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## Ralph Miller

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### Education and Early Influences

Ralph R. Miller (1940–) grew up on the south side of Chicago, near Hyde Park, in the shadow of the University of Chicago, and near a lot of great bookstores. Miller entered MIT in 1958, and in 1962 he earned a BS in Physics with a thesis titled, "Considerations of Precision Nuclear Spectroscopy Utilizing Fiber Optics Detection Systems." Miller went on to earn a Master's degree in High Energy Physics from Rutgers University (1964) with a thesis titled, "An Automated System for the Detection of Elementary Particles." While at Rutgers, his interests shifted to psychology, and under the supervision of William Pavlik, Miller went on to earn a Master's degree in Social Psychology from Rutgers (1966) with a thesis titled "No Play: A Means of Conflict Resolution." While working on his Masters, Miller became interested in the social learning theory of Neal Miller and John Dollard and was greatly influenced by his interactions with those focused on learning and conditioning processes, such as Norman Spear, George Collier, Michel D'Amato, and Carolyn Rovee Collier. With his focus being now the study of learning and memory in rodents and humans, Miller joined the laboratory of Donald Lewis at Rutgers. He went on to earn a Ph.D. in Physiological Psychology (1969) with a thesis titled "Effects of Environmental Complexity on Amnesia Induced by Electroconvulsive Shock," which investigated amnesia and recovery of memories after amnestic insult. Miller's work was extremely timely, as there was extensive debate at the time regarding whether amnesia-inducing trauma disrupted memory consolidation or retrieval. In Miller 1973, he published a landmark paper on *Psychological Review* ("Amnesia, consolidation, and retrieval"), which is still considered a citation classic in this area. As a graduate student, Miller was one of the original investigators to observe that cued reactivation of an old memory renders it briefly vulnerable to experimental amnesia (Misanin et al. 1968). Today, that brief window of vulnerability is presumed to represent retrieval-induced destabilization during which memories are labile and subject to change prior to entering a period of "reconsolidation." Notably, Miller has always strongly disagreed with the "reconsolidation interpretation" of the phenomenon because recovery from the performance deficit induced during the vulnerability period is sometimes observed.


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## Academic Career

After obtaining his Ph.D., Miller joined the Psychology Department faculty at Brooklyn College of the City University of New York (1969) and rose through the ranks to become a tenured Associate Professor (1973) and Professor (1978). During this time, he spent a year as a visiting Fellow in Experimental Psychology at the University of Cambridge (Kings College, UK, 1975–1976). In 1979, Miller joined the faculty at the State University of New York at Binghamton (today, Binghamton University), where he has spent the rest of his career. In 2003, Binghamton University awarded him the rank of Distinguished Professor of Psychology. Throughout his academic career, Miller has served as Editor of *Journal of Experimental Psychology: Animal Learning & Cognition* (2014–2019) as well as *Learning & Behavior* (1997–2002). He has also served as President of the Eastern Psychological Association, the Pavlovian Society, and Division 3 of the American Psychological Association. He was named Fulbright Scholar on two occasions. At the time this entry was written, Miller's work had resulted in 345 publications and continuous federal funding for a 43-year period. Since becoming a professor, 22 students earned their Ph.D. and 13 individuals received Postdoctoral training under Miller's supervision.

## Major Contributions to the Study of Animal Cognition and Behavior

Although Miller is arguably one of the most recognized researchers in the field of animal learning, conditioning, and cognition, throughout his career he has made significant contributions to the theoretical and empirical advancement of neuroscience, cognitive processes, social processes, animal behavior, and psychopathology. Much of Miller's work has used Pavlovian associative conditioning procedures with rats; however, he has also made significant contributions using contingency judgment and evaluative conditioning with human participants. Miller's contributions have been significant to the understanding of memory retention through metamorphosis in frogs, Machiavellianism, causal reasoning in human and nonhuman animals, source monitoring in Korsakoff's syndrome, preference for signaled shock, neophobia, electroconvulsive shock (ECS)-induced amnesia, occasion-setting, treatment of fear of public speaking, associative interference, experimental extinction, fear relapse, artificial intelligence, processing information as a member of a group, altruism and selfishness, opioid analgesia, conditioned inhibition, coding of temporal intervals, tail shock methodology, biological significance, context and habituation, treatment for smoking cessation, infantile amnesia, cue-competition phenomena (e.g., blocking, inhibition, overshadowing, and relative stimulus validity), associative learning as a model of schizophrenia, and adaptive memory.

