful with the bee and the mollusks* Aplysia, Hermissenda, Limax, *and* Tritonia.

Invertebrates are also excellent subjects for a genetic dissection of behavior and learning and memory. Two animals that have been particularly useful are the fruit fly Drosophila *and the worm* C. elegans. *The basic strategy is to alter the genotype with a mutagen and to test for specific defects in the ability of the animals to learn or remember. The role of individual biochemical processes and genes then can be related to specific aspects of learning and memory.*

The entries that follow discuss each of these invertebrates except APLYSIA, *which is the subject of a separate section. For additional information on insect species, see* INSECT LEARNING.]

ASSOCIATIVE LEARNING AND MEMORY PROCESSING IN BEES

The social life of the honeybee colony forms the ecological framework for the individual animal's behavior and is crucial for each bee's survival, because an individual bee cannot exist on its own (Frisch, 1967; Lindauer, 1967).

Associative Learning

The study of learning and memory formation in bees under natural conditions has focused on latent learning during navigation and on operant learning in the context of food collection. In the laboratory it has focused on appetitive classical conditioning. Bees departing from the hive perform observatory learning flights (Capaldi et al., 2000), and establish a map-like spatial memory for their colony's location relative to landmarks within the framework of their sun compass system (Menzel et al., 2000). When a searching bee discovers a nectar- or pollen-producing flower, it quickly learns to associate the surrounding visual and olfactory signals with the reward. It learns olfactory stimuli (e.g., floral odorants) and colors very quickly (within one or a few learning trials). Patterns need more learning trials. Whereas latent learning during navigational tasks may not require a rewarding stimulus, reward learning is a forward-associative process because signals perceived before the reward are associated, whereas those perceived during the reward or during the departure flight are associated less effectively or not at all.

Research on various operant learning phenomena (e.g. reversal and multireversal learning, overlearning, inhibitory learning, context-dependent learning, and reward schedule learning) has found performances similar to those in mammals (Couvillon and Bitterman, 1988; Menzel, 1990). Multiple experience with varying signals but one constant feature (e.g., different kinds of symmetrical patterns) leads to the formation of a concept (the concept of symmetry) that allows the bee to choose new patterns with the same feature as learned targets (Giurfa, Eichmann, and Menzel, 1996). Bees also develop a concept of sameness and difference when they are trained in delayed matching-to-sample tasks, in which they are required to respond to a matching stimulus or a nonmatching stimulus (Giurfa et al., 2001). They also transfer the learned rules to new stimuli of the same or a different sensory modality. Thus, not only can bees learn specific objects and their physical parameters, but they also extract rules and apply them to novel situations.