### The Learning-Performance Distinction

If Miller's work were to be summarized in one sentence, it would be *the systematic investigation of the difference between what has been learned and how that learning is expressed in performance*. His view is that performance (e.g., conditioned responding) does not always reflect what a subject has encoded; thus, there are complex processes that determine whether or not a given environmental situation results in the elicitation of a conditioned response. The learning-performance distinction is a long-standing debate in the history of the study of learning and conditioning. For example, in his classic studies of *latent learning*, Tolman (1948) observed that rats allowed to navigate a maze did not express learning of the layout of the maze until they were under a motivational state that facilitated expression of that learning. That is, what they knew (learning) was not necessarily expressed in their behavior (performance). Another example of the learning-performance distinction is the phenomenon of *spontaneous recovery*, first reported by Pavlov (1927). Pavlov presented dogs with a sound (the conditioned stimulus or CS) that was paired with food (the unconditioned stimulus or US), resulting in a salivation conditioned response when the CS was presented. Repeated presentations of the CS alone resulted in low levels of conditioned responding (extinction). Pavlov observed that the response recovered without further training if time was allowed to elapse between extinction and assessment. This observation suggested that extinction involves some kind of masking of the acquired CS-US association that remained intact through extinction.

Miller's interest in the learning/performance distinction stems from his work as a graduate student at Rutgers. In a series of seminal studies, Miller and colleagues trained rats with a passive avoidance conditioning procedure followed by ECS. With this treatment, rats showed amnesia for the passive avoidance conditioning experience. If rats received a single "reminder" shock (Miller and Springer 1972a, b) between ECS treatment and assessment, however, the avoidance response was expressed. This showed that the association *was* formed during training and that the amnesia-inducing ECS did not destroy it or keep it from being consolidated and retained; it merely prevented its expression. Indeed, they observed that the memory was formed in 0.5 s or less since the amnestic treatment presumably disrupted all relevant ongoing neural processing in the brain 500 ms after training (Miller et al. 1969). Miller's findings in this area, along with the work of others such as David Riccio, Norman Spear, and Mark Bouton, have helped shape our understanding that many instances in which performance is not consistent with the conditions of training may reflect not a failure to acquire and retain a memory, but a difficulty in retrieval of acquired memories that remain intact even after treatments intended to disrupt them.

### Acquired Information Expression is Relative to the Situation: The Comparator Hypothesis

In Miller's view, responding based on an acquired association does not only depend on the strength of the memory of the association, but also on the context in which the memory was acquired and retrieved. According to this view, CS-US pairings will control behavior not only as a direct function of the strength of the CS-US association, but as a relative comparison of the strength of this association and the strength of association between the background cues and the US. These background cues (the environment or "context" as well as other stimuli that were present in the learning situation) are presumed to serve as "comparator stimuli" for the CS that is being assessed (the "target" CS). The degree to which the target CS produces a conditioned response will be determined by the extent to which the target CS can retrieve the memory of the US (the associative strength of the target CS-US association) *relative* to the extent to which other cues that were present in the situation during learning can retrieve the memory of the US; this latter retrieval of the memory of the US is indirectly triggered by the target CS because presentation of the target CS retrieves a memory of the comparator stimuli, which in turn retrieve a memory of the US. Thus, the comparison is between a memory of the US directly retrieved by the target CS (with a strength that equals that of the associative strength of the CS-US association) and a memory of the US indirectly retrieved by the target CS (with a strength that equals the product of the strength of association between the target CS and its comparator stimuli *and* the comparator stimuli and the US). Hence, if the memory of the US activated directly by the target CS is stronger than that activated indirectly by the target CS, responding will be robust; in contrast, if the memory of the US activated directly by the target CS is weaker than that activated indirectly by the target CS, responding will be attenuated. Thus, failures in performance are expected not because the association between the target CS and the US is weak, but because associations to the comparator stimuli prevent full expression of the CS-US association. Since the mid-1980s, Miller's *Comparator Hypothesis* (*cf.* Miller and Matzel 1988) has been supported by hundreds of studies and has sparked novel research showing that responding can be modulated through training of the comparator stimuli (e.g., Blaisdell et al. 1999), with new theories being developed to explain these phenomena (for reviews, see Denniston et al. 2001; Stout and Miller 2007). The Comparator Hypothesis has undergone significant evolution since its first formulation, with an extended version, the development of which was prompted by the empirical discovery that overshadowing and latent inhibition treatments mutually counteract their response-attenuating effects other (Blaisdell et al. 1998), that incorporated rules for dealing with multiple comparator stimuli (ECH; Denniston et al. 2001), and a mathematical formalization of the ECH (Sometimes Competing Retrieval [SOCR]; Stout and Miller 2007).

### Temporal Coding as an Essential Component of the Formation and Expression of Associations

Temporal contiguity (the extent that two events occur in close temporal proximity) was described by Aristotle as one of the basic laws of association between ideas. Not surprisingly, contiguity is essential for the formation of associations between the CS and US; however, sometimes contiguous events (e.g., a CS and US that are presented simultaneously) do not lead to robust behavior. Miller has suggested that the temporal relationship between paired events is encoded as part of the "association" that links their representation in memory. This temporal information includes synchronous versus asynchronous onset, order of presentation, and duration. In this strict contiguity view, an association is formed as long as the two events are presented fairly close together. This temporal information is not just incidental; rather, it is a critical determinant of how the association will later be expressed in behavior. Miller's *Temporal Coding Hypothesis* (e.g., Arcediano and Miller 2002; Miller and Barnet 1993) incorporates the extent to which the CS predicts the US and how this predictability is modulated by their temporal relationship. The most commonly held view of classical conditioning is that pairings of a CS and a US lead to the CS predicting the US, and that conditioned responding is determined by this predictive relationship; functionally, the CS prepares the subject for the impending occurrence of the US. Various observations support this view: if the CS and US occur simultaneously (simultaneous conditioning) or the US precedes the CS (backward conditioning), little conditioned responding is observed because the CS has little predictive value. According to Miller's Temporal Coding Hypothesis, however, prediction only determines whether performance, not learning, is to occur. In this view, if the CS and US are presented together, an association is formed between them. Performance depends on the temporal arrangement of the CS and US and is determined by the extent to which the CS predicts the US. Miller has presented extensive evidence that these latent associations can be uncovered through the use of second-order associations. For example, if a CS1 receives backward pairings with the US (i.e., US-CS1), CS1 elicits little responding (CS1 is not predictive of US occurrence). If a second CS (CS2) is paired with CS1 (CS2-CS1), however, CS2 comes to be predictive of CS1's occurrence. If CS1 has developed an association to the US, then CS2 should come to elicit a response because CS2 holds a predictive relationship to the time at which US occurrence should be expected. Such integration of multiple experiences with temporal components has been demonstrated in human and nonhuman subjects (e.g., Arcediano et al. 2003).

## Conclusion

R.R. Miller has been one of the greatest contributors to the advancement of animal learning, memory, and cognition. His theoretical contributions, including the Comparator Hypothesis and Temporal Coding Hypothesis, have not only served to provide a framework of understanding the complex dynamics of acquired behavior, but have sparked novel research and theoretical developments that have advanced our understanding of the complex relationships between what is learned and what is expressed in behavior. Miller's prolific experimental contributions have spanned multiple fields beyond learning and memory, including social, abnormal, and physiological processes, and have had broad impact beyond psychology. With a career that spans over 50 years, Miller's work is still considered to be current, with even his graduate student research continues to shape our understanding of learning and memory, such as the reconsolidation debate.

## Cross-References

- ▶ Altruism
- ▶ Associative Learning
- ▶ Avoidance
- ▶ Classical Conditioning
- ▶ Conditioned Inhibition
- ▶ Contiguity
- ▶ Extinction
- ▶ Habituation
- ▶ Ivan Pavlov
- ▶ Learning
- ▶ Long-Term Memory
- ▶ Machiavellian Intelligence
- ▶ Neophobia
- ▶ Retention

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